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Repairing a fractured pipeline: improving the effectiveness of agricultural R & D in the UK

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ABSTRACT
The farming industry in the United Kingdom faces considerable challenges in playing a proportionate role in meeting increasing global food needs whilst minimising the environmental, social and economic impacts of production agriculture. To do so effectively requires the generation, promotion and uptake of new knowledge, skills and technologies. This article discusses the significant changes that are needed in order to meet these goals.

KEYWORDS: Agriculture; research; development; knowledge transfer; policy; industry

Agriculture worldwide has benefitted enormously from the effective application of appropriate science and technology. Without the development of high-yielding crops and animals, effective agrochemicals, veterinary medicines and improved cultivation practices, we would not be able to feed the current world population, let alone contemplate meeting the demands of nine billion humans by the middle of the 21st century. In most cases, these successes were based upon a solid foundation of innovative basic science that linked effectively both into directed strategic and applied research and into effective deployment of new knowledge and practice by producers.

In the UK, the 20 years immediately following World War 2 were a kind of 'golden age' for this process. Because of pressing needs to stimulate home production and reduce imports, there were real incentives to link all the different components of the 'research pipeline' together. Basic science was delivered by universities but also by a large number of Research Institutes that were focussed on specific sectors and that were also engaged in the strategic and applied research that would foster effective delivery. Initially at least, the Agricultural Research Council controlled the funding for both basic and strategic/applied research, and linked closely with the development and extension activities of the National Agricultural Advisory Service (NAAS)[2] and the Levy Boards[3]. As an example of how effective this process was; over the period 1950–1970 average wheat yields doubled from ca 2-ca 4tonnes/ha driven roughly equally by the development of new varieties and by improved cultivation practices. There were also good links between government-funded research in universities and institutes and the 'in-house' research and development (R&D) of (e.g.) agrochemical companies, catalysed by arrangements such as joint studentships and fellowships. Perhaps even more importantly, producers were rewarded not only by sale of produce but also by significant production support from government.

Unfortunately, this 'golden age' began to tarnish and challenges began to emerge from the 1970s onwards. Ironically this was just as I was looking for my first permanent job in agricultural research, and the sector seems to have been undergoing major upheavals ever since! There were three major causes for these challenges. The first was the success of the process, leading to the complete disappearance of food shortages in developed countries and indeed significant over-production in some areas. The second was the ever-increasing costs of government support for farming, which became unpopular as shortages vanished whilst the third was the increasing globalisation of developed-country economies, which opened up imports of produce, often at lower cost. At the same time, the environmental movement began highlighting some of the negative impacts of intensive production systems in terms of habitat loss and damage together with increased diffuse pollution. Increased food security, driven by globalisation and production increases impacted directly and negatively on farmers in terms of reduced margins, since processors, retailers (and ultimately consumers) were always able to deal with a range of primary providers, all of whom were in competition with each other.

If one examines the way in which agricultural research is organised in the UK today, and how that impacts on producers, the position is much more complex and much less integrated. The majority of basic research is still funded via the research council system but both the Biotechnology and Biological Sciences Research

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[2] A free public-sector extension service.
[3] Quasi-governmental organisations engaged in research and development in production of specific commodities (e.g. meat, potatoes, cereals), financed by statutory levies on farmers and growers.

Council (BBSRC) and the Natural Environment Research Council (NERC) have remits that go well beyond farming and land use. The role of universities as research providers has increased and that of research institutes has decreased, and funding for strategic and applied research has been separated from that for basic research. Defra[4] emphasises research in support of policy rather than in support of industry and its research budget has fallen significantly in real terms. Although there is considerable global investment by industry, consolidation and European antagonism to agricultural biotechnology means that the industrial R&D base in the UK is much smaller than it used to be. There is no longer a free advice and extension service for farmers in England, although mechanisms do exist in Scotland, Wales and Northern Ireland. On the positive side, Levy Boards still fund applied research and development, and the recently-created Technology Strategy Board (TSB) is beginning to fund applied research linked to industry needs and industry involvement.

The end result of these changes is that, although a considerable sum of public money (estimated at *circa* £365 million[5] in 2010[6]) is used to fund research on aspects of agriculture and land use, the impact of this is problematic. There is a range of reasons for this including:

- The needs of research providers to demonstrate academic excellence as well as relevance or impact. This particularly impinges on the award of competitive funding for basic research, where the strategic needs of end-users may not be paramount.
- The emphasis on environmental research that does not directly address the needs of the industry. This shift in emphasis is justified by increasing concerns over issues like climate change and habitat damage, but this has been driven almost entirely by redirecting existing funding away from 'production-oriented' research.
- The net reduction in funding for strategic research. Declines in industry and Defra funding means that it is much more difficult to bridge the gap between a potentially valuable piece of basic research and the demonstration of commercial value. There are still ways of doing this but the imbalance means that potentially valuable knowledge does not always get taken up and used.
- The decline in profitability in the industry reducing the value of the levy and thereby the amount of development and knowledge transfer that can be carried out.
- The lack of a comprehensive, integrated UK-wide extension service.

In the early years of the 21st century, there were those who suggested that farming should be treated like other 'sunset' industries, and that the UK should treat food as a widely-traded global product that could be accessed from whichever source was the cheapest. Whilst there is no doubt that developed countries like the UK will continue for the foreseeable future to be able to purchase food in a competitive global market, attitudes towards maintaining a viable UK farming industry have changed recently. The UK Government Foresight analysis on food security (Foresight 2011; Beddington 2011, *inter alia*) rehearses some arguments in support of this:

- The need to underpin the UK food industry (its largest industrial sector)
- The societal value of maintaining a resilient food chain with high safety and welfare standards at a time of increasing global demand;
- The preservation of the delivery of essential ecosystem services as a consequence of maintaining viable farms;
- Minimising the adverse environmental consequences of food production and promoting the effective integration of land use into the UK climate change policy framework;
- Promoting an integrated and effective approach to the growing threat of animal disease and zoonoses;
- Maintaining public confidence in the UK food chain from farmers to retailers;
- Supporting a shift to land use systems where food and renewable resources both need to be generated efficiently and sustainably.

It is my submission that this shift in attitude to farming will require a further realignment of the way in which research is managed in order to improve both its focus and its delivery. Whilst there are some examples of current good practice in the management of basic, strategic and applied science; financial constraints will force us to consider new ways of working that will help to restore the integration of the immediate post-war years whilst accepting that the target has widened to include financial, environmental and social gains as well as production ones.

At a strategic level, I think four main issues need to be addressed:

1. *Ensuring that the farming industry has a stake in the entire R&D strategy.*
   This means that the R&D and knowledge transfer (KT) priorities of the levy bodies must (a) be effectively integrated with those of other providers and (b) recognise the need to invest in longer-term developments that will help to prepare for the new opportunities and challenges of a food-hungry and energy-hungry world. This is a very challenging objective. Low profitability not only reduces the amount available to invest but also tends to shorten horizons since survival is paramount. Farming needs to look ahead and develop a framework for R&D that identifies the key knowledge and skills gaps that are likely to reduce competitiveness over the next 20–30 years. As well as developing this framework, there needs to be better communication between those looking for 'industry-relevant' R&D and those setting the basic and strategic research agenda. Some progress is being made via the Agricultural and Horticulture Development Board (AHDB), TSB, Defra and the UK Research Councils, and the Scottish funding model does seek to deliver an integrated

[4] The UK government Department for Food, Environment and Rural Affairs.
[5] In early October 2012, £1 was approximately equivalent to US$1.61 and €1.25 (www.xe.com)
[6] See the Oxford Farming Conference Research on agricultural research needs and priorities: http://tinyurl.com/9mkw4jr

stream of policy- and industry-relevant research that is linked directly to effective on-farm KT. Nevertheless, there remains a pressing need to improve clarity, focus, integration and longer-term relevance of industry-funded R&D

2. *Ensuring that new knowledge and skills reach the end user effectively and uniformly.*
   Even in its heyday, agricultural extension in the UK only reached directly a minority of farmers. Others learned from their more innovative neighbours whilst a substantial 'rump' did not benefit at all. Even to meet the current rather modest targets for greenhouse gas (GHG) reductions on-farm it will be necessary to change practice across a substantial majority of farms, and this is even more true of the longer-term challenges outlined above. I find it difficult to see how this will happen across the UK despite the best intentions of levy bodies and some agricultural charities. There are examples of good practice, such as the implementation of GHG inventories and models on farm, but uptake is patchy and differs markedly from region to region. I remain particularly concerned that, whilst there may be sufficient resources to achieve effective uptake of new knowledge in terms of increasing profitability, no-one is really considering how to implement best practice in terms of balancing production gains against impacts on ecosystem service provision, or even balancing the costs and benefits of alternative land use systems. Failure to transfer knowledge effectively negates much of the value in creating it, and I perceive a need for organisations all along the R&D pipeline to consider innovative modes of knowledge transfer as a matter of urgency.
3. *Aligning more effectively policy-oriented research with the future direction of the farming industry.*
   The significant reduction in strategic R&D funding from Defra is unlikely to be reversed in the short- or medium-term and there remains a need for research to support both policy development and policy delivery. However, effective delivery of key land use policies depends upon the active and informed participation of farmers and land manages. 'Sticks and carrots' will always play a part, but seeking ways of increasing the involvement of farmers in the processes of setting the research agenda and delivering the desired policy outcomes will help to ensure both value for money and the minimisation of unintended consequences. The farming unions are active in representing their member's interests in both national and European discussions on agricultural policy. A more joined-up and participatory approach to assembling the evidence base might be of value to all and improve the effectiveness of government intervention.
4. Maximising the value of basic research.
   World-class basic research is the intellectual capital upon which future technological advances will be built and UK Research Councils have been extremely successful in promoting such research, even at a time of financial pressure. However, the Government's Impact agenda has focussed attention on how the products of this research can 'trickle down' to promote economic activity and benefit 'UK Plc'. In agriculture, BBSRC (with other academic partners) has addressed this by involving industry and others in the development of Research Clubs[7]. These clubs are established specifically to promote the direct uptake of knowledge from basic research by land-based industries. They also give the industry greater involvement in suggesting research priorities. The challenge is to maximise the opportunity for research to generate impact whilst maintaining an appropriate breadth of basic research and not stifling ambition.

The move towards funding larger, integrated cross-disciplinary projects improves the chances of successful innovation but also increases the significance of 'failure' and tends to focus efforts in some areas at the expense of others. As the challenges become more complex, it is likely that new approaches will need to balance benefits and disbenefits across the full range of inputs, outputs and systems that comprise modern farming (Pretty, 2003). This will require basic research across biological, physical, environmental and social sciences to be integrated and managed effectively and for the results to be used coherently for the benefit of the sector. The recent Royal Society report on food production refers to the concept of 'sustainable intensification' (Royal Society 2009); increasing yield whilst decreasing footprint. This is a major scientific challenge that lies beyond the remit of any single research funder to underpin, so the task remains to improve the integration not only across scientific disciplines but right along the R&D pipeline.

In this brief article, I have argued that there is a compelling need for UK agriculture to define a significant national and global role for the future, in which the challenges of meeting increased demand for food can be balanced against the need to deliver other ecosystem services and to broaden the range of products from land. If this role is to be sustained, then I believe that the industry has to change its approach to commissioning R&D and to delivering extension and training, and research funders need to adapt to an environment where effective deployment of innovative multi-disciplinary research is seen as an essential part of the process rather than an infrequent by-product.

About the author

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[7] E.g. its Crop Improvement Club: http://www.bbsrc.ac.uk/publications/innovation/circ-brochure.aspx

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The use of Farm Business Survey data to compare the environmental performance of organic and conventional farms

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ABSTRACT

This paper considers two main questions: Is it possible to use Farm Business Survey (FBS) data to derive well-established environmental indicators and can these FBS derived indicators also provide a reasonable comparison of the environmental performance of organic and conventional farms? The results suggest that the indicators can be obtained from FBS data and that the majority of the indicators provided meaningful results, despite some data limitations within the FBS dataset. The comparison of organic with conventional FBS data in the UK suggests that organic farms have lower fertiliser and crop protection costs (as would be expected) but that differences in feed costs, stocking density and cropping diversity were dependent upon farm type. This research confirms that FBS data can be used to derive indirect environmental indicators which are able to identify significant differences between farm types and management systems. These indicators are also likely to be applicable at EU level through their use within the Farm Accountancy Data Network (FADN), which collates farm economic data across the EU. This is of interest to researches and policy-makers who could use FADN data to track some aspects of environmental performance across many countries and track changes over time. These results may also be useful to farm consultants and managers who could potentially use a similar approach in using individual farm financial information to benchmark some aspects of farm environmental performance.

KEYWORDS: Farm business survey; environmental indicators; organic

1. Introduction

The environmental impact of agriculture is an area of increasing concern to the general public, to policy-makers (European Commission, 2011) and other stakeholders, including farmers themselves. As part of a move to more environmentally friendly agriculture, 18% of the EU-27's utilisable agricultural area is managed under agri-environmental schemes (Westbury *et al.* (2011) and references therein) and it is possible that this may increase further in the future. In a further strengthening of agri-environment policy, current proposals for common agricultural policy (CAP) reform include a 'greening payment' to encourage environmentally friendly farming practices (European Comission: Agriculture and Rural Development, 2011).

To justify continued financial support for agriculture in the EU it is necessary to have some means of tracking changes in agricultural practice which may impact on the environment. For instance being able to assess whether implementation of greenhouse gas action plans appears to be having an impact on emissions will become increasingly important as the UK fulfils its obligations under the Climate Change Act (2008). With agri-environmental schemes operational in all countries throughout the EU, measuring the impact of such schemes and providing evidence that they do provide environmental benefits is becoming increasingly necessary to justify this public expenditure. Consumers also express an interest in the environmental benefits of the farming systems used to produce their food (Hughner *et al.*, 2007; Mondelaers *et al.*, 2009b; Zander and Hamm, 2010) , suggesting that it will become increasingly important for producers to be able to assess the environmental impacts of their farm management and communicate these to their customers.

One means of assessing the environmental benefits of farming is to carry out assessments on-farm (Hani *et al.*, 2003; Meul *et al.*, 2008). However, on-farm assessment can be time consuming for the advisor/assessor and the farmer. Also, if the aim of assessment is to obtain a national picture (for example assessing a particular agricultural policy or agri-environment scheme) then a (possibly prohibitively) large number of assessments in various parts of the country, covering various farm types would be required.

An alternative approach would be to make use of existing surveys which could be analysed to provide indicators of environmental performance. The potential disadvantage of indicators which make use of existing surveys in the manner described above is that they do not directly measure the environmental aspect which

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they are assessing but rather give information about management practices or other aspects that may influence it (Bookstaller *et al.*, 2008; Makowski *et al.*, 2009). It is necessary to assess the validity of such 'indirect' or 'proxy' indicators as they are potentially less accurate than direct measurement. However, the advantage of such indicators is their lower cost (Bookstaller *et al.*, 2008; Makowski *et al.*, 2009) and the ability to use surveys which have been carried out regularly over a long period of time and so to track changes in practices which may impact on the environment. This advantage means that it is worth investigating the use of indirect indicators further and this has been explored in a number of European research projects e.g. IRENA (EEA, 2005), SEAMLESS (Van Ittersum *et al.*, 2008), BioBio (Dennis, 2009).

Some projects, e.g. IRENA and SEAMLESS, have tried to combine environmental and financial databases to undertake integrated assessments but due to their complexity have often been unable to provide results across the EU or have not been updated regularly due to high costs. However, it may be possible to achieve at least a basic environmental performance indication from annual data collections such as economic or financial surveys e.g. the EU FADN (farm accountancy data network). Thus, it appears necessary to explore whether it is possible to obtain such environmental indicators from financial information in existing surveys.

In England and Wales the FADN data is collected through The Farm Business Survey (FBS). It is a survey of farm income and expenditure which is carried out in England and Wales on an annual basis on a representative sample of farms (based on proportions of different farm sizes and types within the sample as compared to the overall population of UK farms based on Farm Structure Survey data). Therefore it is a potential candidate for use in providing indirect environmental indicators. Similar surveys are also carried out in Scotland and in Northern Ireland which records more detail on fertilisers and physical quantities of feeds.

As part of the FADN, indicators that are developed utilising FBS data may also be transferrable for use in other countries. However, the survey focuses on financial rather than physical or environmental data. Thus some indicators may require additional calculation to convert from financial to physical values. Others may not give as much detail as would be ideal from an environmental assessment perspective.

Westbury *et al.* (2011) investigated the use of FBS data to carry out an agri-environmental footprint index (AFI) assessment to measure the environmental impact of arable, lowland livestock and upland livestock farming in England and to assess whether there were differences in AFI due to participation in agri-environmental schemes. The variables they used included fertiliser units (tonnes, derived from cost) per ha utilisable agricultural area (UAA), crop protection costs per ha UAA, % of UAA that was irrigated, electricity costs and machinery, heating and vehicle fuels and oil per ha UAA, Shannon indices of both crop diversity and land-use diversity, the percentage of farm land that was woodland or uncropped land, average number of livestock units per ha UAA, and percentage of UAA that was classified as rough grazing. Where physical units rather than costs were required they were obtained using standard costs (i.e. costs for that specific product pertaining at that time).

Similarly, Corson *et al.* (2010) used FADN data but focussed on the use of such data to estimate emission inventories of French farms. They estimated fertiliser nitrogen, phosphorus and potassium (N, P, K) inputs, pesticide inputs and the N, P, K imported in animal feed and the amount of N, P, K output based on quantities of agricultural products sold. Physical amounts were obtained from cost data using standard costs and information on the concentration of N, P, and K in commercially available fertilisers and animal feedstuffs.

Environmental indicators have also been developed as part of EU-funded research projects, (as mentioned above). The EU-funded BioBio project ('Indicators for Biodiversity in Organic and Low Input Farming Systems') suggested a range of indicators under the main headings of genetic, species, and habitat diversity and included a section on farm management indicators that can be derived from existing data sets (Dennis, 2009). Also, the 'Indicator Reporting on the Integration of Environmental Concerns into Agricultural Policy' (IRENA) project aimed to develop a set of indicators for monitoring environmental integration into the CAP (EEA, 2005). Those indicators which they deemed 'useful' included; area under nature protection or organic farming, cropping or livestock patterns, level of intensification, population of farmland birds, emissions of methane, nitrous oxide or ammonia, land use change. However, it is worth noting that not all of these indicators are easily assessed using the financial data available from FADN/FBS.

In this paper the potential of FBS data to provide environmental indicators is investigated by considering a comparison of conventional and organic farming systems with the main aim of assessing whether is it possible to derive some of the well-established environmental indicators developed in the above mentioned projects from a set of Farm Business Survey (FBS) data.

The study focused on well established indicators selected from a range of sources including those referred to above because they have been found by other authors to be useful in assessing the environmental impact of farming (see Table 1) and because they could be derived from farm income/business data. Similar indicators have been suggested by many other authors (Cooper *et al.*, 2009; Halberg *et al.*, 2005a; Halberg *et al.*, 2005b), although without a view to deriving them from accounts/economic data sets.

As the indicators were used outside the context in which they were originally developed, it was necessary to verify that they give reasonable results in this new context. This was done by using them in a comparison of organic and conventional farms. As discussed previously, successful identification of indirect indicators of environmental performance which could be derived from financial data would be useful to both researchers and policy-makers. The long term records stored within the FBS dataset allow continuous, long-term coverage of the changing situation across a range of farm types (and potentially countries using FADN data). Thus such indicators could therefore be used to evaluate the impact of various policy decisions. The approach could also be of potential interest for consultants and farm managers who could use financial

Table 1: The indicators used in this study and the previous research which supports the use of these indicators.

Indicators	Eurostat (2011)	Biobio (Dennis, 2009)	IRENA (EEA, 2005)	Westbury *et al.* (2011)	Gomez-Limon and Sanchez-Fernandez (2010)
Fertiliser use	X	X	X	X	X
Pesticide use	X	X	X	X	X
Purchased feed use		X	X		
Intensification/ Extensification	X		X		
Agri-env schemes		X	X		X
Crop/land-use diversity	X	X	X	X	X
Average LUs per ha forage		X		X	

data that a farm must keep for taxation purposes to derive some level of environmental information about that farm.

The paper aims to answer two main questions. Firstly it aims to assess whether such environmental indicators can be successfully derived from the mainly financial data collected in the Farm Business Survey and secondly it aims to use these indicators to compare organic and conventional farms as a means of verifying the effectiveness of the indicators. Section 2 discusses the indicators used and how they have been derived from FBS data. Section 3 presents the results from using these indicators, demonstrating their use in comparing organic and conventional systems across farm types. Section 4 discusses the results and the potential for the use of these types of indicators in the future.

2. Methods

The use of FBS data to provide environmental indicators was investigated using FBS data from 2008–09 (Department for Environment Food and Rural Affairs and National Assembly for Wales, 2008–2009) and 2009–10 (Department for Environment Food and Rural Affairs and National Assembly for Wales, 2009–2010). The data were unweighted as the weightings provided with FBS data do not take into consideration whether or not a farm is organic and so may not result in a representative sample for organic farms (Hansen *et al.*, 2009). The FBS database has two main sections: the 'Calcdata' section contains the variables which Defra (UK Department for Environment Food and Rural Affairs) considers will be most useful to researchers and policy makers. These include variables such as LFA status, region, livestock units for various livestock types, costs of various inputs, and areas of various crops. Some of these are taken directly from the farm return data collected, others are calculated by Defra from the farm return data. The second section of the database is the 'FASdata' section which contains all of the farm return data collected. The variables used to calculate the indicators (shown in italics below) were taken from the 'Calcdata' section of the FBS database.

For several indicators two denominators are shown. The use of UAA as a denominator can be seen as giving a bias towards extensive farming as extensive systems are likely to have a higher denominator, giving a lower total value for the indicator and, in many cases, implying a lower environmental impact. However extensive farms may also potentially have lower yields. Therefore, the financial output was also used as a denominator in some cases as a proxy for production levels. The output value excluding subsidies was used in this study as, since decoupling, subsidies in general do not tend to vary with physical output and so this was deemed to be the best proxy for production levels.

The indicators and the FBS variables used to calculate them (text in italics) are listed in Table 2 below.

The Shannon crop diversity index sums over all the crops considered. For example, if a farm has 20ha of crops, consisting of 15ha wheat and 5 ha oats the Shannon diversity index would be: $H=-(15/20)\ln(15/20)-(5/20)\ln(5/20)$. The higher the result, the greater the diversity (one single crop will give $H=0$). The 'total area considered' was taken as the denominator in the area fractions due to the fact that the FBS crop areas can include main crops and multiple cropping (i.e. where more than one crop is planted in a year they will count both crops) whereas UAA and other total areas calculated in the 'Calcdata' section of the FBS database only use the main crop areas (i.e. they correctly measure the total area of the farm but therefore if a field is cropped twice in one year do not take that into consideration) and so using these as denominators could result in a negative Shannon index. Farms with no land in any of these categories were excluded from the sample.

The data were split into the 'robust farm types' (cereals, general cropping, horticulture, pigs, poultry, dairy, LFA [less favoured area] grazing livestock, lowland grazing livestock, mixed and 'other' farms). Where 'all' farm results are quoted, these are not weighted based on the sample sizes of the individual farm types and so can be skewed by one farm type with particularly high or low values for the indicator e.g. the horticulture farm results skew the 'all' farms results upwards for the intensity indicator. The 'robust farm types' are a Defra classification of farm types which aggregates some of the EC types (which are very specialised) to provide 10 types of farm as described above. Farms are classified into one of these types based on the contribution of different enterprises towards their overall financial situation (i.e. based on output per production unit). Following the disclosure requirements for Defra, samples of five farms or fewer cannot be published.

As farm types are being directly compared within a year it would be possible to use costs as proxies for physical amounts without taking into consideration price changes, as would be necessary if performance across several years was analysed. The limitations of this approach are discussed in the conclusions.

The results of this comparison are discussed later in this paper with regards to the question of whether FBS data can be useful in providing environmental

Table 2: Indicators used and their calculation using FBS calcdata variables.

Indicator	Calculation
Cost of fertiliser per ha utilisable agricultural area (UAA) and per output	*agriculture.fertiliser.costs/UAA* and *agriculture.fertiliser.costs/output.from.agriculture.excl.subsidies*
Cost of pesticide per ha UAA and per output	*agriculture.crop.protection.costs/UAA* and *agriculture.crop.protection.costs/output.from.agriculture.excl.subsidies*
Purchased feed per UAA and per livestock units (LU)	*(feedingstuffs.costs.purchased-fodder.costs)/UAA* or *LU*
An intensification indicator (EEA, 2005) consisting of the sum of fertiliser cost, pesticide cost and purchased concentrate cost divided by UAA	*(agriculture.fertiliser.costs+agriculture.crop.protection.costs+(feedingstuffs.costs.purchased-fodder.costs))/UAA*
Monetary receipts from agri-environmental schemes per ha UAA	*agri.environment.schemes.payments/UAA*
Average number of grazing livestock units (GLUs) per ha of forage area	*Grazing.LU/(forage.grazing.fallow.area-fallow.area)*
Shannon crop diversity index	*Shannon crop diversity index* $= H = -\sum p_i ln(p_i)$ Where each p_i is the area fraction of each individual crop (i.e. the area of the crop over the total cropping area). The area fractions are calculated as: *barley.area / total area considered*, *beans.area / total area considered*, *horticulture.area / total area considered*, *oilseed.rape.area / total area considered*, *peas.area / total area considered*, *potatoes.area / total area considered*, *permanent.grass.area / total area considered*, *sugar.beet.area / total area considered*, *wheat.area / total area considered*, where total area considered was calculated as: *Total area considered = barley.area + beans.area + horticulture.area + oilseed.rape.area + peas.area + potatoes.area + permanent.grass.area + sugar.beet.area + wheat.area.*

indicators. For all of the indicators, where the denominator is zero (giving a divide by zero error) the farm is excluded from the sample for that particular indicator.

For each indicator the mean and median are quoted. The means of ratios were calculated by taking the ratio for each individual farm and then averaging over all farms i.e. taking mean(A/B) rather than mean(A)/mean(B). This approach was taken as it is the calculation method which must be used in taking the medians and so it meant that the formulae were consistent across the main descriptive statistics used. Also, calculating the mean in this way gives each farm equal weighting. It will mean, however, that farms with larger values for the ratios will result in a larger overall mean than if mean(A)/mean(B) were used but this is balanced by also taking the median which is much less susceptible to outliers.

Two approaches were taken to assessing the significance of any apparent difference in performance on each of the indicators between organic and conventional farms of each farm type. A two-tailed t-test was used to compare organic and conventional farms (Levene's test was carried out first to evaluate whether or not the variances were equal and then the appropriate p-value was taken based on this). However, this commonly used test for comparing two samples of data assumes that the data has a Gaussian (also known as normal) distribution. In the case of FBS data split by farm type this assumption did not often hold true. As the organic and conventional data sometimes had different distributions, it was not possible to use transformations to regain a Gaussian distribution. The data were therefore also evaluated using a non-parametric test, the Mann-Whitney U test. This test compares medians (rather than means as in the t-test) and so is less likely to be influenced by outliers and does not assume a Gaussian distribution for the data.

The Mann-Whitney p-values quoted were based on the asymptotic significance as the exact significance test was too demanding of computing power and so could not be completed, a common issue in using this test. The Mann-Whitney U tests were also re-run using the alternative Monte Carlo significance test. This gave the same results for all of the variables except for purchased feed cost/livestock units for LFA grazing livestock farms, and grazing livestock units per forage area for LFA grazing livestock farms. In both cases a very slight difference in p-value led to a difference in significance level and in both cases the asymptotic significance gave the lower significance and so, to err on the side of caution, is the significance level quoted in the tables below. Where the results of both the t-test and the Mann Whitney U test agree there is a strong assurance that the result is accurate. Where they disagree the Mann-Whitney U test has been assumed to be the more accurate as its assumptions are better suited to this data set.

In all of the tables showing the statistical results *** represents significance at the 0.5% level, ** at the 1% level, * at the 5% level, N.S indicates that no statistical significance was found and n/a indicates that no comparison of organic and conventional was carried out either because the organic sample was unavailable or, in the case of 'all farms', because the farm-type specific tests are more meaningful. Both tests were run using SPSS Statistics (V18) (IBM, 2009).

In all of the comparisons there was good agreement between the 2008–09 and 2009–10 data and therefore only the results for 2009–10 data are presented in Section 3, however it will be highlighted in the discussion where there were differences between the two years. For most variables the mean values were considerably higher than the median value, due to outliers with very high values. Therefore the median value may be more indicative of typical values for each farm type.

3. Statistical results of the comparison

This section presents the statistical results, followed by a discussion of the implications of these with regards to verifying that these indicators are valid in the following section.

Fertiliser costs per UAA and per output

Considering individual farm types, it can be seen from Table 3 that horticultural farm expenditure was highest for fertiliser per UAA whereas poultry farms spent the least; costs were also low for pig farms and both types of grazing farms. Considering costs per financial output, poultry and pig farms again showed low costs but there were higher costs for cereals and general cropping farms. LFA grazing livestock farms had higher fertiliser costs per output than other livestock-related farm types (possibly due to lower financial income).

The statistical significance of the results is also investigated in Table 3. This shows the mean and median fertiliser costs per UAA and per financial output for conventional (marked CF) and organic (marked OF) farms and the results of the t-test and Mann-Whitney U test. It can be seen from these that there is good agreement that fertiliser cost differs significantly between organic and conventional farms for all farm types, as would be expected from the nature of organic farming (Mondelaers *et al.*, 2009a). Only for horticultural farms in 2009/10 (and in 2008/09 for the t-test only) does there appear to be a lower significance.

Crop protection costs per UAA and per output

Table 4 indicates that horticultural farms had the highest costs for crop protection per UAA and that pig, poultry and grazing livestock farms (LFA and lowland) had lower expenditure. It was also found that cereals and general cropping farms had the highest crop protection costs per financial output (Table 4) whilst poultry farms had the lowest.

Crop protection costs differed significantly across the farm types whether the denominator was UAA or financial output and that organic farms had significantly lower costs, which would be expected due to severe restrictions on crop protection usage on organic farms.

Purchased feed cost per UAA and per LU

This indicator included both purchased forage and purchased concentrates, and Table 5 indicates that the purchased feed costs were particularly high on poultry and pig holdings (both per UAA and per LU). However, it should be noted that for both of these there was limited or no organic data. Lowland grazing livestock farms in particular had lower purchased feed costs with LFA grazing livestock farms having slightly higher costs. Dairy holdings had higher purchased feed costs than grazing livestock farms but lower than pig and poultry holdings.

There was less of a significant difference between purchased feed costs for organic and conventional farms than there was for fertiliser or crop protection costs (Table 5). For dairy farms the purchased feed cost per livestock unit was slightly higher for organic than for conventional farms but this was generally not significant (or only significant at a low confidence level in 2008/09) and probably reflects the higher price of organic feed rather than greater use of purchased feed, and is discussed further later. For lowland grazing livestock there was a greater difference, with organic farms having significantly lower purchased feed costs. This was also reflected in LFA grazing livestock farms although with slightly lower significance. In general, the results for mixed farms indicated that median

Table 3: Statistical results for fertiliser cost /UAA (£/ha) indicator and fertiliser cost / output (£/£) indicators

		Fertiliser cost per UAA					Fertiliser cost per output (£)[i]				
Farm type		sample	mean	t-test	median	Mann-Whitney	sample	mean	t-test	median	Mann-Whitney
Cereals	CF	356	158	***	156	***	356	0.201	***	0.198	***
	OF	17	11		0		17	0.021		0.000	
General cropping	CF	197	175	***	158	***	197	0.141	***	0.132	***
	OF	12	19		9		12	0.015		0.003	
Horticulture	CF	200	5897	N.S	365	*	201	0.036	N.S	0.027	*
	OF	10	3246		21		10	0.024		0.005	
Pigs	CF	54	37	n/a	0	n/a	62	0.01	n/a	0.000	n/a
Poultry	CF	52	11	n/a	0	n/a	67	0.002	n/a	0.000	n/a
Dairy	CF	397	145	***	136	***	397	0.06	***	0.054	***
	OF	51	8		0		51	0.004		0.000	
LFA grazing livestock	CF	252	47	***	39	***	525	0.083	***	0.076	***
	OF	41	7		0.6		41	0.02		0.001	
Lowland grazing livestock	CF	253	53	***	32	***	253	0.06	***	0.046	***
	OF	32	6		0		32	0.008		0.000	
Mixed	CF	185	96	***	93	***	185	0.097	***	0.076	***
	OF	23	13		0		23	0.016		0.000	
All	CF	2253	616	n/a	92	n/a	2275	0.092	n/a	0.071	n/a
	OF	190	179		0		190	0.013		0.000	

[i]In late September 2012, £1 was approximately equivalent to €1.25 and US$1.62.

Table 4: Statistical results for crop protection cost/UAA (£/ha) indicator and for the crop protection cost/output (£/£) indicators

		Crop protection cost / UAA					Crop protection cost / output				
Farm type		sample	mean	t-test	median	Mann-Whitney	sample	mean	t-test	median	Mann-Whitney
Cereals	CF	356	107	***	105	***	356	0.135	***	0.128	***
	OF	17	2		0		17	0.004		0.000	
General cropping	CF	197	138	***	120	***	197	0.105	***	0.102	***
	OF	12	13		9		12	0.007		0.006	
Horticulture	CF	200	1062	N.S	430	***	201	0.028	***	0.013	***
	OF	10	491		0		10	0.005		0.000	
Pigs	CF	54	38	n/a	0	n/a	62	0.009	n/a	0.000	n/a
Poultry	CF	52	11	n/a	0	n/a	67	0.002	n/a	0.000	n/a
Dairy	CF	397	18	***	11	***	397	0.007	***	0.004	***
	OF	51	0		0		51	0		0.000	
LFA grazing livestock	CF	525	2	***	1	***	525	0.004	***	0.002	***
	OF	41	0		0		41	0		0.000	
Lowland grazing livestock	CF	253	9	N.S	3	***	253	0.008	***	0.004	***
	OF	32	1		0		32	0.002		0.000	
Mixed	CF	185	54	***	42	***	185	0.046	***	0.044	***
	OF	23	6		0		23	0.004		0.000	
All	CF	2253	133	n/a	15	n/a	2274	0.04	n/a	0.008	n/a
	OF	190	28		0		190	0.002		0.000	

organic feed costs were lower, although the results were not significantly different.

Purchased concentrate cost per UAA and per LU

Considering individual robust farm types (Table 6), it can be seen that the highest costs per livestock unit occurred for pig and poultry farms followed by dairy farms. LFA and lowland grazing livestock farms had much lower costs for concentrate feed.

As for purchased feed cost, there is less of a significant difference between organic and conventional farms with regards to purchased concentrate costs than for fertiliser or crop protection costs. For dairy farms the purchased concentrate cost per livestock unit was slightly higher for organic than for conventional farms but this was generally not significant (or only significant at a low confidence level in 2008/09) and again probably reflects higher organic feed prices rather than greater use of purchased concentrates. For lowland grazing livestock there was a stronger significant difference, with organic farms having lower purchased concentrate costs. This was similarly reflected in LFA grazing livestock farms though with lower significance.

The minima were negative for a small number of farms (10 farms) i.e. *fodder.costs* exceeded *feedingstuff.costs.purchased*, suggesting that the *fodder.costs* variable may include some home-grown forage cost and so this indicator approximates the cost of purchased concentrates but may underestimate it. Extracting data directly from the FBS fieldbook data may allow the use of exact purchased concentrate value, but was not undertaken within the confines of this project.

Intensification indicator

The intensification indicator is based on IRENA Indicator 15 (EEA, 2005), and consists of the sum of

Table 5: Statistical results for purchased feed cost /UAA (£/ha) indicator and for the purchased feed cost/LU (£/LU) indicators.

		purchased feed cost /UAA					purchased feed cost/LU				
Farm type		sample	Mean	t-test	Median	Mann-Whitney	sample	mean	t-test	median	Mann-Whitney
Pigs	CF	54	26556	n/a	3885	n/a	62	529	n/a	595	n/a
Poultry	CF	52	164764	n/a	8720	n/a	67	1228	n/a	592	n/a
Dairy	CF	397	703	*	633	**	397	341	N.S	340	N.S
	OF	51	549		511		51	380		383	
LFA grazing livestock	CF	525	123	***	91	***	525	121	**	109	***
	OF	41	68		44		41	87		59	
Lowland grazing livestock	CF	253	188	N.S	90	***	253	100	***	71	***
	OF	32	30		11		32	34		15	
Mixed	CF	185	294	N.S	294	N.S	185	204	N.S	85	N.S
	OF	23	483		44		23	175		54	
All (incl cereals, horticulture, gen cropping)	CF	2253	4645	n/a	70	n/a	1833	231	n/a	123	n/a
	OF	190	380		47		177	191		73	

Table 6: Statistical results for purchased concentrate cost /UAA (£/ha) indicator and the purchased concentrate cost/LU (£/LU) indicator

		purchased concentrate cost /UAA					purchased concentrate cost/LU				
Farm type		sample	mean	t-test	median	Mann-Whitney	sample	mean	t-test	median	Mann-Whitney
Pigs	CF	54	26552	n/a	3885	n/a	62	528	n/a	595	n/a
Poultry	CF	52	164764	n/a	8720	n/a	67	1228	n/a	592	n/a
Dairy	CF	397	666	*	588	**	397	323	N.S	313	N.S
	OF	51	521		485		51	363		365	
LFA grazing livestock	CF	525	104	**	77	***	525	100	*	87	***
	OF	41	61		41		41	76		52	
Lowland grazing livestock	CF	253	173	N.S	82	***	253	92	***	66	***
	OF	32	25		10		32	28		12	
Mixed	CF	185	286	N.S	71	N.S	185	196	N.S	79	N.S
	OF	23	478		40		23	170		35	
All	CF	2253	4632	n/a	60	n/a	1833	220	n/a	109	n/a
	OF	190	369		41		177	181		63	

the purchased concentrate cost, fertiliser cost and crop protection cost divided by the UAA (ha). This value was utilised to identify intensive, high input farms compared with more extensive production systems which are generally believed to have lower environmental impact (EEA, 2005) although they may also have lower yields and so figures per product may be less favourable.

Table 7 suggests that pig and poultry farms are particularly intensive, followed by horticultural farms, whereas LFA grazing livestock farms are much less intensive production systems and therefore may have lower environmental impacts.

It can be seen from the table that, in general, there were significant differences in the intensification indicator between organic and conventional farms, with conventional farms generally appearing to be more intensive than organic farms.

Agri-environmental scheme payments per UAA

Data for this variable were more evenly distributed than those for some of the other indicators e.g. fertiliser, with few outliers due to the limited value any one farm may receive through agri-environment schemes. The comparison between conventional and organic farms revealed that organic farms obtain a higher level of agri-environment scheme payments suggesting that there is more enthusiasm for scheme participation or that more schemes are suited to organic farming.

Considering farms by robust type (Table 8), it can be seen that horticultural, pig and poultry farms received the lowest level of payments; cereal, general cropping, lowland grazing livestock and LFA grazing livestock holdings received the highest levels, contrasting strongly with minimal payments on horticulture, pig and poultry holdings.

Statistically, organic and conventional farms were significantly different at the 0.5% level for all farm types except horticulture, with organic farms receiving significantly higher agri-environment payments (Table 9). For horticultural holdings the results were less significant with both organic and conventional horticultural farms receiving low levels of payments under these schemes.

Table 7: Statistical results for the intensification indicator (£/ha UAA).

Farm type		sample	mean	t-test	median	Mann-Whitney
Cereals	CF	356	279	***	274	***
	OF	17	18		8	
General cropping	CF	197	344	N.S	312	***
	OF	12	265		40	
Horticulture	CF	200	6967	N.S	838	**
	OF	10	3783		143	
Pigs	CF	54	26627	n/a	3886	n/a
Poultry	CF	52	164786	n/a	8720	n/a
Dairy	CF	397	828	***	755	***
	OF	51	529		490	
LFA grazing livestock	CF	525	153	***	127	***
	OF	41	68		51	
Lowland grazing livestock	CF	253	235	N.S	132	***
	OF	32	32		13	
Mixed	CF	185	436	N.S	216	***
	OF	23	497		73	
All	CF	2253	5381	n/a	273	n/a
	OF	190	577		63	

Table 8: Statistical results for agri-environment scheme payments over UAA (£/ha):

Farm type		sample	mean	t-test	median	Mann-Whitney
Cereals	CF	356	39	***	30	***
	OF	17	144		119	
General cropping	CF	197	34	***	29	***
	OF	12	86		76	
Horticulture	CF	200	10	N.S	0	**
	OF	10	34		0	
Pigs	CF	54	24	n/a	0	n/a
Poultry	CF	52	14	n/a	0	n/a
Dairy	CF	397	24	***	20	***
	OF	51	85		61	
LFA grazing livestock	CF	525	37	***	30	***
	OF	41	126		93	
Lowland grazing livestock	CF	253	40	***	29	***
	OF	32	116		90	
Mixed	CF	185	38	***	30	***
	OF	23	87		70	
All	CF	2253	32	n/a	26	n/a
	OF	190	102		80	

Shannon crop diversity index

It has been postulated by some authors that greater cropping diversity (i.e. a greater range of crops being grown on the farm and a wider range of varieties within a crop) is associated with greater biodiversity in general (supporting a wider range of pollinators, and farmland birds, for instance) or with greater provision of ecosystem services and so has a positive environmental impact (Altieri, (1999); Hajjar *et al.*, (2008)). One suggested means of assessing the cropping diversity on a farm is to use the Shannon index.

A higher Shannon index value is indicative of a more diverse range of crops. A farm with several small fields of different crops but a large proportion of one crop will have a lower Shannon diversity index than a farm with the same number of crops evenly divided across the farm.

The formula used to calculate the Shannon index in this study is very basic being based on nine widely grown crops, two of which (horticulture crops and permanent pasture) are categories for a number of different crops.

The results shown in Table 9 suggest that the highest index values, and greatest cropping diversity, occurred on general cropping farms, followed by cereals farms and mixed farms. The lowest cropping diversity, as might be expected occurs on grazing livestock farms (which would be expected to mainly consist of permanent grassland). For the majority of the farm types there is no significant difference between organic and conventional farms. For mixed farms and lowland grazing livestock farms there was a significant difference with organic farms having a lower index suggesting that they have lower diversity in the crops considered here than conventional farms. These results will be discussed later, in particular evaluating what they imply with regards to using this kind of index based on financial information.

Grazing livestock units per forage grazing

This indicator gives an indication of the amount of pressure on the grazing land and the reliance of the farm on external inputs.

Table 9: Statistical results for the Shannon crop diversity indicator

Farm type		sample	mean	t-test	median	Mann-Whitney
Cereals	CF	356	1	*	1.05	N.S
	OF	16	0.81		0.69	
General cropping	CF	196	1.14	N.S	1.19	N.S
	OF	12	1.04		1.00	
Horticulture	CF	201	0.1	N.S	0.00	N.S
	OF	10	0.13		0.00	
Pigs	CF	42	0.28	n/a	0.00	n/a
Poultry	CF	35	0.11	n/a	0.00	n/a
Dairy	CF	387	0.18	N.S	0.00	N.S
	OF	50	0.15		0.00	
LFA grazing livestock	CF	524	0.03	N.S	0.00	*
	OF	41	0.05		0.00	
Lowland grazing livestock	CF	251	0.14	***	0.00	***
	OF	32	0.01		0.00	
Mixed	CF	185	0.78	***	0.75	***
	OF	23	0.51		0.58	
All	CF	2209	0.4	n/a	0.00	n/a
	OF	188	0.26		0.00	

Table 10: Statistical results for grazing livestock units per forage area (grazing LU/ha)

Farm type		Sample	Mean	t-test	Median	Mann-Whitney
Dairy	CF	397	2.13	***	2.06	***
	OF	51	1.47		1.39	
LFA grazing livestock	CF	525	1.02	***	0.95	*
	OF	41	0.81		0.77	
Lowland grazing livestock	CF	253	1.56	*	1.3	***
	OF	32	0.92		0.83	
Mixed	CF	182	1.6	N.S	1.24	***
	OF	23	0.91		0.91	
All	CF	2111	1.2	n/a	1.02	n/a
	OF	185	0.97		0.97	

It can be seen from the results in Table 10 that LFA grazing livestock farms had the lowest stocking density, followed by lowland grazing farms and then dairy farms. There was a significant difference between all organic and conventional farm types with organic farms having lower stocking densities for all farm types.

Summary and discussion of differences

The results of the Mann-Whitney U test comparing organic and conventional farms showed that there were statistically significant differences between organic and conventional farms in terms of input costs. Fertiliser and crop protection costs were significantly higher for all conventional farm types when compared with organic holdings, reflecting the lower use of external inputs within organic cropping systems. This might be expected due to the strong emphasis on reducing these inputs in the organic regulations (EC No. 834/2007 and several implementing regulations) and agrees with the results of a meta-analysis of several LCA (life cycle analysis) studies comparing the environmental impacts of organic and conventional farming (Mondelaers *et al.*, 2009a). Similarly, the IRENA intensification indicator indicated greater intensity for all conventional farm type median values, though t-test results were more variable. The results appear to confirm that in general, conventional farms tended to be more intensive than organic holdings.

With regards to purchased feed costs, significant differences between organic and conventional farms depended on the robust farm type. Purchased feed and purchased concentrate costs for dairy farms only showed differences of low statistical significance with organic farms having slightly higher costs per livestock unit. This was probably due to higher organic feed prices rather than higher usage. Nix (2011) quotes a price for concentrates for conventional dairy farming of £220 per tonne whereas Lampkin *et al.* (2011) quote a price range of £310–£400 for compound concentrate feeds for organic dairy farms. This difference in prices would be sufficient to explain the higher organic purchased feed cost in this study (especially given the low significance of the difference). It is not possible to confirm whether the differences are due to higher usage or higher feed cost using FBS data alone (it required additional information from farm management handbooks). This is one of the limitations of this form of analysis using costs as a proxy for physical amounts. However, by factoring in the average costs of organic and conventional feed for the year it is possible to convert these cost figures into approximate usage figures.

For lowland grazing livestock there was a stronger significance, with organic farms having lower purchased feed costs. This was also reflected in LFA grazing livestock farms although with a slightly lower significance. Given the emphasis in organic farming on home-grown feed and the farm being a closed system the expectation would be that in general organic farms would use less bought-in feed. Thus these lower purchased feed costs appear reasonable.

Dairy and lowland grazing livestock farms showed significant differences in stocking density between organic and conventional management with organic farms tending to have lower stocking densities, again this is in accordance with the organic regulations. LFA grazing livestock farm differences were only significant at the 5% level, perhaps reflecting the fact that such farms tend to be unable to support larger stocking densities regardless of management system. Again, these results would appear to be reasonable and so suggest that the indicator is valid and works as a good proxy for level of intensification.

The Shannon index results indicated that some types of organic farms (mixed and grazing holdings) appear to have less cropping variety than conventional holdings, contradicting the findings of Mondelaers et al. (2009a) that organic farms generally have high agri-biodiversity. As discussed previously, the Shannon crop diversity index was calculated using the crop fractions of a selection of crops and the denominator was taken as the total of these. It must, therefore, be considered that a farm with a zero index (i.e. if the only crop, from those considered, that it grows is for example permanent grass) signifies that it only has one of the crops considered. It may be that a large diversity of other crops is grown on the farm but were not considered here. Additionally, permanent grass may include a large number of species of grass, legumes and various herbs. This is not recorded in the FBS and so cannot be derived from the data. As stated by Magurran (2006) in discussing the Shannon index, 'A more substantial source of error arises when the sample does not include all the species in the community'. Thus, the fact that the FBS does not record crop varieties or break down permanent pasture into species means that the Shannon index calculated here is prone to issues. This highlights one important limitation of using FBS/FADN data to derive environmental indicators: The data are obtained for financial reasons and so may not contain all the information which would be desirable to measure environmental factors to best effect. This suggests that, while the other indirect indicators included in this study have proved to be useful and effective, this type of index requires more information than can currently be provided by financial surveys. Indeed as stated by Magurran (2006) there are concerns about using the Shannon index in an ecological context (due, in part, to its need to include all species in the community – often an unknown when ecological assessments are being carried out) and other measures of biological diversity and being used in preference to the Shannon index in these contexts.

4. Discussion and Conclusions

The indicators used in this study were selected because they are well-established environmental indicators which have been used in a number of previous studies (Corson *et al.*, 2010; Dennis, 2009; EEA, 2005; Westbury *et al.*, 2011) and have been shown to provide useful information on the environmental performance of farms. The aim of this study was to assess whether it was possible to derive these environmental indicators from the financial data contained within the Farm Business Survey database and to use them to compare the performance of organic and conventional farms. Only indicators that could be derived from FBS data or on-farm financial records were considered, because such data is recorded on a regular basis from a large number of farms and across a number of countries (FADN). Other indicators have been suggested by other authors (Cooper *et al.*, 2009; Halberg *et al.*, 2005b) but would not be possible to derive from financial data and so were not considered here.

Advantages and limitations in the use of FBS data for assessing environmental performance

This analysis found the use of FBS variables to provide indirect environmental indicators to be challenging at times but found that it could provide some useful indication of environmental performance (i.e. detecting statistically significant differences between farms managed under organic or conventional methods) as will be discussed in the next section. The Farm Business Survey is primarily designed to obtain financial data and so is not designed to provide environmental data, but it records some information which can be used as a 'proxy' for direct environmental measurements.

As was pointed out by Westbury *et al.* (2011) the FBS lacks information about environmental features (such as hedgerows), intensity of cultivation and management of grassland and this limits the type of environmental indicator that can be derived from the survey. Similarly the lack of information about crop varieties or the number of species present in permanent pasture was highlighted above as a limitation in trying to use the Shannon index with these data. If such elements were added to the FBS this would allow a greater range of indicators to be used.

The significant advantages of using FBS data include its sample size, historical database and ability to distinguish between organic and conventional holdings. However, one of the limitations of this type of analysis using FBS data is the lack of quantitative data for inputs. Prices may vary significantly between organic and conventional feeds (as shown by the dairy results in this study), fertilisers and crop protection products and so comparing the cost for organic farms to the cost to conventional farms or the costs of two different types of fertiliser does not necessarily equate to comparing physical quantities used, even within the same year. This use of cost as a proxy for physical quantities is more unreliable if comparisons are taking place over several years, e.g. if using the indicators to track changes in environmental performance over time. In this case standard costs or price index data would need to be used to derive physical quantities from cost as otherwise inflation and other price fluctuations would affect the results. In this case it would be more accurate to ascertain the proportion of different feeds, fertilisers, crop protection products used in each year and by different types of farms and to then combine this information with standard costs (i.e. costs which were pertaining for those products at that point in time), as carried out by Corson *et al.* (2010). By taking this approach it is possible to obtain a much more accurate estimate of physical inputs from cost data. Alternatively, Westbury *et al.* (2011) suggested that adding specific estimates of fertiliser and pesticide use per hectare to the data collected within the FBS would improve precision further.

The results presented here suggest that these indicators are identifying expected differences between organic and conventional farming (in a statistically significant manner) and so are potentially useful in assessing environmental performance. However, the limitations discussed in this section mean that some indicators cannot be derived using financial data.

At present the authors are not aware of any environmental surveys carried out on a large sample of farms (equivalent in scale to FADN) on a regular basis across all countries of the EU. Being able to use indirect indicators of environmental performance derived from FBS/farm accountant type data would therefore be very valuable. The FBS is part of the EU FADN and so indirect indicators derived from economic data can usually be used across the EU. Farm Business information is recorded annually in the UK and has been recorded for a number of years in most EU countries and so retrospective studies can be carried out using these data as well as tracking of current changes in management practices. Comparisons between countries are also possible. It is therefore of interest to test the validity of these indicators and to assess whether they can be effective in assessing environmental performance. This is discussed below.

Discussion of indicator results – verification of the indicators

The results presented here contrast with those of Westbury et al. (2011). They concluded that either agri-environment scheme participation was not always associated with better environmental performance or that FADN indicator data were not able to detect differences in environmental performance. In the current study, the FBS derived indirect environmental indicators detected statistically significant differences between organic and conventional holdings in line with the findings of Mondelaers et al. (2009) in a meta-analysis of research comparing the environmental impact of organic and conventional farming.

The results with regards to the Shannon index, while they may appear negative, are also important as they show that not all indicators developed in an environmental context can be derived from financial information, some are best suited to on-farm assessments or more detailed environmental surveys. However, the results of this study suggest that most of the indirect indicators investigated (with the exception of the Shannon index) can be used to assess some aspects of environmental performance and identify statistically significant differences between organic and conventional production. This suggests that they are sufficiently sensitive to differing management techniques to be used to assess some aspects of environmental performance. This means that annual economic surveys such as the FBS can be used to give some environmental information, tracking changes over time and comparing countries through the EU.

Policy and societal context

Many industries, including agriculture are currently coming under closer scrutiny as concerns grow about their impact on greenhouse gas emissions, and therefore climate change, biodiversity, water and air quality and use of scarce resources.

As a result of these public concerns over the environmental impact of agriculture there is increasing interest amongst policy makers in encouraging farmers to consider the environment and to provide environmental benefits /reduce negative environmental impacts of farming. As a result, agri-environment schemes to encourage environmental benefits through agriculture have operated in all EU countries. Beyond these schemes, there is current discussion over 'greening' of the CAP as part of the 2014–2020 reforms. This is likely to result in Pillar One changing from being a policy put in place to encourage high levels of food production to ease food security concerns to being a policy encouraging more environmentally friendly farming (beyond cross-compliance measures) by having 30% of Pillar One dependent on carrying out environmentally supportive practices defined in legislation (European Commission, 2011). To monitor such policy measures, governments require means of monitoring its impact and being able to make use of current surveys which are carried out across the EU as part of the FADN could be very valuable in this context. It would allow the basic environmental assessment of agriculture through indicators which do not require additional surveys and therefore additional funds at a time of financial austerity.

There is also a great deal of interest from consumers in the environmental impact of the food that they eat. Recent studies of the motivation of consumers of organic foods have found that motives include environmental concerns as well as personal motives such as perceived health benefits (Hughner *et al.*, 2007; Mondelaers *et al.*, 2009b; Zander and Hamm, 2010). The recently introduced LEAF (linking environment and farming) marque is further evidence of consumers' interest in the environmental impact of their food as is recent marketing of certain products such as Jordan's cereals based on their environmental credentials. Membership of LEAF and of the farm assurance scheme is recorded in FBS as is organic status making it possible to also use these sorts of indicators to see whether there are significant differences between these farms and farms which are not members of such schemes.

Conclusions and future work

It appears from the analysis presented here that it is possible to use financial survey data such as the FBS to provide indirect information on the environmental performance of farms and it is possible to provide comparisons across different types of farms and farming systems. Extending these indicators to FADN data at EU level could allow policy-makers to track performance of some key agri-environmental aspects, to help monitor the impact of policy decisions and of changes in farm management approaches (e.g. a change in the proportion of organic farms within a country, the impact of an increased emphasis on the environment within the CAP). Furthermore this type of approach could be extended and used by farm consultants/managers to use financial information (usually recorded for taxation reasons) to assess some aspects of environmental performance on an individual farm or group of farms.

Indeed, as useful as individual indicators may be, it is possible that combining a range of indicators, such as the IRENA intensity indicator and others into an overall score that takes account of intensity, crop variation, variation in habitat and stocking rates, as well as agri-environment payments could provide an overall score, in a similar approach to that taken by Gomez-Limon and Sanchez-Fernandez (2010). Although an indirect measure of environmental performance may never achieve a perfect assessment a combined score could be weighted to reflect the relative importance of the various factors.

Ultimately, it would be very useful if physical quantities e.g. of fertilisers and concentrates were included in FADN data such as the FBS (the Northern Irish FBS already includes some physical quantities e.g. feedstuffs including concentrates), as this would allow more accurate input indicators to be derived. Also, if the CAP is given more environmental emphasis then the inclusion of additional direct environmental information in FADN data would be very helpful to researchers and policy-makers as was previously discussed by Westbury *et al.* (2011).

Notwithstanding the limitations mentioned earlier and these possibilities for future improvement to this approach, the results presented here show that it is possible to use indicators derived from financial information to give a reasonable and valid comparison of environmental performance.

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Visitor satisfaction in agritourism and its implications for agritourism farmers in Sri Lanka

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ABSTRACT

The aim of this paper is to evaluate visitor satisfaction in agritourism and to understand the implications for agritourism farmers in Sri Lanka. This has been done following the Expectancy Disconfirmation Theory. There are 21 attributes under five different aspects selected for the satisfaction measurement. This study also provides a comparative picture of local and foreign visitors. The study has been conducted on three randomly selected agritourism destinations. Results reveal that out of 21 attributes, nine attributes emerge at the satisfied level, and there were ten indifferences and two dissatisfied. Further, the overall satisfaction levels of both groups of visitors were at moderate levels and comparatively a higher level of satisfaction of local visitors can be observed over foreign visitors. Although the possibility of revisiting the destinations is low, recommending the destinations to others was high for both groups. However, both groups emphasized the necessity of improving appropriate educational programs, entertainment activities, variation of farm products with processing, availability of direct sales to visitors, increasing the efficiency of staff members, upgrading the hygiene and sanitation situation, and improving the road conditions leading to the destinations in order to enhance the satisfaction of visitors. The findings of this research may be useful in developing policy and undertaking promotional measures for intensifying agritourism sector, as this sector has a place within the current focus of rural development in Sri Lanka.

KEYWORDS: Agritourism; Expectancy Disconfirmation Theory; Visitor Satisfaction; Sri Lanka

1. Introduction

Agriculture plays a vital role in the economy of many countries. However, today it is facing numerous challenges and profits are being squeezed mainly in developing countries for several reasons such as the rising cost of inputs, poor productivity of farmland, falling prices received for outputs, adverse domestic environments, inappropriate policies, etc., (International Fund for Agricultural Development, 2010). This has caused commodity production to be less profitable over time and thus agriculture gradually is becoming less attractive for investment by farmers. If agriculture is to be truly sustainable, it must be able to yield significant returns for its essential investments, such as land, water, capital, and labour, for those working in the sector. Traditional methods of farm management are becoming less viable day by day. Novel farm resource management methods are crucial in this context, including alternative strategies to find extra income from existing resources that avoid the economic uncertainty of farming. Agritourism is such an important strategy, which can assist in the management of farm recourses, marketing, earning additional income, and many other benefits not only for the farmers but also for local residents (Lack, 1995; Topcu, 2007).

Agritourism

Agritourism or farm tourism is a type of rural tourism and is highly recognized as a mean of farm diversification and an alternative source of farm income (Colton and Bissix, 2005; Byrd and Gibson, 2004; Sharpley, 2002). Although there is a large number of synonyms and definitions for the term agritourism under different contexts, the general meaning of agritourism is the practice of attracting travellers or visitors to an area/s used primarily for agricultural purposes, in order to experience a broad spectrum of agriculturally based products and services. Moreover, according to Bruch (2008) Agritourism is an activity, enterprise or business which combines primary elements and characteristics of agriculture and tourism and provides an experience for visitors which stimulates economic activity and impacts both farm and community income. Brumfield and Mafoua (2002) have described agritourism as a "direct marketing activity, that may provide special opportunities to growers to reduce risks via diversification in a competing and urbanizing economic environment, which may share quasi-fixed inputs (e.g. information, machinery, labour, etc.) with other enterprises and enhance business efficiency and profitability."

Agritourism is one of the fast-growing travel trends in the world (Agritourism World, 2008), where farmers can

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offer their visitors the opportunity to visit farms or agricultural lands for a short period of time and to enjoy many different activities. Thus, it is a rural-urban relationship, which can bridge the gap between peasants and city dwellers for the benefit of both. The number of agritourism activities depends on the size of the farm and nature of the farming activities. The activities involved in agritourism vary from simple farm visits to complex situations such as educational and recreational/ entertainment programs, including bed and breakfasts. The three main activities in agritourism are; 'things to see,' 'activities to do,' and 'farm products to buy' (Adam, 2001). Many agritourism activities require only a small farm crew in order to be successful. For instance, conducting farm tours, bed and breakfasts, tractor/ bullock cart rides, maintaining grapes, mangoes, and other horticulture farms, birds/animal zoos, running cottage industries for making jam, chutney, curd, yoghurt, etc., and many other activities may be operated with little additional investment in labour (Agritourism Development Organization in India, 2008).

Since agritourism is consisted of many beneficial functions for the operator that need the cooperation of people involved in agritourism, specially family members, agritourism can be further described as a *multi-functional* and *cooperative* strategy that is useful in agriculture and rural development (Sidali, Spiller and Schulze (2011). The current or third agricultural production system named *post-productivist* agricultural system which is complex than the first (*subsistence*) and second (*productivist)* agricultural systems, plays a vital role in supply of agritourism (Wilson, 2007, Essex, et.al., 2005).The five main tasks of the post-productivist agricultural system are qualitative priorities in food production, alternative income sources for farmers, sustainability of agricultural lands, conservation of environment, and new employment opportunities. Moreover, agritourism can be analyzed regarding five important dimensions, the agricultural, economic, socio-cultural, environmental, and educational dimensions (Topcu, 2007). Further not giving benefits only for male party, but also agritourism has the ability to make use of extra time and labour of female party such as female farmers, housewives, unemployed maid, girls in farm families, in a fruitful way giving them certain level of financial and other benefits without affecting much of their daily routines, agritourism is a *gender equity* agricultural development endeavour (Topcu, 2007; Rentinga et al., 2009; Marsden and Sonnino, 2008).

Agritourism is a developing industry at present in the world, and it includes experiencing agricultural life and leisure recreations, which could take advantage of the agricultural business, village life, the rural landscape, and village culture (Malkanthi and Routray, 2011a). Also, it is a hybrid concept that merges elements of two complex industries, agriculture and travel/tourism, to open up alternative income sources for the farmers as well as the surrounding community (Wicks and Merrett, 2003). Brscic (2006) has explained that agritourism as a special form of tourism takes place within the family farm that represents a specific form of business, giving a number of benefits to the families involved, with multiple impacts on the socio-economic relations and space in rural areas.

According to Bernardo et al. (2007), the list of agritourism activities continues to grow, and might include a variety of participants and educational and spectator experiences such as outdoor recreation (farm visits, fee fishing, photography, etc.), educational experiences (demonstration programs, training sessions, guided farm tours, cooking classes), entertainment activities (harvest festivals, barn dances, hay tunnels), hospitality services (farm stay, home stay, bed and breakfasts), and on-farm direct sales (U-pick operations, sales centres, roadside stands). Wicks and Merrett (2003) have mentioned that agritourism can be successfully integrated into local economies and environment and rural lifestyles without a great disruption to enhance the agriculture sector of a country. Blacka et al. (2001) have divided agritourism facilities in Virginia into six categories: lodging and camping (bed and breakfasts, campsites, youth camps, farm vacations, weddings, honeymoons), special events and festivals (music festivals, haunted houses, holiday celebrations, harvest festivals), off the farm (farmers' markets, roadside produce stands), recreational activities and events (fee fishing, hiking, rock climbing, horseback riding, skeet shooting), tourism-related direct marketing (pick your own fruits/vegetables, sell processed food on the farm, sell herbal organic products) and youth and or adult education (organized tours, agricultural educational programs, demonstrations). Lack (1995) divided agritourism in British Colombia into three groups: retail sales/direct marketing (goods produced on-site, customer-harvested produce and goods produced off-site), tours (tours of processing facilities, scenic tours, and tours of production facilities), and activities (accommodation, cultural activities, recreation and educational or hands-on experiences). It is important to include all of the possible agritourism activities because it helps the tourist to see, enjoy, and learn about agriculture as well as to increase the length of stay and satisfaction of the visitors. In some countries, since farms are large, there are a large number of agritourism activities for visitors to enjoy even for several days. However, the number of agritourism activities on a farm is comparatively lower in Sri Lanka.

Moreover, agritourism is increasingly used as a diversification strategy to uphold a more diverse and sustainable rural economy and to protect farming incomes against market fluctuation (Phelan and Sharpley, 2010), and it is expected to yield a number of economic as well as non-economic benefits to farmers, visitors, and communities. In this sense, agritourism has been suggested to help family farms stay in business, protect the agricultural heritage, enhance the productivity of farm resources through their recreational use, and even to improve the economic situation of local communities (Nickerson et al., 2001; Ollenburg and Buckley, 2007, Veeck et al., 2006; Wilson et al., 2006). From the farm unit perspective, agritourism is claimed to raise farm revenues and to help other entrepreneurial goals of the farmer, such as the improvement of their quality of life (Barbieri, 2009; McGehee and Kim, 2004; Nickerson et al., 2001; Ollenburg and Buckley, 2007).

At the farm level, agritourism improves the value of the farmer's own products through its involvement with the social and cultural context (Nilsson, 2002) and also at the regional level; it can help with rural development by creating new job opportunities and new value added products. The positive influence of agritourism on the local system is shared between diverse economic sectors, as tourist spending relates not only to farms but also to restaurants, crafts, commerce, and other firms located in the region. Furthermore, the direct boost made by tourist spending creates multiplying effects in the local economic system as a whole (Fleischer and Tchetchik, 2005; Vaughan et al., 2000). Therefore, it is believed that agritourism sustains farm and rural economies. The value additions for farm products and the attraction of visitors to rural areas are important strategies in agritourism. Further, agritourism has the ability to sustain the history and culture of agriculture and the environment by preserving open spaces on farms (Bruch, 2008).

1.2 Visitor satisfaction: theoretical background

Visitors, also known as customers, consumers or buyers of any sector of tourism, are one of the most important components (demand side) of a tourism business. Visitor satisfaction is important for successful destination marketing as it influences the selection of the destination, the consumption of products and services, publicity (word-of-mouth), and the decision to return (Kozak and Rimmington, 2000). After the concept of satisfaction was identified as the most important theme in psychology and visitor behaviour, a considerable number of studies have been focused on this concept due to its importance as a basic parameter used to evaluate the performance of destination products, facilities, and services (Noe and Uysal, 1997). On the theoretical level, visitor satisfaction is broadly discussed in the literature and has been defined frequently. According to Engel et al. (1993), most traditional studies have used the cognitive approach, defining visitor satisfaction as a post-consumption assessment where a selected alternative at least meets or exceeds expectations. However, some studies that followed have considered satisfaction as an emotional response resulting from the consumption experience (Spreng et al., 1996). Recent sociologists have understood that the satisfaction should be considered from a more affective perspective (Oliver et al., 1997; Wirtz and Bateson, 1999) than a cognitive perspective. Expectancy Disconfirmation Theory (EDT) is highly used in analysing customer satisfaction (Weber, 1997), **which** has been developed by considering both cognitive and affective perspectives and their relative nature (Oliver, 1980). Though small differences can be seen between different theories and concepts, most of them are more or less similar. The application of these theories depends on the context, the availability of data, the tourists' cooperation in gathering primary data, etc.

Expectancy Disconfirmation Theory (EDT)

Several researchers have studied visitor satisfaction and have provided theories about tourism (Bramwell, 1998; Bowen, 2001). For example, Parasuraman, Zeithaml, and Berry's (1985) expectation perception gap model, Oliver's expectancy-disconfirmation theory (Pizam and Milman, 1993), Sirgy's congruity model (Sirgy, 1984; Chon and Olsen, 1991), and the performance-only model (Pizam, Neumann, and Reichel, 1978) have been applied to the measurement of tourist satisfaction with specific tourism destinations. In particular, expectancy-disconfirmation theory has received the widest acceptance among these theories because it is broadly applicable.

According to Oliver (1980), EDT consists of two subprocesses having independent effects on customer satisfaction: the formation of expectations and the disconfirmation of those expectations through performance comparisons. EDT holds that consumers first form expectations of the products' or services' performance prior to purchase or use. Subsequently, purchase and use contribute to the consumer's beliefs about the actual or perceived performance of the product or service. The consumer then compares the perceived performance to prior expectations. Consumer satisfaction is seen as the outcome of this comparison (Clemons and Woodruff, 1992). Moreover, a consumer's expectations are: (a) confirmed when the product or service performance matches prior expectations, (b) negatively disconfirmed when the product or service performance fails to match expectations, and (c) positively disconfirmed when the product or service performance is perceived to exceed expectations. Dissatisfaction comes about when a consumer's expectations are negatively disconfirmed; that is, the product performance is less than expected (Churchill and Surprenant, 1982; Oliver and Beardon, 1985; Patterson, 1993).

Pizam and Milman (1993) used Oliver's (1980) EDT model to improve the predictive power of travellers' satisfaction. They applied the basic dynamic nature of the disconfirmation model to tourism research while testing part of the original model in a modified form. Some studies on customer satisfaction are also important in tourism behaviour research. For instance, Pizam, Neumann, and Reichel (1978) examined the factor structure of tourists' satisfaction with the destination areas. They explained eight distinguishable dimensions of tourist satisfaction. Moreover, Yu and Goulden, (2006) reported on international tourists' satisfaction of travel based on tourist attractions, facilities, services, and prices for four groups of visitors; namely Europeans, Americans, Japanese, and others (Asia Pacific). A similar study has been done by Hui et al. (2007) on tourists' satisfaction, recommendation, and willingness to revisit Singapore. And also, Lee et al. (2007) investigated the relationships among perceived value, satisfaction, and recommendation for the Korean Demilitarized Zone (DMZ) using the EDT approach.

Barsky and Labagh (1992) applied the EDT concept to accommodation research. The proposed model in these studies showed that customer satisfaction was the function of disconfirmation, measured by nine 'expectations met' factors that were weighted by attribute-specific importance. The model was tested with data collected from random subjects via guest comment cards. As a result, customer satisfaction was found to be correlated with a customer's willingness to revisit. Chon and Olsen (1991) discovered a goodness of fit correlation between tourists' expectations about their destination and their satisfaction after the tourists have bought the travel service and products, if the evaluation of their experience of the travel product is better than their expectations, they will be satisfied with their travel experience. Furthermore, Chon and Olsen (1991) provided an intensive literature review of tourist satisfaction. One thing to be noted, however, is that although the posited social cognition theory offers an alternative way of explaining satisfaction processes, its methodological mechanism is analogous to that of EDT. In other words, the concepts of congruity and incongruity can be interpreted similarly to the concepts of confirmation and disconfirmation, both of which can result in either positive or negative directions. EDT is one of the most commonly adopted approaches used to examine the satisfaction of consumers and it currently dominates the study of consumer satisfaction.

However, a limited number of researches have been conducted regarding agritourism visitor satisfactions in only a few countries in the world at present. For example, Coomber and Lim (2004) have conducted a study on 'farm tourism; a preliminary study of participants' expectations and perceptions of farm tours' and discovered that the participants were satisfied with the farm tour. As another instance, an agritourism market analysis in New York has been conducted by Hilchey and Kuchn (2006) and revealed that visitors were highly satisfied with the agritourism operations. An ethnographic study by Christou, Lashley, and Saveriades (2009) on agritourist satisfaction through the formation of expectations, satisfaction achievement and behavioural intentions, reported high agritourist satisfaction and positive future behavioural intentions.

With this background, the objective of this paper is to analyse the satisfaction level of agritourism visitors, their future behaviour towards agritourism, and the implications for the farmers in a Sri Lankan context.

Agritourism in Sri Lanka

Sri Lanka is an agriculture-based country in South Asia, bearing the name of the 'Pearl of the Indian Ocean.' Since ancient times, it has been world famous for its tourism and hospitality industry. Sun, sea tourism, culture tourism, and religious tourism like mass tourism sectors are very popular in the country. These mass tourism destinations are able to attract large numbers of local and foreign visitors. Therefore, the tourism industry is a most significant sector in Sri Lanka and it is proved by being the sixth major earner of national income. Its contribution to the GDP is 2.6% while generating nine million direct and indirect job opportunities in the country (Sri Lankan Tourist Board, 2010). In the recent past, with the introduction of rural tourism sectors in the country, a gradual development of agritourism could be seen. Some people prefer rural tourism destinations to mass tourism destinations, as they are less crowded and polluted, peaceful, and tranquil (Schmitt, 2010).

Agritourism is one of the sectors of rural tourism, which is gradually becoming popular among urban and suburban populations and students due to certain special inherent features. Some of them are good food (healthy, clean, and high-quality food items including traditional ones), education (learning opportunities on the farm, farming industry, traditional lifestyle) and cheap service (inexpensive gateway). Sri Lanka is mainly an agricultural country and it is comprise of 24% agricultural lands out of the total land area. Therefore, vast arrays of crops and plantations are grown in the country and a large number of families (an estimation of 1.8 million) are engaged in and depend on farming (UNCTAD, 2007).

The modern agricultural sector of the country has seen significant improvements in terms of productivity and the quality of the agricultural products. It is important to note that the traditional farming systems in Sri Lanka are also experiencing an emerging trend and an advanced level with indigenous practices. Sufficient and well-distributed annual rainfall and better intensity and longer duration of sun light prevailing in Sri Lanka are the precious grounds for enhancing the productivity and quality of cultivation throughout the year. As an emerging trend for the organic farming in the country, a significant number of organic farms (3,300) can also be seen in the country, covering 0.065% of the total land. Sri Lanka is one of the major producers of organic products in Asia and one of the leading sources of organic tea (UNCTAD, 2007). Furthermore, the country is famous for indigenous medicines, herbal cultivations, and productions and is well known for spices cultivations. In the past, farm visits were allowed free of charge as a social service. However with economic development, agritourism was initiated during the late 20th and the early 21st centuries in the country and now it is gradually developing as a business. Sri Lanka Tourism Development Authority has certain emphasized the development of the agritourism sector of the country under the eco-friendly tourism industry in the country.

It seems that a huge potential exists for the development of agritourism in Sri Lanka. Mainly the Ministry of Tourism, including a number of government organizations, such as the Tourist Board, the Tourism Development Authority, respective Provincial Councils, a number of national universities and non-government organizations such as the Responsible Tourism Partnership of Sri Lanka, the Sri Lanka Ecotourism Foundation, Sarvodaya Community Tourism Initiatives, and Sewalanka Foundation, are now emphasizing community-based, sustainable tourism and thus agritourism is receiving special attention. Agritourism development was included in the Development Policy Framework of the country from 2010 to 2016 (Ministry of Finance and Planning of Sri Lanka, 2010). According to a preliminary study conducted by the author, a list of currently existing agritourism destinations (some destinations conduct agritourism as a small part of their other tourism businesses) in ten districts of the country by 2010 is presented in Table 1.

Fifteen agritourism destinations could be identified in those ten districts of the country. Since the agritourism is newly initiated in the country, the industry is at the developing stage in Sri Lanka and no evidence of studies/research could be found in the literature. Therefore, this study was conducted on agritourism in Sri Lanka by analyzing visitor satisfaction level using 21 attributes under five main aspects of agritourism destinations to bridge the existing gap in the literature, as well as to suggest improvements for the agritourism farmers and how to move forward in this promising industry.

Table 1: Agritourism destinations in Sri Lanka

Destination	Location	District	Starting year of Agritourism operation
CIC Farm	Higurakggoda	Polonnaruwa	2005
New Zealand Farm	Ambewela	Nuwara Eliya	1996
Paradise Farm	Kitulgala	Kegalla	1999
Ceylinco Fruit Farm	Midigama	Galle	2002
Spice Garden	Mawanella	Kandy	1998
Sigiriya Village	Sigiriya	Matale	2001
Hotel Sigiriya	Sigiriya	Matale	2002
Galapita Healing Garden	Buttala	Moneragala	2003
Landa Holiday Resort	Belihuloya	Ratnapura	2000
Adventure Park	Ella	Moneragala	2004
Kanda Land Eco-Centre	Buttala	Moneragala	2001
Tree Tops Farm	Buttala	Moneragala	1998
Woodlands Network	Bandarawela	Badulla	1997
Walawa Nadee Ecotourism	Ambalantota	Hambantota	2006
Samakanda Ecological Centre	Habaraduwa	Galle	2002

(Source: Field survey, 2010)

2. Research Methodology

Expectancy Disconfirmation Theory (EDT) is the most suitable approach for examining visitor satisfaction, as it has a very clear theoretical basis and is meaningful in practical situations. The EDT holds that consumers first form expectations of products or service performance prior to purchase or use. Subsequently, purchase and use convey to the consumer beliefs about the actual or perceived performance of the product(s) or service(s). The consumer then compares the perceived performance to prior expectations. Consumer satisfaction is seen as the outcome of this comparison (Clemons and Woodruff, 1992).

Study area

Out of the existing agritourism destinations (Table 1), three destinations were randomly selected for this study. The selected destinations were Paradise Farm at Kitulgala, Tree Top Farm at Buttala, and the Samakanda Ecological Centre at Habaraduwa. Paradise Farm is about 78 km from Colombo, situated at Kitulgala in Kegalle district and it was established in 1999. It has 33 acres of integrated land, including tea and fruit crops, and is comprised of three cabanas with capacity for about 12 visitors. The annual average number of visitors is 528. It is surrounded by a natural landscape and has a temperate climate. Tree Tops Farm is 247 km from Colombo and is situated in a forest at Buttala in Moneragala district. It was started in 1998 with over 10 acres of land. Now it has been extended to over 25 acres of land and can accommodate 10 visitors. The annual average number of visitors is 752. It has a sub-tropical climate. The Samakanda ecological centre is situated on abandoned tea land at Habaradua in Galle district. It was begun in 2002. It has 35 acres of land area as well as three medium-size cottages and has the ability to provide accommodations for 15 visitors at a time. All of these places are medium-size agritourism destinations and are currently functioning at an average standard.

Research design

Secondary as well as primary data were used in the study. The secondary data were collected mainly from journal papers, reports, online information, etc. A visitor survey was conducted to gather the required primary data in the three selected agritourism destinations. Other than the a visitor survey, three group discussions were also conducted with three visitor groups, one from each destination, to gather detailed information and to cross check the survey data.

Questionnaire development

After doing a thorough literature search on visitor satisfaction in tourism and also agritourism, a set of attributes regarding visitor satisfaction was initially selected. Then these attributes were evaluated using a panel of tourism experts (two university professors in rural tourism, the assistant director of the Tourism Development Authority, and three officers of the three Provincial Councils related to Rural Tourism Development) to ensure the validity of the selected attributes for the study. Moreover, out of fifteen, three agritourism farmers were randomly selected and also considered for this consultation. At last 21 agritourism attributes were found suitable to the Sri Lankan situation, covering five aspects of agritourism (destination characteristics, available services and facilities, nature of staff members, situation of the surrounding environment, and price level of place and products) and were selected for the study. They are explained in Table 2. The questionnaire consisted of four parts. Part 1 included questions to collect data related to the demographic characteristics of the visitor, and the Part 2 consisted of questions to gather data on the expected values for the 21 attributes of agritourism destination, answered at the beginning of the visit. These attributes were measured on a five point Likert scale ranging from 1 (very poor) to 5 (very good). Part 3 consisted of questions related to the data collected on the perceived values for the 21 attributes of agritourism destination, answered at the end of the visit. These attributes were also measured on a five point Likert Scale ranging from

Table 2: Detailed information on the selected agritourism attributes

Aspect/Attribute	Detailed information
Destination characteristics	**Destination-related characteristics**
Arrangement of the destination	Partition of different sections of the farm, farm tour route, footpath, direction boards, name boards, allocation for places for parking, resting, etc.
Number of educational programmes	Number of available education-related programs such as farm tours, demonstration culinary classes, practical programs, etc.
Number of entertainment activities	Number of activities for entertainment, pick your own, harvesting festivals, petty zoos, camping sites, cultural festivals, etc.
Level of direct sales of the destination	Quantity and quality of direct selling items on the farm.
Services and facilities	**Services and facilities available on the farm**
Quality of farm products	The quality level of farm products such as maturity, appearance, cleanliness, purity, sorting, packaging, labelling, etc.
Variety in farm activities	Availability of different farm activities such as crop cultivation, poultry, piggeries, cattle, bee keeping, fish ponds, organic farming, biogas units, etc.
Level of accommodation facilities	Level of chairs, beds, bed sheet, towel, nets, bathrooms, electricity, telephones, television, Internet, reading materials, etc.
Photography, audio, and video facilities	Facilities available for getting photos, doing audio recordings, videotaping, etc.
Staff members	**Qualities of facilitators and staff members at agritourism destinations**
Helpfulness	The level of helping visitors when required
Efficiency	How quickly they accomplished requests of visitors
Friendliness	How friendly they were with the visitors
Courtesy	How faithful and polite they were to the visitors
Surrounding environment	**The nature of the farm environment**
Natural beauty and greenery	The level of the natural beauty and greenery of the surrounding environment
Friendliness and courtesy of local residents	How friendly, hospitable, and faithful the local residents were
Hygiene and sanitation of the farm environment	Condition of the hygiene and sanitation in and around the farm
Road condition to the destination	Condition of the roads to the destination and surrounding area
Safety and protection of the area	Available strategies for safety and protection such as police, hospitals, fire brigades, etc.
Price level	**Price levels of different facilities available at the farm**
At the destination	Price of the entrance fees, service charges, value added taxes, etc.
For food and drinks	Price of different food items and various drinks available in the destination
For accommodation	Price of accommodations such as charges for rooms, cabanas, farm houses, etc.
Off the farm products and other items	Price of on-farm selling items such as fresh fruits, vegetables, jam, jelly, milk products, etc.

1 (very poor) to 5 (very good); and part 4 included three additional questions related to the overall satisfaction and future behaviour of the visitors, again measured on a five point Likert scale ranging from 1 (Very poor) to 5 (very good).

Data collection

A visitor survey was conducted covering the local and foreign visitors at three selected destinations. The survey was carried out from November 2009 to April 2010 in Sri Lanka, covering two main holiday seasons of the country. This was a two-step survey. In step one, visitors filled out the first and second parts of the questionnaire and in step two they filled out the third and forth parts of it. A comparatively lower number of local as well as foreign visitors could be seen due to a lack of publicity for the destinations, and also the unsafe situation that prevailed in the country due to the ethnic war (from 1983 to 2009). Since there were a low number of visitors, all of the visitors above 20 years were included in the data collection of the survey. The total sample size was 204 including 128 local and 76 foreign visitors. The owners of the farms and resorts extended their support and helped out during the research as the findings would be very much useful for them as well.

Data analysis

A descriptive analysis was conducted to study the visitors' demographic features in order to develop their profiles. Two sample-paired *t-tests* were applied for the analysis of visitor satisfaction. Further, one sample *t-test* was conducted to find out the level of overall satisfaction and future behaviour of the visitors. Finally, independent *t-tests* were done to compare differences in overall satisfaction and future behaviour between local and foreign visitors. The Statistical Package for the Social Sciences (SPSS Version 17) was used to perform all of these statistical analyses.

Decision making criteria on satisfaction levels of visitors

According to EDT theory, satisfaction level is based on the comparison of Expected Value (EV) and the Perceived Value (PV) for each and every travel attribute. EV is the level of the service intended, before visiting the destination, and PV is the level of the service experienced by the visitors after visiting the destination. Therefore, if PV>EV (the difference is positive and significant) is considered as *Satisfied* situation or *positive expectancy disconfirmation*, and if EV>PV (the difference is negative and significant) was considered as *Dissatisfied* situation or *negative expectancy disconfirmation* and EV=PV (the difference can be negative or positive, but it is not significant) was considered as *interference*, *Just Satisfied* or *expectancy confirmation* situation (Oliver, 1980). In this study, the mean perceived value (MPV) (using part 3 of the questionnaire) and the mean expected value (MEV) (using part 2 of the questionnaire) for 21 agritourism attributes were calculated. Then the mean difference of each attribute was checked using a paired *t-test*. Decisions regarding satisfaction levels were taken using the EDT.

3. Findings and Discussion

Demographic profiles of the visitors

The results of the descriptive analysis of the important demographic characteristics of the visitors' are presented in Table 3. This information will be helpful for understanding the category of visitors that mostly preferred the agritourism sector of the country.

Table 3: Profiles of the visitors

Variable	Local visitors % (n=128=63%)	Foreign visitors % (n=76=37%)
Gender		
Male	52.9	65.4
Female	47.1	34.6
Age (Years)		
20–35	14.2	10.5
36–45	44.6	45.8
46–55	31.2	34.4
Above 56	10.0	9.3
Marital Status		
Married	71.2	63.7
Single	28.8	36.3
Educational level		
Primary	3.9	0.0
Secondary	23.5	15.8
Degree	41.2	47.4
Post-graduate	31.4	36.8
Employment status		
Employed	49.8	58.4
Unemployed	9.2	5.1
Retired	5.6	3.2
Other	35.4	33.3
Monthly Total household income (Sri Lankan Rupees (LKR))		
<20,001	5.5	0.0
20,001–40,000	39.1	0.0
40,001–60,000	45.8	0.0
60,001–80,000	9.0	0.0
80,001–100,000	2.6	0.0
100,001–200,000	0.0	3.9
200,001–300,000	0.0	30.3
300,001–400,000	0.0	47.4
>400,000	0.0	18.4
Residential sector		
Urban	73.4	78.8
Rural	26.6	21.2

(Source: Visitor Survey, 2010)

According to the results of Table 3, it is noted that the number of local visitors was higher (63%) than foreign visitors (37%). When gender is considered, although for the local visitors, male and female visitors were more or less similar (53% and 47 % respectively), for foreign visitors, the number of male visitors was higher (65%) than females (35%). The dominant age group of the local and foreign visitors was 36–45 (middle aged). In terms of marital status, both groups consisted of higher numbers of married people than singles. Out of the total respondents, 73% of the locals and 84% of foreigners had an education higher than the secondary level. Furthermore, a higher level of visitors of both groups (50% and 58%) was employed. With regard to the respondents' income, although a majority of local visitors (46%) were receiving a monthly household income of 40,001–60,000 Sri Lankan Rupees (LKR)[3] the majority of foreign visitors (47.4%) were receiving a monthly income of 300,001–400,000 LKR. Furthermore, most of the local (73%) and foreign (79%) visitors were from urban areas. Therefore, it is clear that the agritourism visitors in Sri Lanka are typically middle aged, educated, married, urban people having comparatively a higher income level. Agritourism operators should be able to understand the needs of this market category and serve them accordingly. Analysis of the demographic characteristics of visitors is common in most of the visitor satisfaction studies. Jolly and Reynolds (2005) and Reynolds (2007), for example, have studied demographic characteristics and some other related information concerning agritourism visitors in Sacramento and Yolo counties in California in the USA. Moreover, a research by Lobo et al. (1999) has also focused on the demographic characteristics of visitors in San Diego County in the USA.

Satisfactory, indifference, and dissatisfactory attributes in agritourism

First, the mean perceived value (MPV) and mean expected value (MEV) for the 21-agritourism attributes was calculated. After that, two values for each attribute were compared using paired *t-test* and satisfaction level was decided according to the EDT, as explained before. The results are presented in Table 3.

Satisfactory attributes

The results indicate that the visitors were satisfied with nine tourism attributes (Table 3); namely *accommodation facilities*, *photography facilities*, *helpfulness, friendliness and courtesy of staff members, natural beauty of the area, friendliness of local residents, price levels of destination, and the price levels of food and drinks*. Agritourism farmers were able to provide these general facilities in an adequate manner, making visitors happy. In these agritourism operations, half of the attributes were found to be at a satisfactory level. Agritourism farmers would be happy with the above results and they would make efforts to continue the facilities for future operations.

[3] At the beginning of October 2012, 100 LKR was approximately equivalent to £0.48, US$0.77 and €0.59 (www.xe.com, accessed 2 October 2012).

Indifference attributes

Ten attributes, such as *arrangement of the destination, educational facilities, entertainment programs, quality of farm products, variety in farm facilities, efficiency of staff members, hygiene and sanitation of the farm and surrounding, safety and protection of visitors, price of accommodation and price of farm products,* showed neutral feelings or indifference between expected and perceived feelings. These are important attributes and are important for increasing the consumer satisfaction in agritourism. Therefore, the visitors expect a certain standard for these attributes. However, due to lack of facilities, skills and awareness, etc., agritourism farmers had failed to provide these things adequately. It is the responsibility of agritourism farmers to improve these attributes to a significant level in order to attract more visitors and also so that visitors return to the destinations.

Dissatisfying attributes

The visitors were dissatisfied with two attributes, *direct sales of the product and goods at the destinations* and the *road conditions*. There were very few products available, and those were available only in small quantities. This is due to the lack of attention and motivation in producing various farm products in an attractive manner on the part of the agritourism farmers. Visitors were also dissatisfied with the road conditions available in these areas. Agritourism destinations are situated in rural areas and the condition of most of the roads in rural areas is poor. However, visitors are educated people, with busy schedules, and they expect easy and quick access to the agritourism destinations. Agritourism farmers have to pay close attention to correct these problems at the earliest possible time. These two factors are very important for the growth of agritourism destinations and for them becoming popular among the visitors.

Differences in the satisfaction levels of local and foreign visitors

Other than the analysis of satisfaction levels of all the visitors, the satisfaction levels of local and foreign visitors were also analysed and compared in the same way to find out the similarities and differences between the two groups (table 4). According to the results, except for a few differences, the satisfaction levels of the both groups showed a similar trend. When the first character (destination-related characteristics) was concerned, the two groups had shown different results. While local visitors were satisfied with the first attribute and were just satisfied with next three attributes, foreign visitors were just satisfied with the first one and dissatisfied with the other three attributes. The reason behind such a level of satisfaction of local visitors could be due to less experience with the agritourism destinations that they have visited in Sri Lanka and the just satisfied level of foreign visitors may be due to their

Table 4: Comparison of mean differences of all the visitors using paired T-Test

Aspect/Attribute	Total visitors (n=204)				
	MPV	MEV	MD	t- value	Satisfaction level
Destination characteristics					
Arrangement of the destination	3.67	3.61	0.054	1.771	JS
Number of educational programmes	3.51	3.55	−0.039	−1.033	JS
Number of entertainment activities	3.03	3.05	−0.020	−.706	JS
Level of direct sales of the destination	2.27	2.48	−0.206	−4.764*	DS
Services and facilities					
Quality of farm products	3.65	3.61	0.039	−1.267	JS
Variety in farm activities	3.39	3.38	0.010	.294	JS
Level of accommodation facilities	4.06	3.94	0.118	5.203*	S
Photography, audio, and video facilities	4.19	4.04	0.147	5.502*	S
Staff members					
Helpfulness	4.26	4.08	0.186	6.076*	S
Efficiency	3.87	3.93	−0.059	−1.819	JS
Friendliness	4.12	4.00	0.118	4.771*	S
Courtesy	4.40	4.26	0.137	5.683*	S
Surrounding environment					
Natural beauty and greenery	3.77	3.67	0.108	4.954*	S
Friendliness and courtesy of local residents	3.75	3.61	0.147	5.502*	S
Hygiene and sanitation of the farm environment	3.30	3.35	−0.049	−1.315	JS
Road condition to the destination	3.04	3.15	−0.108	−4.515*	DS
Safety and protection of the area	3.14	3.11	0.025	0.928	JS
Price level					
At the destination	3.19	3.00	0.186	4.983*	S
For food and drinks	3.10	2.95	0.147	3.313*	S
For accommodation	2.86	2.88	−0.020	−0.371	JS
Off the farm products and other items	2.87	2.88	−0.010	−0.198	JS

MPV= Mean Perceived Value; MEV=Mean Expected value; MD = Mean Difference between perceived and expected values
S = Satisfied; DS = Dissatisfied; JS = Just Satisfied
*=Significant at 95 Confidence Level

wider experience with better agritourism destinations worldwide. Both groups were dissatisfied with the direct sales of the destinations.

Under the second aspect (availability of services and facilities), the results were similar for both groups. The first two attributes, quality of food and drinks and variety in services, were under the just satisfied level for both local and foreign visitors. Since both groups were educated and had higher incomes, they expected the quality and variety of these aspects. Rozman et al. (2009) have discussed the importance of the quality and variety of farm services in their study on 'A multi-criteria assessment of tourist farm service quality.' Further, Reichel et al. (2000) have studied 'Rural tourism in Israel; service quality and orientation' and reported that there is a need for service quality improvements along with the appropriate training. Both groups of visitors were satisfied with the level of accommodation and photography facilities available at agritourism destinations.

When the third aspect (staff members) was concerned, both groups were satisfied with the first, third, and fourth attribute: *helpfulness, friendliness,* and *courtesy*. However, both groups of visitors were just satisfied with *the efficiency of staff members*. Since both groups were educated and people from urban areas, they naturally expected higher efficiency from the work of the staff members.

In the fourth aspect (surrounding environment), except for the price of the farm products and the price of other items (the last attribute), other attributes showed similar results for both groups. All of the visitors were happy with the destinations, which were situated away from cities and rich in natural beauty and greenery. Furthermore, the local residents of these areas showed a high level of respect toward the outside visitors. However, the two groups were just satisfied with the *hygiene and sanitation* of the destination environments. Since both groups were well educated and had a good standard of living, they considered that the cleanliness of the destination, waste management, and application of agro-chemicals were important for the farmlands. Moreover, both groups of visitors were dissatisfied with the *road condition* of those areas. When the last attribute (safety and security condition of the area) of this aspect was concerned, the results indicated that the foreign visitors were just satisfied with it, while local visitors were satisfied. The foreign visitors paid more attention to these aspects than the local visitors, who were familiar with it.

With reference to the last aspect, *price levels of facilities*, both groups were satisfied with the first two attributes; namely *price level at the destination* and *food and drinks*. Regarding the last two attributes, *price level of accommodation* and *direct sale items*, although local visitors were just satisfied, foreign visitors were satisfied with them. This is natural because foreign visitors were getting a higher monthly income than the local visitors.

Overall satisfaction and future behaviour of all the visitors

The overall satisfaction level and future behaviour of the visitors were estimated using mean perceived values (MPV). Then these values were compared to test the differences using independent *t-tests*. The results are presented in the Table 5.

According to the results for overall satisfaction level concerning the *revisit the destination*, and *recommend the destination to others*, they were at significant levels. However, the *overall satisfaction* level of the visitors was at a moderate level. The level of intention to revisit the destinations by the visitors was at a lower level. This is a common phenomenon in most of the destinations in the world. It was significant that there was a comparatively higher trend to recommend these destinations to others by the visitors. This is a very good indicator for the future development of the agritourism sector of the country. If agritourism farmers can develop the indifference and dissatisfied attributes of these destinations, the overall satisfaction level will automatically increase. Furthermore, it will help to increase the level of revisiting the destination as well as recommending the destination to others.

Comparison of overall satisfaction and future behaviour of local and foreign visitors

A comparison of overall satisfaction and future behaviour of local and foreign visitors was also conducted and the results are presented in Table 6. Few differences could be observed with regard to the overall satisfaction levels and future behaviour of local and foreign visitors. The *overall satisfaction*, *revisit*, and *recommend the destination* items were significant for local visitors. Except for revisit, the two other two aspects (*overall satisfaction* and *recommend the destination to others*) were significant for foreign visitors. Furthermore, the mean perceived values of *overall satisfaction*, *revisit*, and *recommend the destination* were comparatively higher in the case of local visitors than with foreign visitors. Recommending the destinations by both types of visitors to others was a positive reflection for a better future for agritourism.

4. Conclusion and Recommendations

Understanding visitor satisfaction and future behaviour was very important with a strong bearing on agritourism development and expansion in the country. Analysing the facts following the EDT is both a theoretical and practical rationale as several visitors mentioned it during group discussions. It is evident from the demographic features of visitors that the majority of the visitors were middle aged, educated, and were working people having a higher level of income. They were mostly from urban areas. As the demographic factors imply the level of needs of the visitors, operators should be well prepared in meeting their needs and expectations. Hence, agritourism farmers should have the ability and competence to provide a satisfactory level of services to this market segment.

The level of satisfaction of visitors was reflected at a significant level because the visitors were happy with the nine attributes of agritourism. Furthermore, a significant level of intention to revisit by the local visitors and a high level of readiness to recommend the destinations to others by both groups of visitors were positive signs of the sector.

Table 5: Comparison of mean differences of local and foreign visitors using paired T-Test

Aspects/Attribute	Local visitors (n=128)					Foreign Visitors (n=76)				
	MPV	MEV	MD	t-value	Satisfaction level	MPV	MEV	MD	t- value	Satisfaction level
Destination characteristics										
Arrangement of the destination	3.84	3.73	0.109	3.949*	S	3.37	3.41	−0.039	−0.597	JS
Number of educational programs	3.66	3.59	0.063	1.520	JS	3.26	3.47	−0.211	−2.970*	DS
Number of entertainment activities	3.58	3.53	0.047	1.282	JS	2.11	2.24	−0.132	−3.371*	DS
Level of direct sales of the destination	2.44	2.66	−0.219	−3.436*	DS	2.00	2.18	−0.184	−4.115*	DS
Services and facilities										
Quality of farm products	3.81	3.73	0.078	1.728	JS	3.37	3.39	−0.026	−0.815	JS
Variety in farm activities	3.47	3.42	0.047	1.178	JS	3.26	3.32	−0.053	−0.893	JS
Level of accommodation facilities	4.22	4.13	0.094	3.625*	S	3.79	3.63	0.158	3.750*	S
Photography, audio, and video facilities	4.39	4.25	0.141	4.559*	S	3.84	3.68	0.158	3.174*	S
Staff members										
Helpfulness	4.47	4.28	0.188	5.414*	S	3.92	3.74	0.184	3.156*	S
Efficiency	3.98	4.05	−0.063	−1.644	JS	3.68	3.74	−0.053	−0.893	JS
Friendliness	4.19	4.09	0.094	3.625*	S	4.00	3.84	0.158	3.174*	S
Courtesy	4.58	4.45	0.125	4.259*	S	4.11	3.95	0.158	3.750*	S
Surrounding environment										
Natural beauty and greenery	3.63	3.63	0.094	3.625*	S	4.03	3.89	0.132	3.371*	S
Friendliness and courtesy of local residents	3.63	3.50	0.125	4.259*	S	3.97	3.79	0.184	3.542*	S
Hygiene and sanitation of the farm environment	3.33	3.36	−0.031	−0.755	JS	3.26	3.34	−0.079	−1.097	JS
Road condition to the destination	3.03	3.11	−0.078	−3.281*	DS	3.05	3.21	−0.158	−3.174*	DS
Safety and protection of the area	3.22	3.16	0.063	2.910*	S	3.00	3.04	−0.039	−0.652	JS
Price level										
At the destination	3.31	3.09	0.219	3.949*	S	2.97	2.84	0.132	3.371*	S
For food and drinks	3.31	3.19	0.125	2.024*	S	2.74	2.55	0.184	3.156*	S
For accommodation	2.84	3.00	−0.156	−2.162	JS	2.89	2.68	0.211	3.203*	S
Off the farm products and other items	2.78	2.91	−0.125	−1.805	JS	3.03	2.84	0.184	3.156*	S

MPV= Mean Perceived Value; MEV= Mean Expected mean value; MD = Mean Difference between perceived and expected values
S = Satisfied; DS = Dissatisfied; JS = Just Satisfied
*=Significant at 95 Confidence Level

Table 6: Overall satisfaction and the future behaviour of all the visitors

Impression	Total Visitors (n=204)		
	MP V	SD	t-value
Overall satisfaction with the destination	3.36	0.980	48.985*
Intention to revisit the destination	1.27	0.509	35.752*
Recommending the destination to others	3.94	0.740	76.024*

MPV=Mean Perceived Value; SD=Standard Deviation;
*=significant at 95 Confidence Level

Table 7: Comparison of overall satisfaction and the future behaviour of local and foreign visitors

Impression	Local (n = 128)			Foreign (n= 76)			Independent t-test	
	MPV	SD	One sample t-test value	MPV	SD	One sample t-test value	MD	t-test value
Overall satisfaction with the destination	3.50	0.956	41.433*	3.13	0.984	27.732*	0.368	2.632*
Intention to revisit the destination	1.33	0.534	28.137*	1.18	0.453	22.767*	0.144	2.159*
Recommending the destination to others	3.97	0.813	55.252*	3.89	0.602	56.424*	0.074	0.689

MPV = Mean Perceived Value; SD = Standard Deviation; MD = Mean Difference
*= Significant at 95 Confidence Level

However, the visitors were not so happy with many attributes. Under the destination characteristics, *arrangement of the destination*, *educational facilities*, *entertainment programs*, *level of direct sales*, and under the services and facilities, *quality of farm products* and *variety in farm facilities* were not at a good level. Lack of *efficiency* among the staff members was a major weakness. Regarding the surrounding environment, *poor hygiene and sanitation of the farm and surrounding*, *poor road conditions*, and a *low level of safety and protection of visitors* could be seen. In the case of price levels, *price of accommodation* and *price of farm products* were not in line with the expectations of the visitors.

When the indifference and dissatisfied attributes were studied in detail, several weaknesses could be identified. Out of them some are farm level weakness and the others are the problems due to lack of policy guidelines. It is better to explain these two types of weaknesses separately, with the suitable recommendations to overcome them.

Recommendations for farm level operations

Arrangements at the destinations (internal roads, footpath, direction boards in the farm, name boards for different sections, parking and resting areas for the visitors) were not well planned. The number and quality of educational programs (guided farm tours, demonstration programs, practical sessions) were not up to the standard. With regard to entertainment programs, although some programs (pick your own, feeding animals, bird watching) exist, special programs such as harvest festivals, camping sites, petty zoo, and cultural items, etc. were not found. There were only two items available for direct selling: fresh fruits and vegetables. They did not sell processed farm products, and herbal items etc. This is because that the agritourism farmers have lack of knowledge on planning, landscaping, management, marketing, and also lack of experience in hospitality management. Therefore, agritourism farmers need to improve their basic knowledge and skills in order to provide better agritourism services to visitors.

With regard to services and facilities, the quality of farm products is very important. However, in these agritourism destinations, the quality of some products was not so good. The availability of chemical residues, harvesting of premature as well as over-matured farm products, and poor cleaning, sorting, labelling and packaging were commonly seen as problems. To overcome these weaknesses, agritourism farmers need to have better knowledge and awareness of these aspects, and they have to pay attention to maintain good quality farm products.

Furthermore, the farm facilities were at a poor level. Since farms are small in size, they cultivate crops and rear livestock at a small-scale level. Consequently, only limited activities were included as agritourism activities. As solutions to these problems, the establishment of green houses, linkages with other agritourism farmers and formation of agritourism networks can be thought of. Linkages with local residents, introduction of local cultural activities, and local products such as arts and crafts, etc. are equally important.

The low efficiency of staff members was clearly evident in all places. It is because of the fact that the staff members are local people with low level of education and experience. They work traditionally without any modern tools and gadgets. They take more time to think and then do things. As a result, their work efficiency is comparatively low. Learning and getting acquainted with new technology to enhance the efficiency and effectiveness of the staff members at the agritourism destinations is very much crucial. Further, the hygiene and sanitation situation at the destinations were not up to the standard. Poor attention was given to remove farm waste and keeping the farm environment clean and tidy. Farmers are very busy with farming tasks, and agritourism and family activities at the same time. Agrochemicals, polythene sheets, plastic bottles, heaps of garbage, etc. were seen in many places in the farms. This has negatively affected the visitors. Agritourism farmers must follow proper methods and practices in managing such farm and non-farm wastes. Here, the 3R concept (reduce, reuse and recycle), production of compost and biogas from waste are possible alternatives.

Policy recommendations

The poor condition of roads is an important issue that requires high attention for improvement. These agritourism destinations are situated in rural areas, and visitors come mainly from urban areas using comfortable vehicles. Maintaining a high quality road network is the responsibility of local as well as the national governments around agritourism operations. Agritourism farmers have equal responsibility to maintain their internal roads. Mobilising local residents' support and cooperation for improving both internal and external roads should be linked with the local government in promoting the agritourism activities collectively in the area.

Security and safety measures for protecting the visitors against local thieves, wild animals, and bad road hazards leading to accidents at times are of great concerns. Lack of transport services and hospitals are constraints in meeting emergency situation due to potential risk of road accidents. This was very much realised at study locations. Therefore, agritourism farmers need to keep close contacts with these services in order to guarantee quick services whenever required. Not only farmers, especially local authority should support and pay attention to guarantee have these basic needs in agritourism areas.

The price level of accommodations provided by the agritourism operators was high as compared to the neighbouring hotels with better accommodation facilities. The operators need to learn and provide with competitive rather cheaper price as compared to outside providers. Government may consider to provide education and training programs to agritourism operators about improving accommodation quality and fixing proper as well as attractive price to the visitors.

The price of the farm products and other items was expensive. Agritourism farmers claim that they sell fresh organic farm products. However, there was no way to differentiate between organic and inorganic fruits and vegetables. Agritourism farmers should be honest about their products whether organic or inorganic and need to maintain fair price levels for the farm products. Since there is no mechanism and procedure yet to differentiate between organic and inorganic products in the county, it is urgent to establish such a mechanism to overcome these problems. If agritourism farmers follow above mentioned recommendations, they will be able to supply a better quality services to the visitors and enhance the visitor satisfaction in agritourism.

Limitations of the research

There are a few limitations of this research. The research was conducted only at three destinations, which had fewer diversified agritourism functions and services as they were at the initial stage of development at present. The sample size was small, particularly for the foreign tourists, and the data were collected only at one point in time (cross sectional data). Other than the selected 21-agritourism attributes, there might be some other attributes important for visitor satisfaction. However, the findings are useful in developing policies and promotional measures for further expansion of this sector.

Conclusion

The overall satisfaction levels of both the groups of visitors were moderate and a higher level of satisfaction was observed in local visitors compared to foreign visitors. Although the possibility of revisiting the destinations was low, recommending the destinations to others was high by both the groups. However, these two groups emphasized the necessity of improving appropriate educational programs, entertainment activities, diversification of farm products and processing as applicable, availability of farm products for direct sale to the visitors, increasing the efficiency of staff members, upgrading the hygiene and sanitation situation, and improving the road conditions leading to the destinations in order to enhance the satisfaction of visitors. In general, agritourism farmers should pay more attention to several aspects of their operations, especially regarding the attributes that were identified as dissatisfactory and also those that were regarded with indifference on the part of the visitors. After the end of the ethnic war, Sri Lanka is now focussing on promoting tourism in the country. Rural development is the top priority, especially by developing the tourism in rural areas. In this context, agritourism is well placed and can be expanded in and extended to remote rural areas. Thus, the findings of this research may be useful in developing policies and undertaking promotional measures along with improving the quality and networks of rural roads.

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Power in Global Agriculture: Economics, Politics, and Natural Resources

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ABSTRACT

Recent events, such as the 2008 food price crisis, have focussed global attention on the agriculture and food sectors. In particular, many countries have become increasingly concerned with the issue of ensuring the security of their food supply and one key element of this is who has power within the food supply chain. Through examining three dimensions of power – Economic, Political, and Natural Resources – this paper explores where power currently lies in world agriculture and how this might change in the future. Whilst recognising that power is a somewhat abstract concept, through a process of deriving potential indicators, a picture of the distribution of power is drawn. These indicators were also used to develop a simple 'global power index'. The power index indicates that the US and the EU dominate world agriculture in terms of economics and politics, but are potentially vulnerable in terms of their possession of natural resources. On the other hand, the emerging economies have lower political and corporate power, but seem better placed in terms of natural resources. The paper concludes by discussing the implications of these findings for the main food producing regions.

KEYWORDS: Agriculture; Power; International Trade; Trans-National Corporations; Natural Resources

1. Introduction

The 2008 food price crisis has focussed global attention on the agriculture and food sectors. In particular, many countries have become increasingly concerned with the issue of ensuring the security of food supply and one key element of this is who has control or power within the food supply chain. In addition, a number of other recent developments in the agriculture and food sectors and the wider economy make consideration of the issue of 'power' particularly timely.

First, the perception that global power is shifting eastwards has attracted considerable interest (Nye, 2011; Whalley, 2009). For example, the economies of the US and many European countries have continued to decline in recent years, whilst China's economy has continued to grow, even during the recent economic turmoil. This has sparked speculation as to whether or not the recent recession is a sign of the decline of US and European power in the world (Nye, 2011). This speculation raises the interesting question as to whether this decline in western economic power in general is also evident in the agricultural sector.

Second, as the food system has become more globally integrated, there have been major changes in the way trade is conducted between nations. Closed-door policies to protect farmers from outside competition are disappearing as is the operation of state trading. Rather, due to the influence of globalisation - increased transnational migration, movement of assets and capital from one country or region to another – agricultural markets are prone to be more open than ever before. This evolution has given rise to dramatic changes in the global agri-food system, with once food-deficit countries appearing as powerful trade entities, giving rise to increased competition and power struggles in the international arena.

Third, as the agricultural system has become increasingly global it has also become highly commercialised and concentrated. For example, the fact that a few large transnational corporations (TNCs) handle the vast majority of the grain traded internationally is often cited as an example of both the globalisation and concentration of the agriculture sector (Hendrickson, et al., 2008). In addition, rapidly evolving global supermarkets are penetrating almost every corner of the globe. The emergence of these corporate actors in the food system has created a major reorientation in the locus of power, arguably, even further away from farmers (Murphy, 2006).

Fourth, a significant characteristic of the global agri-food system is the reliance on non-renewable natural resources, such as minerals and fossil fuels. Since these resources are scarce they often lead to conflicts and tensions between nation states. These tensions and struggles are likely to be exacerbated in the coming decades due to the impact of climate change. Therefore, natural resource endowments will become an increasing source of power in global agriculture.

The purpose of this work, therefore, is to use available evidence to improve our understanding of the above issues in global agriculture. More specifically, this study attempts to assess who currently has power in global agriculture, how this may change in the future and what this might mean for those involved in the sector.

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Table 1: Indicators and data sources used to assess power in this research

Dimensions	Indicators	Key data sources
Economic	Agricultural Gross Value Added (GVA) Values and volumes of international agricultural trade • Aggregate trade • Commodity-specific trade Dominant TNCs headquartered in the country and their income and assets • Aggregate picture • Commodity-specific pictures	World Bank (http.) database FAOSTAT (TradeStat), FAO Statistical Yearbook (2010), USAID Foreign Agricultural Services database, OECD-FAO Agricultural Outlook 2011–2020 database UNCTAD (2009) data, Financial Times (FT) Global 500 data
Political	Countries: Financial contribution and power within the WTO Countries: Financial contribution and voting power within the World Bank TNCs: Political lobbying and election campaign financing expenditures	WTO reports; other publications World Bank reports; other publications Centre for Responsive Politics (2011) database
Natural Resources	Land (total land and arable land) Water (total, renewable) Minerals (mine reserves, production, consumption and depletion time of phosphate and potassium) Energy (reserves, consumption and depletion of crude oil and natural gas)	World Bank database; FAO Statistical Yearbook (2010) FAO AquaStat US Geological Survey (2011) data Central Intelligence Agency (CIA, 2010) database

In the following sections we elaborate on the concept of power, discuss the indicators and methods used in assessing power, present the results of our analysis, and finally draw some conclusions as to the implications for those involved in the agricultural sector.

2. Conceptual Framework and Research Methods

At the outset it is important to note that there is no single or unified definition of the term 'power'. However, three possible dimensions of power, economic, political and power over natural resources form the basis of this paper.

Economic power can be defined as the ability of an actor to compel, persuade, or control the behaviour of other actors through the deliberate and politically motivated use of economic assets (Frost, 2009; Whalley, 2009). At an international level, exercise of this type of power manifests itself in the denial of market access, withdrawal of investments, the imposition of trade embargoes or the control of exports. For corporate businesses, economic power may arise due to the existence of highly concentrated sectors and manifest itself in the ability to influence price and reduce the competition (Murphy, 2008).

Political power (often closely related to economic power) is the ability of actors to coerce, control or persuade others by using political means. The most obvious source of such power is political legitimacy acquired through electoral processes coupled with holding positions in key decision making bodies. For countries and regions this power may be obtained through positions on such bodies as the United Nations, World Bank, International Monetary Fund, World Trade Organisation, etc. (The Economist, undated). Political power of the TNCs, on the other hand, is manifested through their influence on public policy processes (Clapp & Fuchs, 2009).

Whilst economic and political dimensions of power are often discussed in the literature, the power resulting from the possession of natural resources is less well documented. However, the industrial scale and nature of agriculture means it relies heavily on the use of natural resources, such as water, minerals and fossil fuel. As many of these resources are scarce and non-renewable, those in control of these resources are likely to be in a much stronger position to exert power. By the same token, those who have scarcity in these resources are likely to be vulnerable to outside control (Fanzul, 2006; Hendrickson et al., 2008).

In order to assess these three dimensions of power a number of indicators were developed and these are highlighted in Table 1, along with the sources of data.

As highlighted in the table, three indicators provide the basis of our analysis of economic power. These are agricultural gross value added (GVA), the size of international trade, and the magnitude of corporate concentration. The first indicator shows the size of the agricultural economy and the second implies that actors possessing wealth and market strength are likely to be in a position to influence others or prevent others from influencing them.[2]

The third indicator is based on the assumption that countries that are home to a larger number of TNCs are better placed to exercise power over the countries that have a weaker corporate base. We are aware that this might be contested, but believe that corporations are vital for understanding a country's economic power, because it is the TNCs rather than the nation states themselves that trade the bulk of agricultural commodities (Fanzul, 2006). For example, in the year 2000, corporations were identified as being responsible for

[2] The choice of agricultural based indicators to reflect economic power reflects the focus of this paper on power within agriculture, but it is acknowledged that this may have limitations. For example, it can be argued that countries with stronger levels of total economic power have dominated the agricultural trade agenda in the past. Conversely, it is of course possible that countries with strong agricultural sectors could have low overall economic power which might limit their ability to exert power over trade.

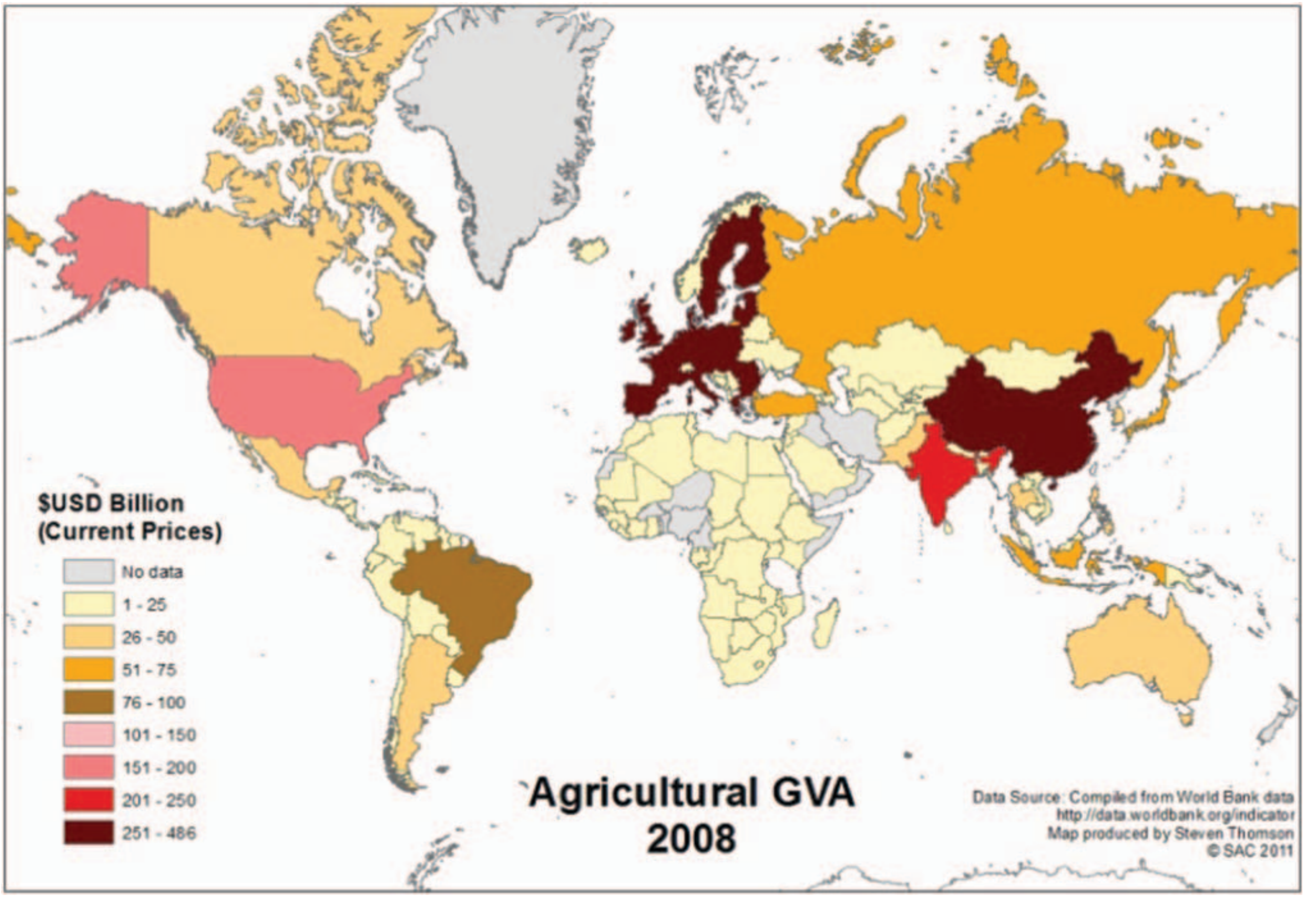

Figure 1: Agricultural GVA, 2008

two-thirds of global trade with their worldwide sales quadrupling from US$3 trillion[3] in 1980 to US$14 trillion in 2000 (Action Aid, undated). Although TNCs, by definition, operate in multiple countries and hence do not belong to any specific country, their power is usually located in the headquarters of their home country. In this study, TNCs are analysed in terms of their location, income, and market share.

As outlined earlier, political power is exercised through political legitimacy, position, authority and governance rules. Since these concepts underpinning political power are not easily quantifiable, examples and narratives are used as evidence of political power. We have analysed two cases that are illustrative of the political power of nation states in world agriculture – the World Trade Organisation (WTO) and the World Bank. Whilst focussing on these organisations we recognise that a number of other international institutions – such as the International Monetary Fund (IMF) and the United Nations (UN) – are also important for understanding the exercise of political power. The political power of TNCs was assessed based on their lobbying and political campaign financing expenditures (Clapp & Fuchs, 2009).

In terms of the possession of natural resources as a source of power we have analysed four aspects representing the key demands of agriculture namely: land, water, agricultural minerals, and energy. The current distribution of these resources between countries and regions and how such factors as resource depletion may alter this distribution in the future are considered.

3. Results

Economic Power

Historically the USA and EU27[4] have had the largest agricultural economies measured by value of agricultural Gross Value Added (GVA). However, the emergence of the Chinese and Indian farm economies has been significant, with China's agricultural GVA increasing six fold between 1988 and 2008 and that of India by 2.4%. In comparison, during the same period, the growth in GVA has only been 1.6% and 1.7% in the EU27 and USA respectively. Figure 1 reveals the largest agricultural economies in 2008.

China's agricultural GVA was US$485 billion, dwarfing that of the next largest farm economies of the EU27 (US$266 billion), India (US$214 billion) and USA (US$176 billion). However, the size of the agricultural sector, whilst highlighting the scale of agriculture and potential importance to these countries, does tell us relatively little about who has power,

[3] In early October 2012 US$1 was approximately equivalent to £0.62 and €0.77 (www.xe.com).

[4] It should be noted that generally within this study the figures for the EU27 are presented as if it is a single entity, whereas this is not the case with other trade agreements such as NAFTA, ASEAN etc. In part this differentiation is undertaken due to the greater level of integration (trade, legislative, monetary and economic) within the EU compared with many of the other agreements. This is not to downplay the importance of these trade agreements.

because it is through interactions between countries (for example trade) that power manifests itself.

It is also important to recognise that whilst as a single entity the EU27 may compete with the US and China in terms of scale, the power dynamic is likely to be very different. The existence of a diversity of interests in such a union may weaken the negotiating position in comparison to a single country such as the US. For example, within the EU, net importing and net exporting countries may have diverging views as to policy and compromises will inevitably occur.

International Agricultural Trade: Aggregate imports and exports

When examining trade patterns in agriculture it is pertinent to remember that historically agricultural trade has been heavily distorted by a range of factors including domestic agricultural policy, import protection and export subsidies. Trade patterns therefore reflect the influence of these factors. However, as 'old style' agricultural protection is declining it is useful to examine how trade patterns are evolving and what this means for the balance of power in agriculture.

According to the Food and Agriculture Organisation (FAO), from 1999 to 2008, annual trade (imports and exports) of agricultural products in the world averaged over US$600 billion. This trade was highly concentrated, with 20 countries accounting for 70% of world imports and 78% of exports. The EU27 (particularly the EU9 countries) played a dominant role in this trade, accounting for 44% and 46% of the total global imports and exports, respectively. However, intra EU27 trade accounted for 75% of total EU27 exports and 73% of imports over the decade, reiterating the significant importance of the EU's internal market to total global agricultural trade.

When intra-EU trade is excluded (Figure 2) the USA and EU27 can be seen to dominate world agricultural trade. Between 2006 and 2008 the EU27 and USA each accounted for just over 16% of total exports (average of $583 billion per annum) with Brazil (7.6%) and Australia and New Zealand (6.17%) the next largest exporters. Among the BRICS coalition only Brazil and China (4.2%) were significant exporters with the other three countries– India, Russia and South Africa – having minimal exports.

The EU27 (17%) was the dominant importer of agricultural produce globally, followed by the USA (12.8%), China (8.4%), Japan (7.7%) and the African continent (7.6%). It should be noted that not all commodities that are imported into a country are for use in the country as a proportion will be re-exported, particularly with some added value. It is noteworthy that in Asia and the Middle East only five countries had large import demands; China, Japan, South Korea, Saudi Arabia and Malaysia, whereas none of the Latin American countries were in the top 20 importers of agricultural produce.

Comparing the export figures with imports, we can see three broad groupings. First, the EU27, USA, and China are both large exporters and importers. Second, Japan and Russia are large importers, but not exporters. Finally, Australia and New Zealand, Brazil, Argentina, and India are major exporters, but not importers.

In terms of power, this does raise the question whether an importing country has power because it is wealthy enough to create the demand for goods? Or

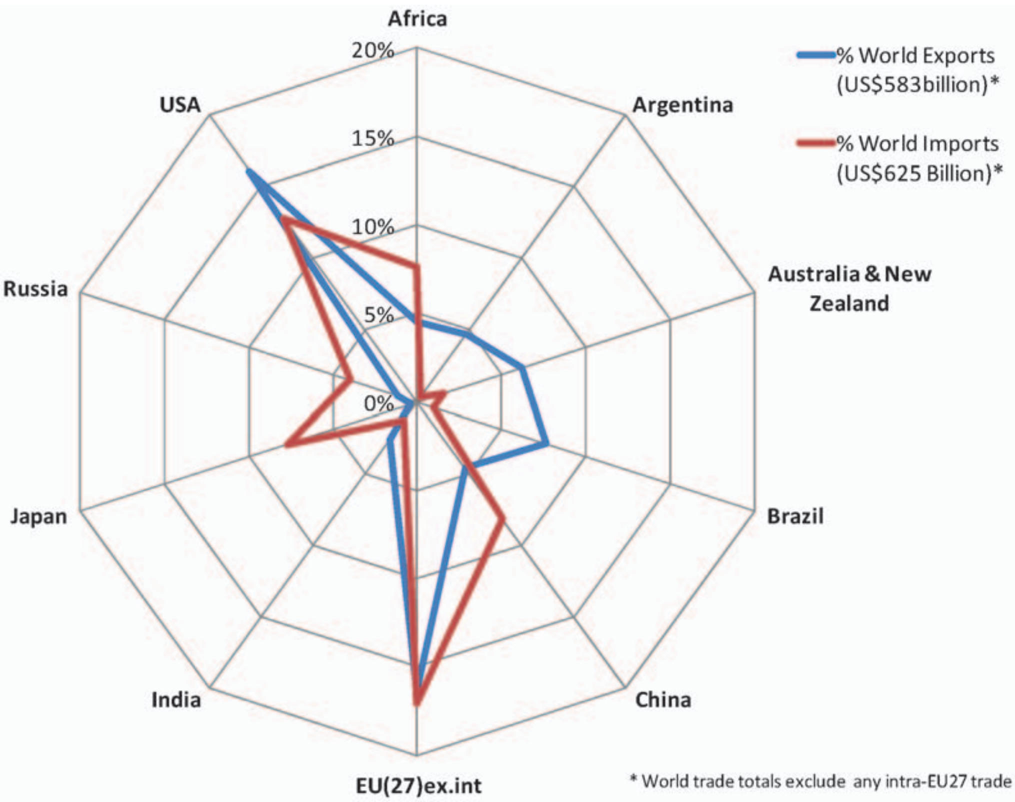

Figure 2: Proportion of World Agricultural Trade (average 2006 to 2008)

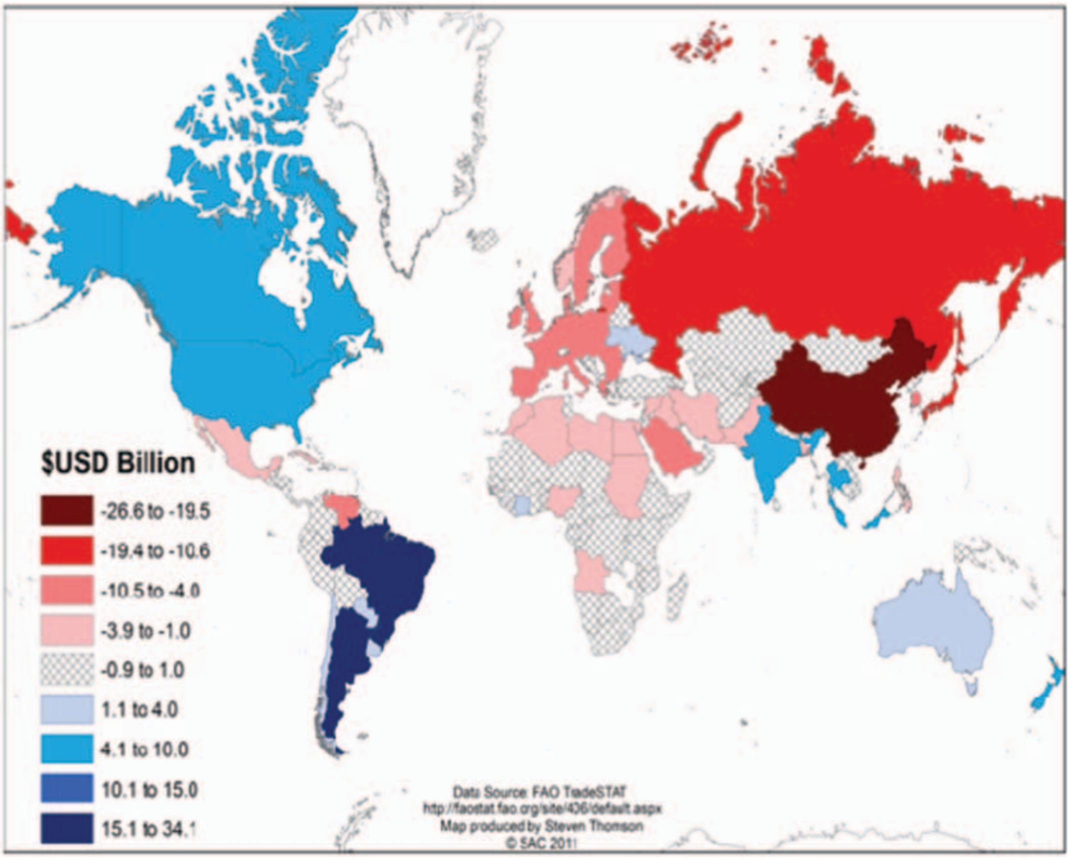

Figure 3: Change in Net Trade (exports minus imports) between average of 1997–99 and 2007–09

does power lies with the country that produces a surplus and exports? We hypothesise that countries with both import and export capacities (group one) are likely to be more powerful than the countries in the other two groups. Whilst Figure 2 provides a snapshot of the overall agricultural trade situation, it is useful to consider how trade patterns have evolved over time.

Figure 3 highlights how global net agricultural trade (exports minus imports) has changed between the averages of the 1997–99 and 2007–2009 periods. The darker blue the country/region, the more the net trade balance has improved (proportionally higher exports); the redder the country/region is, the more the trade balance has decreased (proportionately higher imports). A picture of a New/Old world split seems to emerge with North and South America and Australasia seeing improvement in their net agricultural trade balances whilst Europe's have declined[5] alongside the emerging economies in Russia and China where there have been significant increase in net agricultural imports. There are a number of reasons for these changes, not least significant shifts in agricultural policy within the EU-27 that altered net-production balances (EC, 2011).

International Agricultural Commodity Trade

As previously discussed countries/regions can be placed into the categories of predominantly exporters, predominately importers or a combination of both. Figure 4 shows selected countries that fall into these categories, revealing their import and exports for key agricultural commodities for the 2006 to 2008 period.[6] This highlights the significant role that Brazil plays in global exports of poultry meat, beef and to a lesser extent pork, with Australia and New Zealand being dominant exporters of beef and dairy products. For these agricultural products Japan was highly reliant on imports, as was Russia for beef, pork and poultry meat. The USA and EU27 (excluding internal trade) played significant roles in both supplying exports and importing commodities for their internal market.

Changing trade patterns

Further insight into the nature of trade can be gained by examining the destination of exports from the major exporters and examining how these have changed over time. It is clear that trade patterns reflect, amongst other factors, location and historic relationships, but Regional Trade Agreements and other factors have led to new and evolving trade patterns emerging. Taking beef as an example commodity, Figure 5 presents the change in destinations of exports between the 1997–1999 and 2007–2009 periods.

The maps indicate that there have been significant changes in the trade relationships in the beef sector. Australia has taken the USA's position as the most important global supplier of beef between 1997–99 and

[5] As the map is based on value of net trade, the scale of the change can be affected by changes in prices between the two periods; however, it is still useful to highlight the direction of change.

[6] Whilst noting that intra-EU trade is a very important component of international trade, the following considers the EU27 as a single trading bloc and therefore will exclude intra EU trade from the global figures.

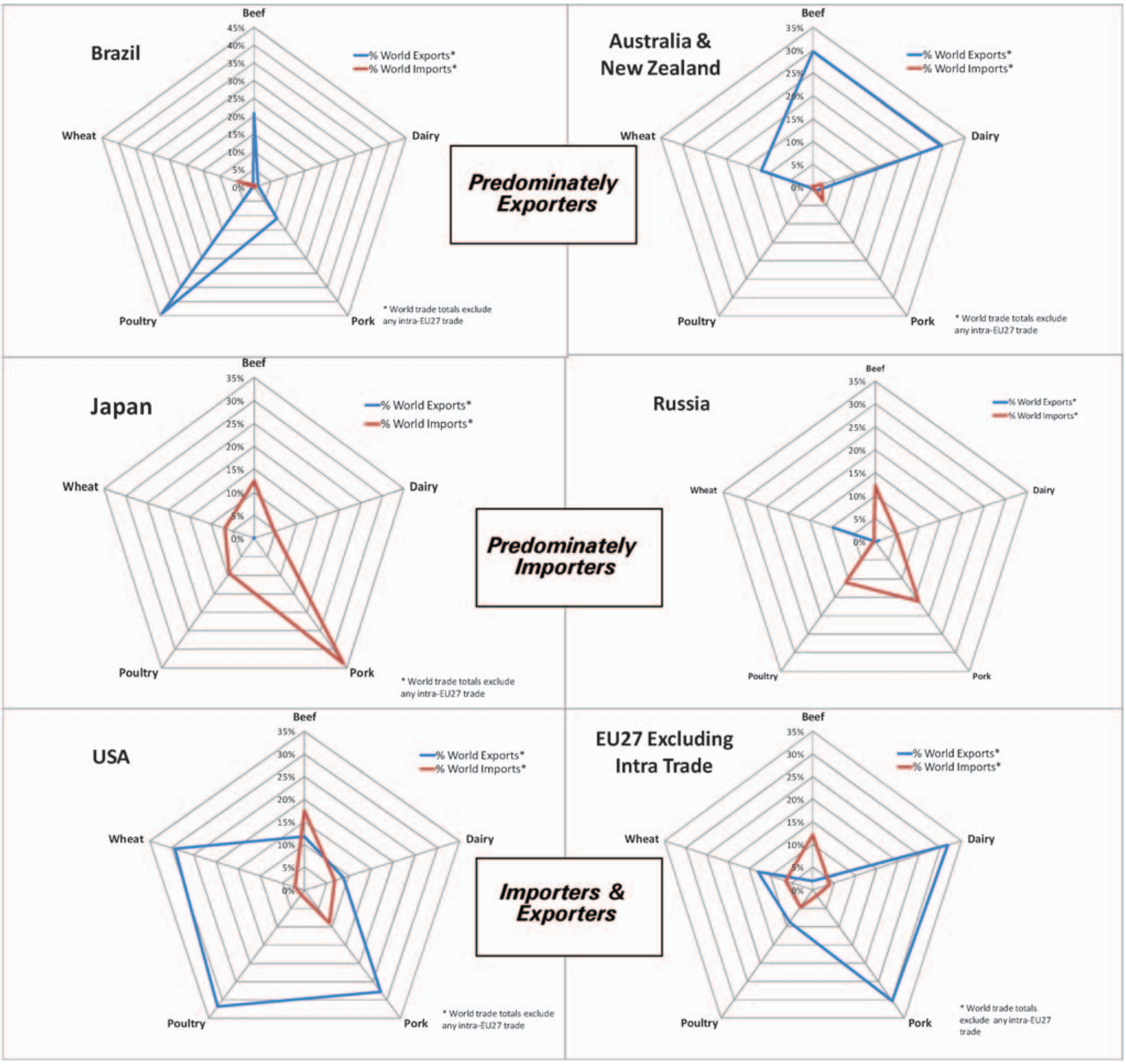

Figure 4: Proportion of Global Trade in Selected Agricultural Commodities, by country / region (average 2006–2008)
Source: FAO

2007–09. Australia's key beef export markets remain relatively similar proportionately (although South Korea rose from 5.4% of Australia's beef exports in 1997–1999 to 14.9% in 2007–2009), although the value of those exports more than doubled. This means that Australia is reliant on three markets for 80% of its beef exports, although all of them are covered by bilateral trade agreements[7] (although the recent US-Korea Free Trade Agreement may impact on Australia's beef trade[8]).

Of particular note is the rapid emergence of Brazil as the second most important exporter of beef in the 2007–09 period (exports having grown 10 fold in the preceding decade). In the late 1990's Brazilian beef exports were only about US$300, with three-quarters going to the EU27. A decade later Brazil exports were over US$3.5 billion and its most important market is now Russia (31% of its exports) with the EU27 now taking under 16 per cent. The USA's beef exports have remained stable in value (although have fallen in real terms) over the period and links to the Japanese market have diminished (falling from 55% of all beef exports to 14%), whilst links to regional partners, Canada and Mexico have grown in importance, highlighting the significance of the North American Free Trade Agreement (NAFTA).

Corporate concentration

The structure of global business is continually changing through a process of mergers, takeovers etc. and therefore it is only ever possible to obtain a snapshot of the situation. UNCTAD, however, provided a list of the world's top 150 agribusiness corporations which we

[7] http://www.bilaterals.org/spip.php?rubrique127
[8] http://www.bilaterals.org/spip.php?article21118

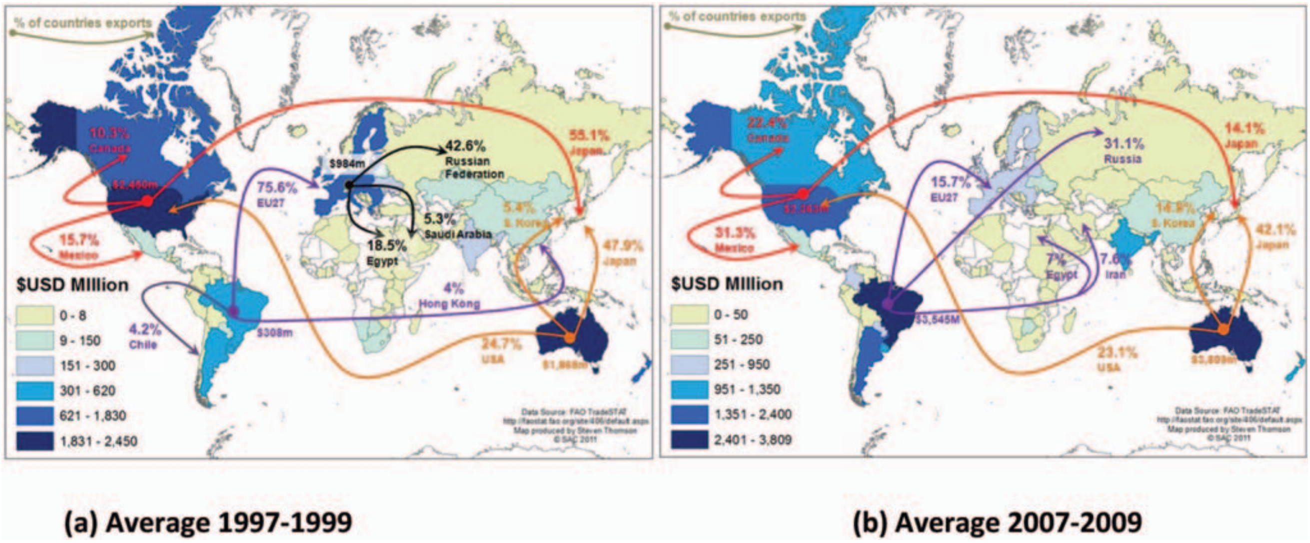

Figure 5: Value of beef exports and main destinations of export destination for major exporters

have taken as the basis for our analysis (UNCTAD, 2009). According to this report, about 89% of these corporations are located in just 20 countries. With 43 (over a quarter) of these companies the USA is home to the largest number. In second position is the UK with 11 of the top 150 companies whilst France and Germany are in third and fourth positions with 10 and seven of the top corporations, respectively.

On a regional basis, 44% of these corporations are located in just 17 countries of the European Union, 31% in just two countries of North America (USA and Canada) and 22% in the 14 countries of the Asia-Pacific region. This suggests that EU leads in terms of overall global corporate power, although individually the major EU economies are small when compared with the corporate power of the USA.

A more disaggregated view of corporate power can be obtained by examining individual sectors. The global food products industry, consisting of agricultural products and packaged foods, generated revenues of US$3.2 trillion in 2008 (IMAP, 2010). A small number of TNCs currently dominate this sector. In terms of annual turnover, the Swiss Corporation Nestlé ranks first in the world with a turnover of over US$112 billion (Figure 6). Archer-Daniels-Midland (ADM) and Unilever rank second and third with annual sales of US$62 billion and US$59 billion respectively. The annual turnover of the top 11 companies combined is about US$393 billion. The total asset value of these TNCs is estimated to be US$439.5 billion. Using this indicator, Nestlé, Kraft Foods, and Unilever rank first, second and third respectively (Figure 6).

The ranking is similar for net annual income. With a profit of about US$37 billion, Nestlé ranks first, followed by Kraft Foods (US$5.7 billion) and Unilever (US$5.69 billion) which rank second and third respectively. The aggregate annual profit of the top 11 TNCs totals close to US$59 billion.

The global retail industry is currently dominated by between 10 and 12 TNCs. In 2007, the top 10 retail TNCs shared 40% of worldwide retail sales (ETC Group, 2008). According to the FT Global 500 data,

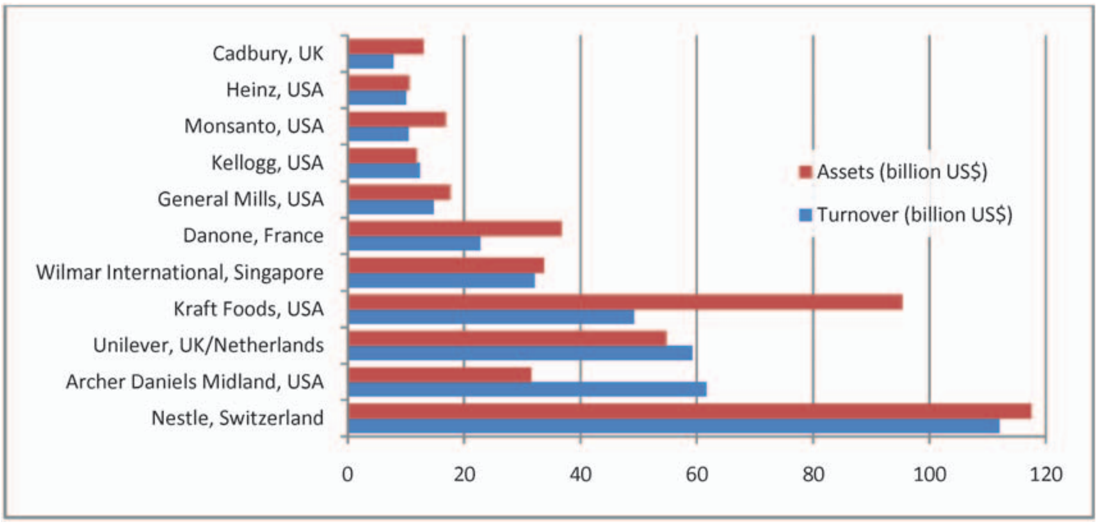

Figure 6: Annual turnover and asset value of world's top food products TNCs
Source: FT Global 500

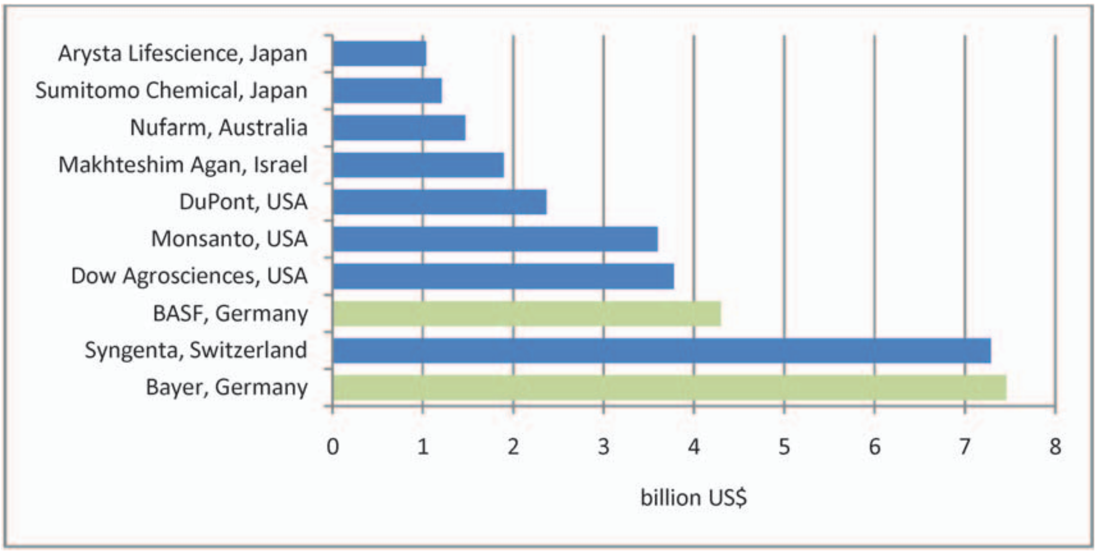

Figure 7: Annual sales of world's top agrochemical TNCs (2008)
Source: Agrow World Protection News, 2008

in 2010, the top 12 retail TNCs collectively had an annual turnover of US$1.32 trillion. With an annual turnover of around US$419 billion, the US Corporation Wal-Mart, by some margin, was the largest. The only UK retail TNC in this list was Tesco (seventh position). The asset values of these top 12 TNCs was over US$564 billion in 2010 and Wal-Mart alone represented 32% (US$180.3 billion) of this. The asset values of the next three TNCs – Carrefour, Tesco and CVS Caremark – were around one-third of Wal-Mart (FT Global 500. This reiterates the economic prowess of Wal-Mart at the global level.

The economic power of TNCs also manifests itself in the market for agricultural inputs such as agrochemicals, seeds and fertilisers. Like the other sectors, we find a high degree of concentration with a few TNCs having substantial market shares (ETC Group, 2008). For example, in 2007, the top 10 agrochemical companies controlled 89 per cent of the global market (Figure 7) with Bayer ranked first in the world, Syngenta second and BASF ranked third. Of the US$38.6 billion sales in the world, Bayer and Syngenta shared 19 per cent each (around US$7.5 billion), and BASF 11 per cent (US$4.3 billion). It is also apparent from Figure 7 that only five companies – Bayer, Syngenta, BASF, Dow and Monsanto – account for nearly 70 per cent of the world's agrochemical market.

According to the ETC group, in 2007, the global sale of proprietary seeds was US$22 billion. As shown in Figure 8, Monsanto was by far the largest company accounting for just under a quarter of global sales (about US$5 billion). Together with DuPont (15%) and Syngenta (9%), these three companies controlled nearly 50 per cent of the world's proprietary seed market in 2007.

Only seven TNCs currently dominate the fertiliser market of the world (Figure 9). In terms of net income in 2007, Potash Corporation ranked first in the world

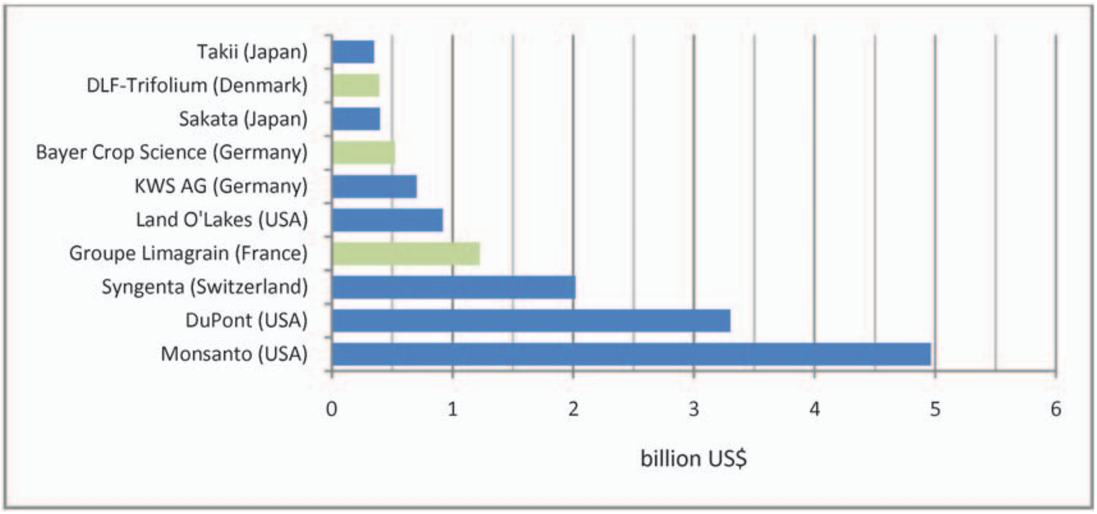

Figure 8: Annual sales of world's top seed TNCs in 2007
Source: ETC Group, 2008

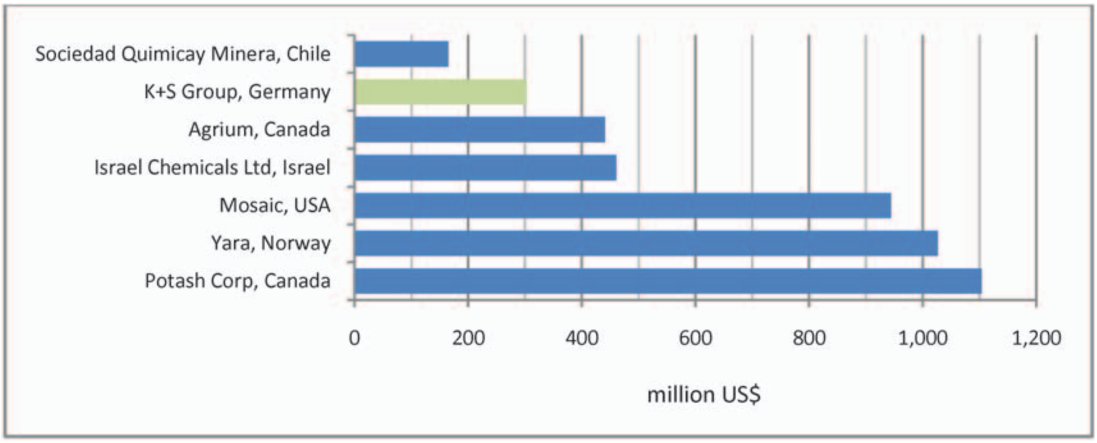

Figure 9: Net annual income of world's top fertilizer TNCs in 2007
Source: ETC Group, 2008

(US$1104 million), while Yara (US$1027 million) and Mosaic (US$944 million) ranked second and third respectively.

Whilst these figures give an indication of the scale of the TNCs and market concentration, they clearly do not tell the whole story in terms of power for a number of reasons. First, it should be noted that a number of very large companies are privately owned and therefore their figures are not publically available. Second, it does not tell us the *number* of countries that the companies operate in, or the number of companies operating *within* a particular country. This is clearly important in terms of the degree of power faced by farmers. Third, as well as rapidly growing in size through the process of mergers and takeovers, other forms of business relationship have increased the economic power of TNCs. An example from the UK is the creation of Frontier Agriculture as a joint enterprise between Cargill and ABF focusing on crop inputs and grain marketing. In effect this increases the economic power of both companies in the UK.

Political Power

Using the WTO and World Bank as examples, we illustrate some of the issues surrounding international political power in the area of agriculture and demonstrate how closely it is linked to economic power.

Power within the WTO

The WTO's main purpose is to facilitate the liberalisation of global trade (including agri-food trade) by acting as a 'platform' for countries to negotiate trade problems, settle disputes (e.g. market access, tariff concessions, and quotas), and formulate and sanction trade rules. The organisation currently has 153 members (countries) that cover almost 90% of global trade. In assessing the power of nation states within the WTO we have relied on three indicators – financial contribution to WTO (proxy indicator), capacity to use WTO's dispute settlement mechanisms and influence in WTO's decision making.

An analysis of the financial contribution of member states to WTO's budgets reveals that the WTO relies heavily on the donations of a few countries – most of which are the large trading nations that we have shown in section 3.1. For example, in 2011, only 12 countries, mostly large economies, collectively contributed over 79% of WTO's budgets. As shown in Figure 10, the five largest contributors in order are: EU-15[9] (38.75%), USA (12.4%), China (11.18%), Japan (5%) and Canada (3%). Disregarding the EU as a single entity, the highest contributors in order are USA, China, Japan, Germany (8.86%), France (4.49%) and UK (4.84%).

The relationship between economic power and political power in the WTO can be highlighted in two areas.

First, a strong relationship exists between the level of financial contribution and the use of the WTO's platform in settling trade disputes. For instance, about 84% (351) of the 419 trade disputes brought into the WTO from 1995 through to 2010 were made by 12 countries only.[10] The remainder of the 141 member countries together launched slightly over 15% of the complaints. Whilst the use of the trade dispute platform is likely to be closely related to the extent of trade, it does also represent the exercise of power as significant resources are required in order follow the dispute process through.

Second, examples provided in the literature indicate that WTO's decision making has historically been dominated by a handful of countries, in particular, the USA. Although the WTO claims that it operates on a 'one country one vote' basis and its decisions are made based on 'consensus' some researchers (e.g. Jamara & Kwa, 2003; Monbiot, 2004; Steinberg, 2002) argue that the WTO's decisions are often made through a process of informal negotiations between a few large and high-income member states, for instance, the so called 'Quad', comprising USA, EU, Canada and Japan (Monbiot (2004: 205–207).

However, although, historically, the developed Western nations, in particular USA, have dominated

[9] These 15 countries are UK, Sweden, Switzerland, Spain, Poland, Norway, Netherlands, Italy, Ireland, Germany, France, Denmark, Belgium, Austria, and Portugal. Among these 15 nations Germany's contribution is the highest (8.86%), followed by France (4.49%), and UK (4.84%). The contribution of other countries range from 3.7% (Italy) to 0.51% (Portugal).

[10] The USA (97) raised the highest number of disputes, followed by EU (82), Canada (33), Brazil (25), India (19), Argentina (15), Japan (14), South Korea (14), Thailand (13), Chile (10) and China (8).

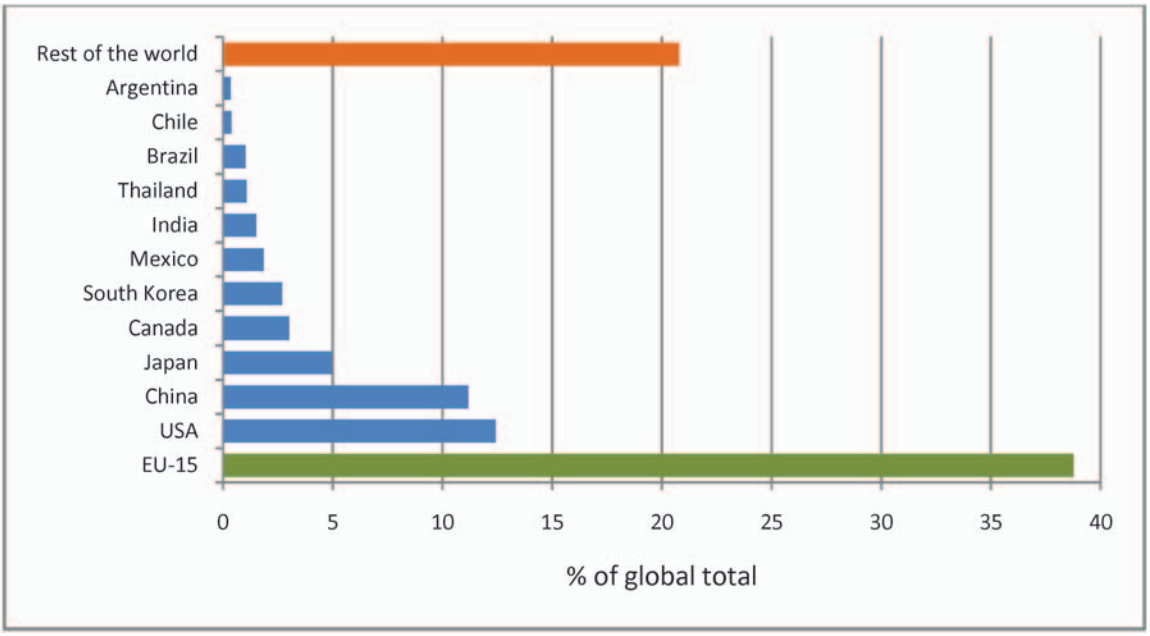

Figure 10: Share of financial contribution to WTO's budgets
Source: WTO, 2011

the WTO, recent incidents indicate a power shift, with the emerging developing countries also appearing as powerful players. This power shift manifested itself in the collapse of the Geneva talks under the Doha Development Agenda (which began in 2001) due to disputes between USA, EU, China and India regarding the liberalisation of agricultural trade. This has been labelled in the international media as a significant shift in global power. A German business daily Handelsblatt, for example, wrote:

"Above all the failure of the WTO talks reflects the changing power relations in the world. Gone are the days when the US and Europe could set the tone and largely draw up the world trade agreements amongst themselves. China and India took a tough stance. They fight hard for their interests and only support free trade when it suits them. The old industrial powers will slowly realize the bitter truth of this. Geneva was just a foretaste" (Quoted in Spiegel Online International, 2008).

Power within the World Bank

Like the WTO, the World Bank is also a global institution, represented by 170 member states (World Bank, 2010). The organisation has historically played crucial roles in shaping global agriculture through its lending operations and technical assistance programmes (see Pincus, 2001). This trend still continues. For example, in the Fiscal Year 2010, the Bank invested about US$2.6 billion in agricultural development programmes, including a Global Agriculture and Food Security Programme (GAFSP) in order to respond to the financial needs in developing country agricultural sectors (World Bank, 2010).

Whilst, the World Bank is represented by 170 member countries, the voting power of individual countries within the Bank is unequal and contingent on the financial contribution made by each member country. Thus, the country that contributes the most has the highest voting power. With 16 per cent of the voting power, the USA currently ranks first, whist the UK ranks fifth. If we analyse this voting power in terms of economic coalitions, we see that the G-7 block[11] has the highest voting power (44%), while the BRIC coalition, comprising of the emerging economies, has only 11% of the votes.

In terms of global power in agriculture, this distinction is important because greater voting power enables countries or coalitions to push forward their own agenda by influencing the key decisions made by the Bank, including which countries receive loans and under what conditions. For example, through its Structural Adjustment lending programmes the World Bank persuaded many developing country governments to slash their budgetary support to agriculture, privatise state-owned corporations and adopt liberalised policies in agricultural trade. The Bank used these reforms as 'pre-conditions' for sanctioning loans to debt-ridden developing countries and this condition-based loan-sanctioning mechanism is still in practice (see Oxfam, 2006). Whilst it is argued that these conditions have a sound economic rationale, they do enable powerful countries, like the USA and its agribusiness corporations, access to developing country markets. Similarly it has been argued that, since the 1970s, the USA has systematically used its influence in convincing the Bank not to grant loans that could facilitate the production of goods that would compete with US products, i.e. palm oil, citrus fruits and sugar (Toussaint, 2006).

However, although the World Bank has historically been dominated by powerful economic coalitions such

[11] The G7 member countries are France, Germany, Italy, Japan, UK, USA, and Canada. The G7 (which is an informal grouping) is considered to be the most powerful economic and political coalition in the world. Although it should be noted that with the addition of Russia it has become known as the G8, and there are reports that France is keen to expand it further to include other countries such as Brazil, India and China. This again can be seen to reflect the changing balance of political power in the world.

as the USA and the G-7 group, recently, there has been a shift in this power game. Although it is still the USA and the EU countries that have most of the power, the Bank has recently provided more power to emerging economies like China and India (World Bank, 2010). This clearly shows a changing geopolitical landscape with clear signs of power shift from the West to the East. As the Chairman of the World Bank Group, Robert Zoellick himself stated in the 2010 annual report of the Bank:

"Our shareholders..... fulfilled the commitment....to increase voting power at the International Bank for Reconstruction and Development (IBRD)[12] for developing and transition countries by at least 3 percentage points, bringing them to 47.19 per cent—a total shift of 4.59 per cent since 2008. Developing-country voting power in the International Development Association (IDA) will rise to more than 45 per cent. Developing and transition countries' shares at the International Finance Corporation (IFC) will increase by 6.07 per cent to 39.48 per cent. These changes in voting power help us better reflect the realities of the new multipolar global economy, where developing and transition countries are now key players."

Political power of TNCs

Evidence from the US highlights the considerable sums that are spent by the TNCs on lobbying and political campaign financing. Between 2008 and 2010, for example, it is estimated that Monsanto alone, one of the world's largest seed and agrochemical firms, spent over US$8.5 million per year in lobbying (Centre for Responsive Politics, 2011) and only three companies – Monsanto, Syngenta and Dow – donated over a quarter million US$ to democrat and republican parties during the 2009–2010 election cycle (Agri-Pulse, 2010). Evidently, the TNCs spent these sums in order to influence public policy processes (Jowit, 2010; Madsen & Davis, 2011). It is therefore contended that the TNCs have significant political as well as economic power. However, it is also evident that civil society organisations are becoming increasingly adept at using the political system themselves to counter some of the power of the large corporations. In 2002, for instance, farmer organisations lobbied and forced Monsanto to withdraw its applications for regulatory approval of GM wheat submitted to the Canadian and US authorities (Falkner, 2009). Similarly, after eight years of campaign by Greenpeace in Brazil, Bayer finally halted trying to introduce GM rice to Brazilian farmers (Greenpeace International, 2010).

Natural Resources and the Future of Power

This section examines how key natural resources (land, water, minerals and energy) are distributed globally and in particular how this distribution maps onto agricultural power.

Land

About three quarters of the world's 4.8 billion ha of agricultural land is located within the borders of only 25 countries. According to the FAO (2010), the countries with the largest shares of global agricultural land are China (10.7%), Australia (8.5%), USA (8.4%), Brazil (5.4%) and Russia (4.4%). Collectively, they occupy over one-third of the world's agricultural area. However, simply ranking by area may be misleading as it does not take into account the population that the land has to sustain (for example, the situation in China) or the quality (productive capacity) of the land. Correcting for population alone, Mongolia has the highest per capita agricultural area (44 ha/person), followed by Australia (20 ha/person) and Namibia (18 ha/person). By using this indicator, some large countries i.e. Russia (32nd), Brazil (35th), USA (36th) and China (109th) become much less land rich.

In terms of total arable land, which may be argued to better reflect productive capacity, the USA ranks first in the world with an endowment of 170.5 million ha – over 12% of the world's total (1.4 billion ha). India ranks second (11.5%), Russia third (8.8%), China fourth (7.9%) and Brazil fifth (4.4%). However, on a per capita basis, Australia ranks first in the world with Kazakhstan and Canada in second and third places, respectively (Figure 11). Brazil ranks 37th in the world with per capita arable land of 0.32 ha, India is 106th with 0.13 ha and China 138th with 0.08 ha. Although, some of the EU countries are within the top 25 in the world in terms of per capita arable land holding these are not the agriculturally powerful. On the contrary, powerful countries like France ranks 41st (0.29 ha) and the UK ranks 126th (0.09 ha) in the world.

Water

The total renewable water resource (by volume) in the world is estimated at just over 54 billion m^3 per year (FAO Aquastat). About 67 per cent of this is located in just 15 countries and many of these water-rich countries are developing economies (Figure 12). The major EU economies appear to be water poor in comparison to these developing countries, with the EU-27 only having the eighth highest water resources globally. The advanced EU economies may therefore be in a more vulnerable situation in terms of natural renewable water levels in comparison to some of the other key agricultural producers such as the USA, Canada and the BRIC countries. However, whilst total renewable water resources provide an indicator of this vulnerability it does not really take into account the extent that water is actually acting as a constraining factor on agriculture. That is while total volumes of water supply are important, the lack of spare or excess capacity is what actually might constrain agriculture moving forward.

Minerals

As mentioned earlier, phosphate rock and potassium are two of the key minerals required by agriculture. In addition, they are non-renewable and currently there are no suitable substitutes available. Therefore, they provide useful examples of how control over production may provide power in agriculture.

[12] IBRD, IDA, and IFC are collectively called the 'The World Bank Group'.

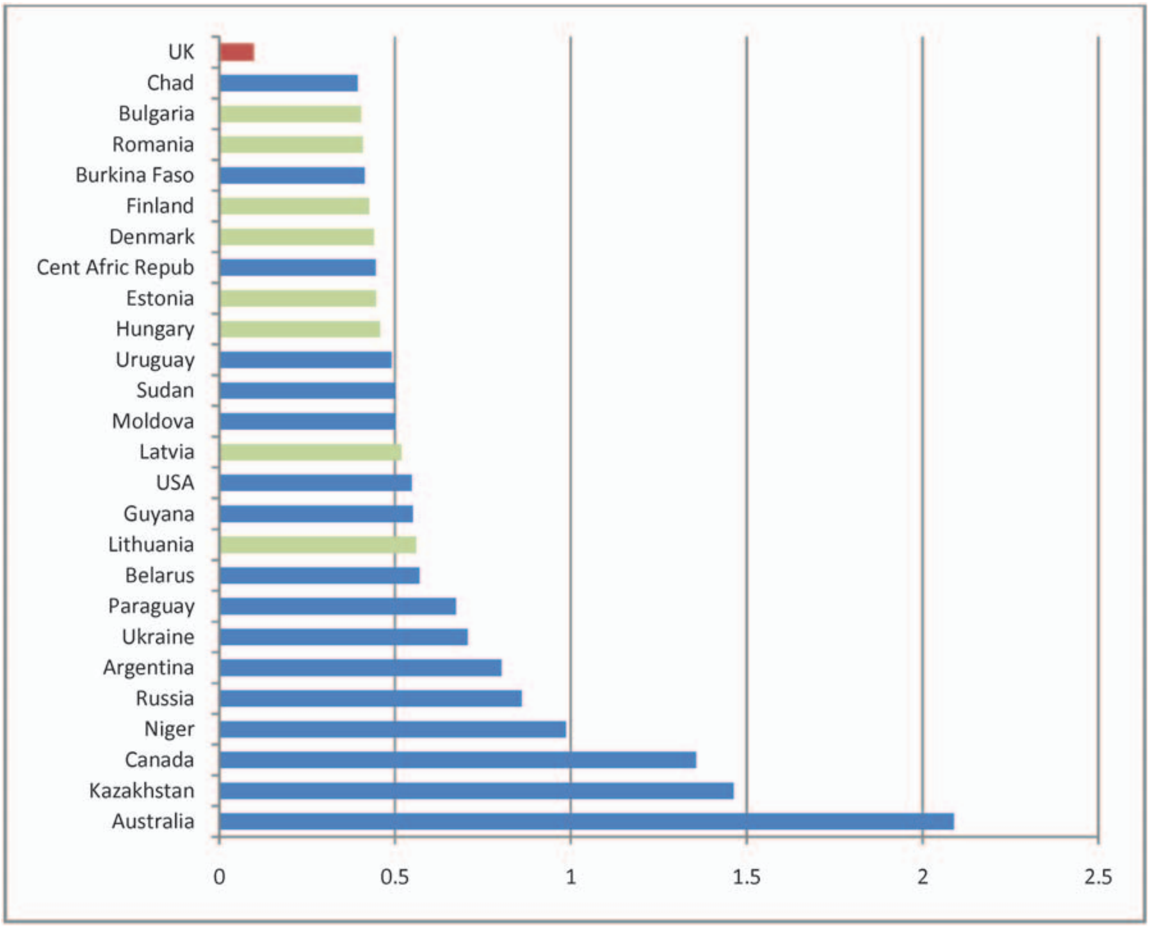

Figure 11: World's top 25 countries according to per capita arable land holding in hectares vis-a-vis UK
Source: FAO, 2010

Almost the entire reserve of world's phosphate rock, which is estimated to be 65 billion tonnes, is located in just 15 countries (USGS, 2011). Nearly 77 per cent of this reserve is in Morocco and Western Sahara (M&WS) and over 98 per cent is in just nine countries (Figure 13).

A number of the countries with considerable phosphate rock reserves are important players in agriculture, such as USA, Canada and three of the BRICS countries. In contrast, none of the EU countries have any phosphate rock reserves, potentially making them vulnerable vis-à-vis the emerging BRICS countries.

In terms of production, China currently ranks first in the world with an average annual production of about 63 million tonnes (Figure 12). In second and third positions are the USA (26.3 million tonnes) and M&WS (24.5 million tonnes).

Looking forward, at the current rate of production and with known reserves, phosphate reserves are forecast to last for a further 400 years. However, with the exception of M&WS, the phosphate rock reserves of a number of currently important producers are going to be depleted in the much nearer future. For example, Canada's reserve is going to be exhausted in just seven years, Australia's in 29 years[13] and China's in about 60 years. Although the current reserves in the M&WS region are more secure into the future, this region is likely to be the focus of a power struggle between the major world economies in future.

The current global Potassium reserve is estimated to be around 9.5 billion tonnes. Almost 100% of this reserve is located in just 13 countries, while over 81% in just two countries – Canada and Russia (Figure 15). Germany is the only country within the EU with any considerable Potassium reserves.

In 2009/10, the average production of Potassium in the world was about 27 million tonnes per year. Canada is currently the largest producer and, in 2010, accounted for over 28% of the world's production (Figure 16). The other major producers were Russia (20%), Belarus (15%), China (9%) and Germany (9%). These five countries currently produce over 80% of the world's Potassium. The UK is the second highest potassium producer within the EU, Germany being the first. However, the amount shared by the UK is only about 1.2% and Germany and the UK together produce slightly over 10% of the world's Potassium.

Looking forward, given the current reserves and the current rate of production, it is estimated that potassium reserves will be depleted in just under 300 year's time. However, six of the above 13 countries are going to deplete their Potassium reserves in between just 19 and 70 years. These include Israel, followed by Jordan, Spain, UK, Germany and China. The immediate depletion of the Potassium reserves in countries such

[13] Although Australia is a phosphate rock producer, the country's reserve is only 82 million tonnes, which is 0.13% of the world. This is why Australia is not shown in Figure 4.4 as having phosphate rock.

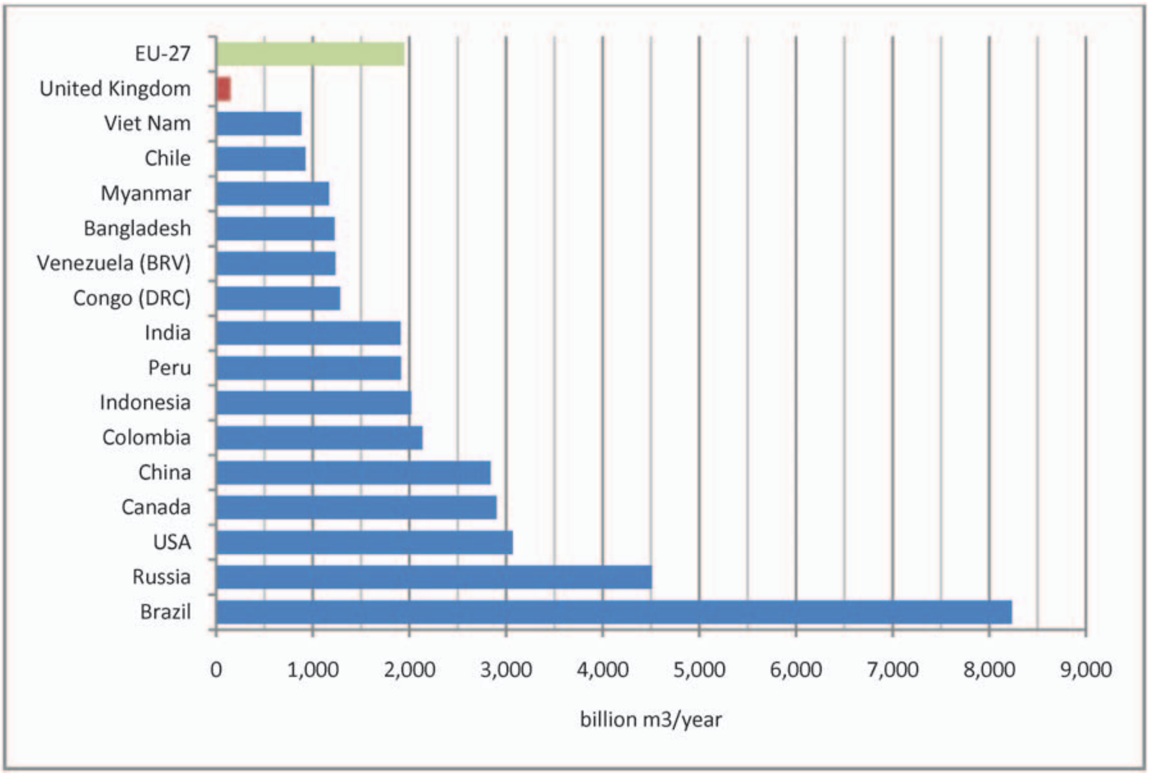

Figure 12: Top 15 water rich countries vis-a-vis EU-27
Source: FAO AquaStat

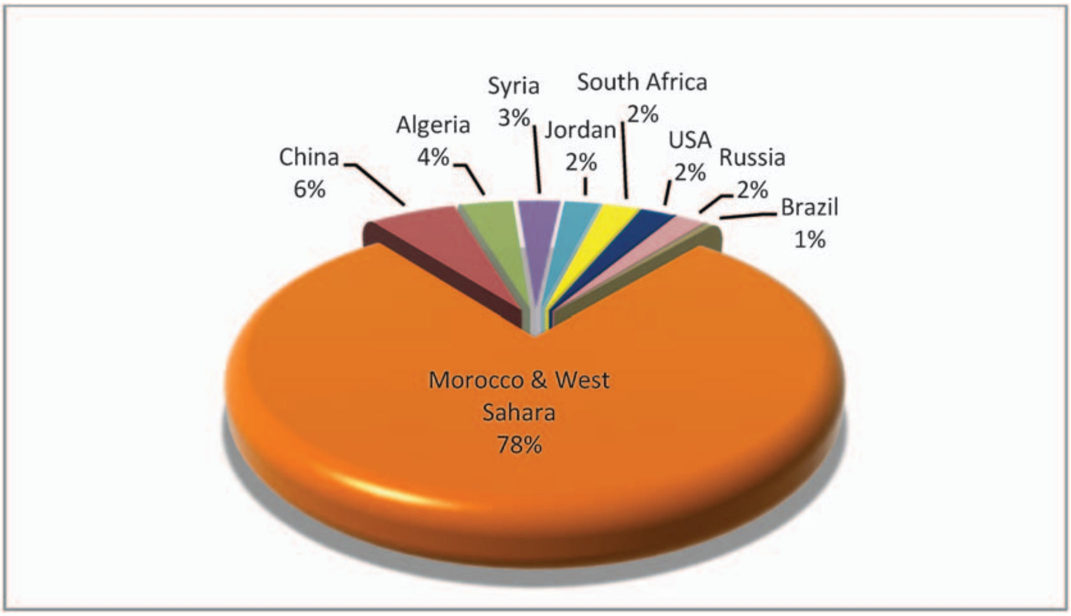

Figure 13: World's phosphate rock reserves
Source: USGS, 2011

as the UK, Germany and China may place them in a vulnerable position vis-à-vis the other top agricultural producers in the world – such as Brazil, Russia, Canada and the USA.

Energy

The final resource considered is energy. Whilst agriculture is estimated to account for less than two per cent of total energy demand in the world, it is essential to modern agriculture. Therefore access to energy is as important to future agricultural production as it is to the rest of the economy.

Over 90% of the world's crude oil reserves are located in a handful of countries, most of which are in the Middle East and North Africa, North America (Canada and USA) and Latin America (Venezuela, Algeria, and Brazil) (CIA, 2010). The only country in Europe with a

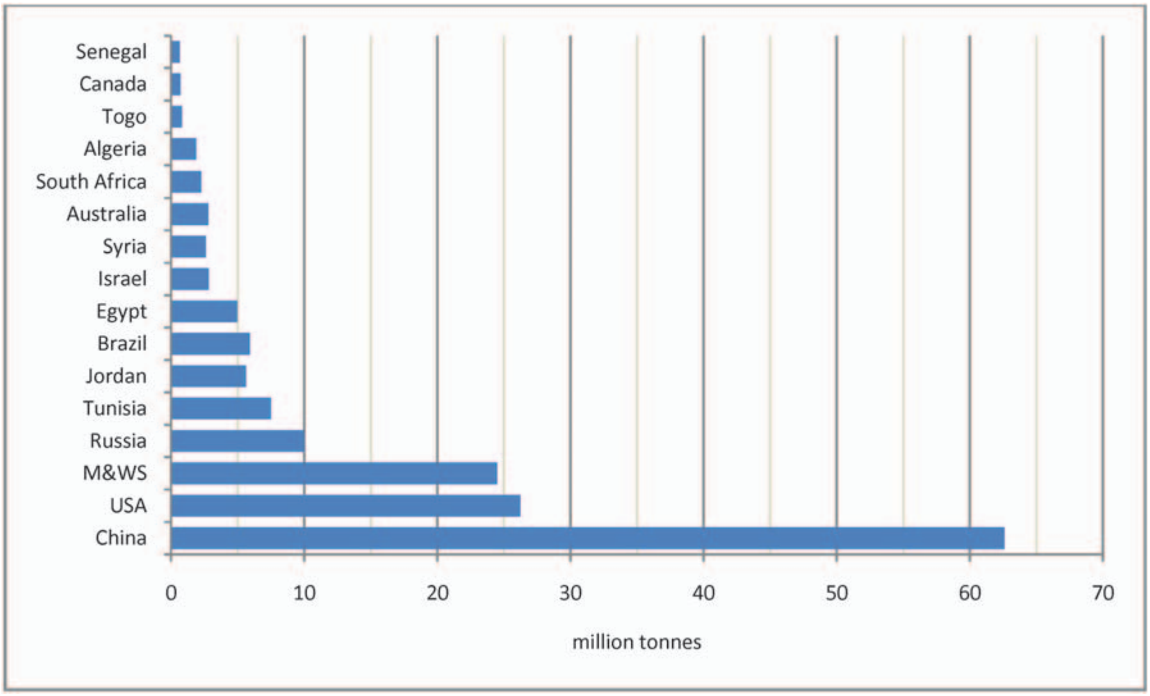

Figure 14: Annual Phosphate rock production (2009–2010)
Source: USGS, 2011

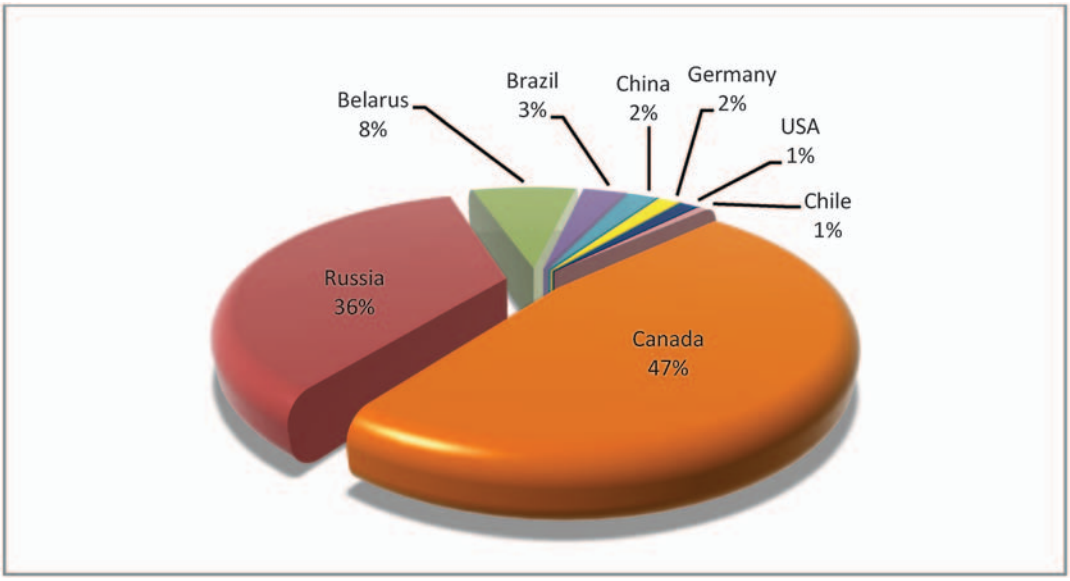

Figure 15: Global potassium reserves
Source: USGS, 2011

significant reserve of crude oil is Russia (74.2 billion barrels). Very few of the EU countries that currently dominate the world in terms of agricultural production and trade have any significant oil reserve.

In terms of crude oil production, a similar picture emerges. Over 85% of the world's crude oil is currently produced by only 25 countries only (CIA, 2010). Among these countries, Russia currently ranks first, while Saudi Arabia and USA rank second and third, respectively. It is noteworthy that, only about a third of the current global 'oil giants' are the global 'food giants'. This means that two-thirds of the existing global food giants have to rely to a large extent on a steady supply of oil from the non-agricultural countries. Other things being equal, this situation suggests a degree of vulnerability. This vulnerability becomes even clearer, particularly for EU countries, if we take into account the high level of oil consumption in these countries (CIA, 2010). For example, our estimates suggest that at the current rate of consumption, domestic reserves can sustain most European countries for between just 24 and 359 days, with the exception of UK, Norway and Denmark. If there is an oil crisis, the energy-intensive agricultural sectors of these countries would clearly be adversely affected.

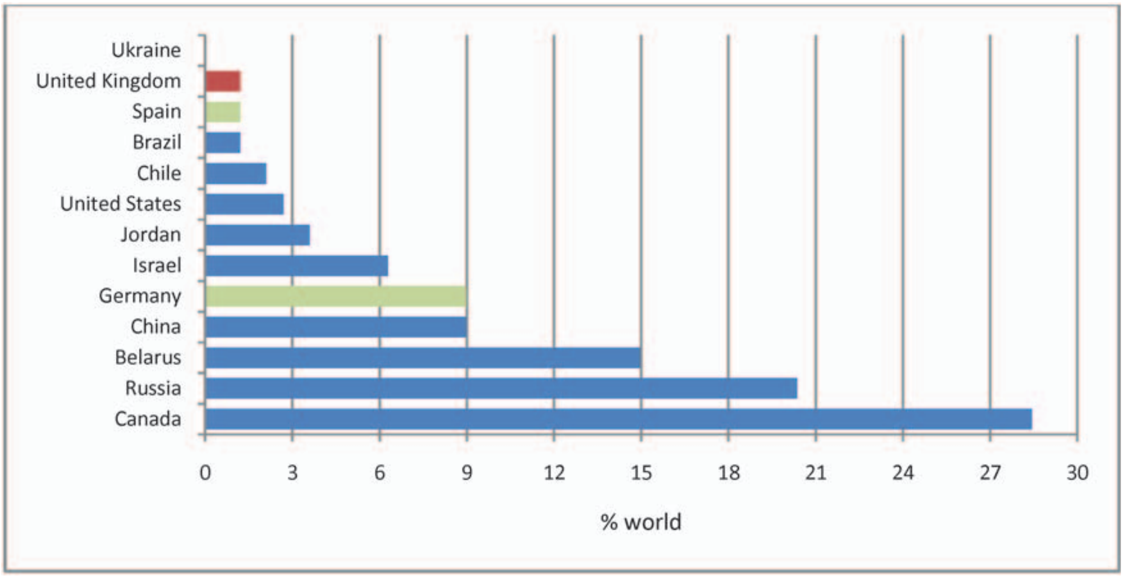

Figure 16: Annual Potassium production (2009–2010)
Source: USGS, 2011

The current world reserve of natural gas is 188 trillion m^3. Like oil, almost all (> 94%) of this reserve is located in just 25 countries (CIA, 2010). Russia ranks first with a reserve of 47.6 trillion (25.30% of the world), followed by Iran (15.75%) and Qatar (13.55%). These three countries share more than one-half (55%) of the world's natural gas reserves. The natural gas reserve is minimal in European countries, except Norway and the Netherlands that collectively share 2% of the world's reserves. It is also noteworthy that very few of the world's other agriculturally important countries have substantial natural gas reserves (CIA, 2010).

4. Discussion and Conclusions

This paper has considered the issue of power in world agriculture – economic, political and natural resources. This section briefly discusses their implications, and introduces the 'Power Index' as a way to draw together the results of the study.

The analysis of the economic power of nation states in the world indicates that, at present, the power is concentrated in North America and Europe. However, certain countries such as Brazil and New Zealand are currently the largest exporters of some commodities (e.g. beef and dairy products) in the world. There is little evidence to suggest that this current power situation is likely to change markedly in the next 10 years. However, it is also apparent that the EU as a whole has retreated from world markets as policies have changed and that the export capabilities of the EU-27 in some key commodity sectors are predicted to decline further in the next 10 years, unless policy measures change markedly. This change may be seen as indicating a decline in the power of the EU-27 within the global context. However, given that a significant proportion of the exports were subsidy driven, the move to a more market orientated situation may in fact improve its competitive position in the longer term. In addition, in the short run, being less reliant on export subsidies will also strengthen the EUs position in trade negotiations.

Our analysis also indicates that, although the emerging economies, in particular, China and Brazil, have clear advantages in certain commodity markets, their corporate power in agriculture is still not on a par with that of North American (US and Canada) and European countries, especially, UK, France and Germany. These major North American and EU economies therefore are in a strong position to consolidate their economic power through their transnational agribusiness corporations. However, a major challenge for them is to balance corporate power with consumer and farmer power domestically, whilst maintaining global power.

The available evidence supports the view that the political power relevant to global agriculture is still concentrated in the hands of the USA, major EU countries and some other economically powerful countries within the G-8 coalition. However, recently there have been indications that this situation is changing and some emerging economies in the developing world are increasingly powerful players on the world stage. This has important implications for European and UK agriculture, in particular, in terms of transnational agricultural trades. In the coming decades, EU countries may have to confront increased pressure to allow greater access to their markets. This pressure is likely to come from emerging economies – like China, India and Brazil and will have implications for domestic producers.

Our analysis also confirms the influence of transnational corporations (TNCs) in global agriculture. Although, their power is not limitless and, it can be argued that ultimately it is nation states who can control agriculture, for example as shown in 2008 when a number of countries implemented export bans to try to ameliorate the impacts of a food crisis. There is also evidence that in some cases civil society organisations and farmer groups have had a significant impact in countervailing or balancing corporate influences. These findings do not corroborate the suggestions made by

Table 2: Global Power Index for Agriculture

Dimension	EU27	US	Brazil	Russia	China	Australasia	Japan
Trade	4.5	5.0	2.0	3.0	3.0	2.5	2.5
Corporate	5.0	5.0	1.0	1.0	2.0	2.0	3.0
Political	5.0	5.0	1.0	3.0	2.0	1.0	4.0
Natural	3.5	4.0	3.3	3.5	4.5	3.3	1.5
Minerals	1.3	2.5	2.3	4.3	3.3	1.0	0.0
Total	**19.3**	**21.5**	**9.5**	**14.8**	**14.8**	**9.8**	**11.0**

some that, in this age of corporate globalisation, the state is powerless to resist corporate activities.

In terms of control over natural resources, our analysis shows a potentially grim picture for many of the currently powerful agricultural countries, including USA and Europe. In particular, European countries, including the United Kingdom, appear to be relatively poorly endowed in global terms with the critical natural resources used in agriculture – such as land, water, potassium, phosphate, oil and natural gas. This situation, especially the availability of water and energy, is likely to become worse because of the impacts of climate change. Although many of the emerging economies, like Brazil, China and Russia are better-placed in terms of water and energy endowments, some of these countries appear to be vulnerable in terms of their possession of agricultural land (more specifically, arable land) and critical minerals relative to their population size. This partly explains the much reported phenomenon of 'land-grabbing' in Africa, in which some major EU countries have also taken part (Friis & Reenberg, 2010).

Three key implications can be drawn from these findings for agriculture worldwide:

- There will be increased competition for available land and resources which is likely to result in significant upward shifts in the prices of these resources.
- In the shorter term, further improvements in resource use efficiency (water, fertiliser and energy) are needed to sustain current levels of production.
- As traditional resources become scarcer, alternative practices will need to be developed and adopted.

Finally, Table 2 attempts to pull together the various dimensions of power that have been discussed into a power index. The index is simply constructed by ranking each country/region on a scale of 1 to 5 for the individual components of power discussed within this report. For example, agricultural trade comprises an average of the ranking for the role in exports and imports (treated equally), whilst natural is an average of the score for land availability (both total and arable), population and water[14]. It is of course an imprecise science but the findings support the general conclusions of the previous chapters.

As might be expected the US and the EU top the power index by some margin. However, the index does highlight their potential vulnerability in terms of natural resources (key agricultural minerals and oil) moving forward. On the other hand the emerging countries at the moment have lower political and corporate power but seem better placed in terms of natural and mineral resources.

One aspect of the index that requires further clarification is the relationship between corporate power and the power index. Our approach has been predicated on the assumption that those countries/regions with a predominance of TNCs are more powerful. Implicitly this suggests that they confer power on a country. Whilst this is our view we accept that there are other ways of viewing this relationship. For example whilst TNCs may well locate in countries with economic and political power they are not necessarily the determinants of that power. In addition, it could be argued that due to their size and power, a predominance of TNCs may in fact be a challenge to the power of the state and this may not always be to the advantage of the agricultural sector.

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Md. Mofakkarul Islam. Dr Islam's background is in international agricultural development and innovation studies. Prior to joining the SAC he taught at Bangladesh Agricultural University and studied at Massey University in New Zealand where he obtained his PhD degree. Dr Islam has worked in a number of policy-oriented international agricultural R&D projects funded by DFID, World Bank, and Japan International Cooperation Agency. His current research activities include UK farmers' perception of climate change, and barriers to the uptake of agricultural innovations in the European context.

[14] The power index was constructed by combining all the information in the report. For each power dimension the individual power components (e.g. imports and exports for 'Trade' or water, total land, arable land and population for 'Natural') were scored on a scale of 0 to 5 for each country / region. The score was allocated by the research team after consideration of the evidence, where 5 meant considerable power and zero meant effectively no power. These individual components of the power dimension were then averaged to populate the table.

Steven Thomson is a researcher within the Land Economy and Environment Group and has worked at SAC for 18 years. He is widely experienced in undertaking research, consultancy and education on a wide range of agricultural and rural economy issues. He has considerable experience in the evaluation of impacts of agricultural policy at farm level and on wider rural areas. He has conducted work for EU, UK and Scottish governments and also for a wide variety of governmental agencies and NGOs in the UK.

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REFEREED ARTICLE

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Farm economics behind the evolution of Chinese rapeseed production

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ABSTRACT

In recent years Chinese rapeseed production has undergone significant changes. In order to explain this evolution, this article focuses on analyzing gross margin ratios and labour cost for rapeseed and wheat which is found to be the major competing crop from a grower's perspective. An econometric model applied to economic data from four main Chinese rapeseed producing provinces provides limited evidence that farm level economics play a role in grower's decision making: an increase in the gross margin ratio by 1% causes the share of rapeseed acreage in the subsequent year to go up by 0.09%; a 1% increase in the relative labour input leads to a reduction in rapeseed acreage by 0.45%. However, results also indicate that grower's decision making regarding cropping pattern is driven by other non-economic factors as well.

KEYWORDS: Rapeseed; China; cropping pattern; gross margin; labour input; log-log model

1. Introduction

Chinese agricultural markets have undergone significant changes in recent years. According to Lu (2002) especially the opening of markets in deficit regions as well as the decentralization of political responsibilities have to be mentioned. However, as reported by Gale (2009) there still significant policy intervention in place. This regards – among others – the so-called governors responsibility for grain production which means many governors have to make sure that grain production is in balance with provincial demand. Furthermore, local government authorities sometimes issue directives or subsidies to increase production of certain crops. Against this background the question arises to what degree farmers cropping decisions are driven by economic forces or by policy interventions.

As will be explained in greater detail below, Chinese rapeseed production has undergone some significant changes in recent years. Therefore rapeseed production seems to be an interesting case to analyze the relevance of economic incentives as driving forces of that change.

Rapeseed is a widely used, high economic value oil-bearing crop in China. It is the second largest oil-bearing crop in China (Statistical Yearbook 2008, p. 12–14). From the eighties of the last century, Chinese rapeseed production developed rapidly (Fu et al. 2003). Chinese rapeseed acreage and output ranked first in the world from 1985 onwards, it accounted for about 30% of the world's total rapeseed acreage and production (Wang, 2004). With more than 6 million hectares under rapeseed, the Yangtze River valley makes up about 85% of total Chinese rapeseed acreage (Qi et al. 2004). This region includes the provinces Hubei, Anhui, Jiangsu and Sichuan (see Figure 1). At the same time, these provinces happen to be the most developed regions in China.

There are two distinct cultivation methods in Chinese rapeseed production: 70% of the acreage is cultivated by transplanting small plants which have been pre-grown in small plots while only 30% of the acreage is direct seeded. In addition, harvesting is done predominantly by hand labour. By the end of 2007, only 6% of the whole rapeseed acreage was harvested by machines (Zong et al. 2008). Hence, calculations from Yang et al. (2003) indicate that about 60% of total cost in Chinese rapeseed production is labour cost. In China, rapeseed is produced as a spring crop as well as a winter crop. However, with a share of about 90% in acreage, winter rapeseed is by far the most important variant of the crop.

At the same time, China is a major global rapeseed producer as well as a major rapeseed consumer. Despite this importance of rapeseed, in recent years a significant reduction in acreage of this crop has occurred. Hence the question arises, what factors are driving this development and under what conditions the development can be reversed. Given the wide-spread assumption in Western Countries that politicians still have a strong impact on economic decisions in China the question arises, to what degree are farm level decisions driven by farm level economics. There is quite some literature available on the supply response of growers regarding price signals (Mohan, 1989; Gun, 1993; Edwin, 2008). In more applied approaches wheat supply in Pakistan is found to be significantly influenced by product prices (Khalid, 2003). Some literature on supply response also indicates that the response to price incentives is much weaker (Mythili, 2006). Some authors even suggest that non-price factors seem to dominate

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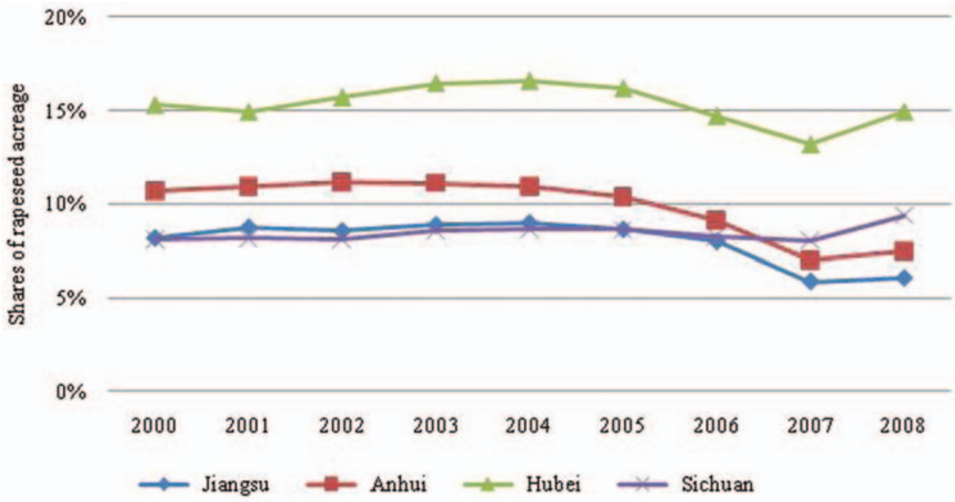

Figure 1: Shares of rapeseed acreage in four Chinese provinces
Sources: China Statistical Yearbook & own calculations

growers' decisions (Askari and Cummings, 1976; Gulati and Kelly, 1999).

This study attempts to use economic data in order to explain the change of rapeseed acreage over time. More specifically, it tries to explain these changes in land use patterns by analyzing gross margins and labour cost for rapeseed production and other major competing crops. Should gross margins for rapeseed production have been significantly and consistently lower than for other arable crops, the decrease of rapeseed acreage and production would be in line with economic theory.

With the lasting overall economic growth of China an increasing demand for labour has been created and the key sector of the economy which is able to provide such additional labour force is the agricultural sector. The booming industry outside agriculture is able to pay relatively high wages, which is why many former farmers decide to quit farming – at least temporarily. However, at the same time agriculture in most parts of China is still a very labour intensive industry. Hence, crops with a specifically high labour input will suffer from an increase in opportunity cost for family labour in particular.

Firstly, the major trends in rapeseed production in terms of acreage, yields per hectare and key production regions are described. Furthermore, statistical data as well as information about production systems applied in key rapeseed production regions are analyzed in order to identify crops which directly compete with rapeseed. Subsequently, the next chapter is devoted to data for gross margins realized in rapeseed and the competing crops as well as data about labour input and labour cost. Based on that, results of statistical and econometric calculations are presented in that part of the study and some key conclusions will be drawn. Finally, a summary of the paper is presented.

2. Evolution of rapeseed acreage and production in China

In China, rapeseed is one of the major crops together with rice, corn, wheat and soybean. At present, in addition to Beijing, Tianjin, Liaoning and Hainan, rapeseed is planted in 27 other provinces or regions.

Winter rapeseed areas include North China, Guanzhong the middle and lower parts of the Yangtze River region which mainly consists of the provinces Jiangsu, Anhui, Hubei and Sichuan. Furthermore, rapeseed is grown on the Yunnan-Guizhou Plateau and in the southern coastal areas. Spring rapeseed is mainly grown in China's western plateau comprising the provinces Qinghai, Inner Mongolia, Gansu and Xinjiang. Significant acreage in spring rapeseed can also be found in the northwest of China.

In 2008 there was a total acreage of 6.5 million ha in rapeseed. Out of this, the four most important provinces Hubei, Anhui, Jiangsu and Sichuan, which are all located in the Yangtze River Basin, accounted for around 50% of the entire Chinese rapeseed acreage. In order to be able to focus on the hot spots, the subsequent analysis will look at these four provinces. Their rapeseed acreage was in the range of 2.7 to 3.7 million ha from 2000 to 2008. In 2006 this acreage dropped off by 2.4% compared to 2005 and in 2007 another decrease of 6.2% occurred. However a modest increase occurred in 2008. Despite this significant reduction, the rapeseed acreage of these provinces always accounted for about half of total rapeseed acreage during the previous nine years (see Table 1).

As can be seen in Table 1, this continuity in the share of the key regions is caused by the fact that national cropping in rapeseed went down from 7,3 million ha in 2004 to 5,6 million ha in 2007 which means a decrease by about 23%. In 2008 rapeseed acreage grew by 16% although absolute figures were still significantly below 2000 to 2005 levels. Initially, the share of rapeseed acreage in each of the key provinces steadily increased from 2000 to 2004, but there was a decline after 2004, especially in 2006 and 2007. Due to an increase in rapeseed acreage in 2008 the share of this crop also went up again. Figure 1 shows the evolution of the individual trends of the provinces: In Hubei the share of rapeseed acreage in the total acreage is the highest of the four main producing provinces, reaching almost 17% in the peak season 2004. Although the share declined over the

Table 1: Rapeseed acreage of the four main provinces (1,000 ha)

	2000	2001	2002	2003	2004	2005	2006	2007	2008
Jiangsu	651	681	668	683	690	661	609	434	454
Anhui	965	953	1,002	1,015	1,003	954	836	620	670
Hubei	1,159	1,118	1,155	1,175	1,186	1,179	1,081	927	1,090
Sichuan	777	780	773	806	814	817	797	747	886
Sub-Total	3,551	3,532	3,599	3,678	3,694	3,610	3,323	2,729	3,101
National	7,494	7,095	7,143	7,221	7,271	7,278	5,984	5,642	6,594
Share	47%	50%	50%	51%	51%	50%	56%	48%	47%

Sources: China Statistical Yearbook & own calculations

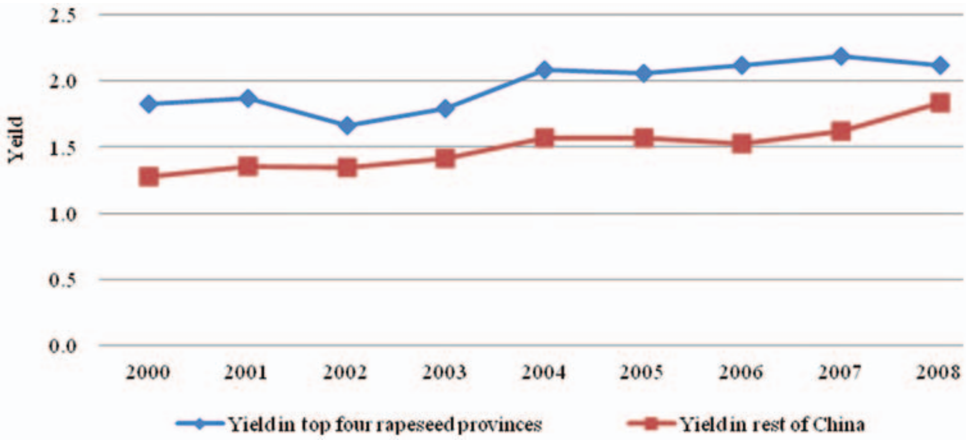

Figure 2: Average rapeseed yields in four provinces and the rest of China (t/ha)
Sources: China Statistical Yearbook & own calculations

past few years, rapeseed still accounts for about 13% of total acreage of Hubei and therefore remains the highest proportion in the four provinces. In Anhui the share of rapeseed acreage was almost stable from 2000 to 2005, but it decreased sharply to the lowest point in 2007. Sichuan evolved differently because here from 2000 to 2007 the share of rapeseed acreage was almost flat at around 8% to 9%. In Jiangsu a similar situation can be found, only in 2007 the acreage was reduced significantly. From Figure 1 it appears that regions with a relatively high share initially experienced a sharp decline after 2004 while regions with only lower shares in the beginning of the period analyzed here where either stable or just saw a moderate decline.

Between 2000 and 2007 rapeseed yields continuously increased with an annual growth rate of about 3.1%. In 2008, a slight drop in the four main provinces occurred (see Figure 2). With yields of about 2.5 t/ha, farmers in Jiangsu have been the most productive. In the other three provinces yields only reached a level of about 1.9 to 2 t/ha (see Table 2). However, since in these regions initial yields in 2000 were lower compared to Jiangsu the growth rate was still significant.

From Figure 2 it can be concluded that in the period examined, the growth in yields was fairly constant. The growth outside the leading regions was slightly lower but also significant. Hence, it seems likely that there is room for further growth in yields. This is even more likely because in other parts of the world, for instance in Europe, it is well known that rapeseed – provided climatic conditions and agronomical treatment are adequate – offers much higher yields in the range of 3 to 4 t/ha or more. Of course such a development will only occur with high yielding varieties and optimized farming practices, including access to modern plant protection inputs.

In the main rapeseed producing provinces, farmers plant rapeseed between the beginning of September and early October. They harvest in late April and early May of the next year. Wheat has basically the same season as rapeseed. As regards cotton, its growth cycle is from April to September. After the harvest of winter crops

Table 2: Rapeseed yields in main production provinces (t/ha)

Yield	2000	2001	2002	2003	2004	2005	2006	2007	2008
Jiangsu	2.20	2.14	1.96	2.13	2.43	2.40	2.45	2.52	2.48
Anhui	1.63	1.87	1.52	1.51	1.90	1.91	1.98	2.10	2.09
Hubei	1.71	1.74	1.31	1.59	1.98	1.86	1.92	2.09	1.97
Sichuan	1.77	1.71	1.87	1.93	2.03	2.07	2.12	2.04	2.14
Average of 4 provinces	1.83	1.87	1.67	1.79	2.09	2.06	2.12	2.19	2.12
Average China	1.52	1.60	1.48	1.58	1.81	1.79	1.83	1.87	1.84

Sources: China Statistical Yearbook & own calculations

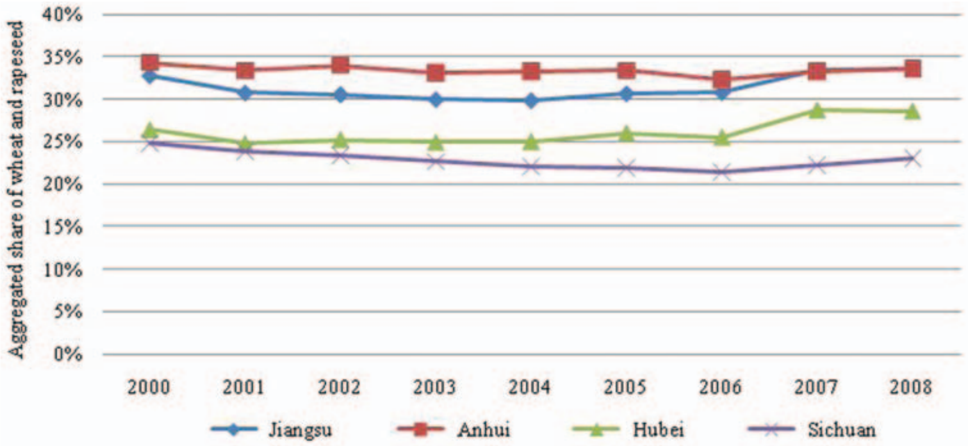

Figure 3: Aggregated share of wheat and rapeseed acreage in total arable land
Sources: China Statistical Yearbook & own calculations

such as wheat or rapeseed, in July or August, farmers usually plant their fields with soybeans, which normally are harvested in November. In the regions considered here, most farmers apply transplantation of rapeseed to make full use of land. That means they use a small part of their field for a very high density seeding in order to get the plants started. Once they have reached a certain growth stage and the previous crop has been harvested, the small seedlings are transplanted to the field at a conventional density.

Based on this information, from a grower's perspective wheat is the most suitable alternative to rapeseed because the growing season is very similar. Consequently, wheat qualifies for the use as the benchmark for the economic analysis of the competitiveness of rapeseed. The hypothesis of wheat being the most likely alternative to rapeseed from an agronomic perspective can be further tested by looking at the evolution of the acreage for the two crops. Since they are really close substitutes, any increase in the acreage of one of the crops should go hand in hand with a decrease in the other – and vice versa. A respective figure has been generated in which the acreage of both crops has been added (see Figure 3). What shows up is that the total acreage of the two crops is almost flat in all provinces. Since we know from Figure 2 that rapeseed acreage went down significantly from 2004 onwards, it can be assumed that indeed both crops are most likely close substitutes.

As demonstrated in the above, a significant change in Chinese cropping patterns took place as far as key areas for rapeseed production are concerned. Furthermore it has been shown that rapeseed and wheat are close substitutes in terms of production systems in the respective provinces. Therefore it is appropriate to use wheat as a benchmark in order to explore the hypothesis of diminishing economic competitiveness of rapeseed as the main reason for the decrease in its acreage.

3. Economic data to explain changes in Chinese rapeseed acreage

As mentioned in the introduction, figures about regional gross margins and regional labour cost as key farm level economic parameters will be used to explain the observed change in cropping patterns in the key rapeseed producing regions. This next chapter deals with this analytical step.

The impact of labour cost

As a first step, the number of hours used in order to produce one hectare of rapeseed and wheat respectively is analyzed. Since the relative importance of labour input for the two crops is of relevance, a ratio has been calculated by using the labour input for wheat as the standard. Hence, the number of hours spent in rapeseed has been divided by the hours spent in wheat. In Figure 4, bars above 1 indicate a higher labour input in rapeseed compared to wheat. As can be seen in this graph, except for one year in the Hubei province and the Sichuan province, all ratios have been higher than one in all provinces all the years analyzed in this article. The very high ratios in the Jiangsu province can be explained by the fact that in this province mechanization of wheat production is much higher than in the other provinces in this comparison. Consequently the labour input is lower in wheat and hence the ratio increases.

The systematic difference in labour input between the two crops is caused by differences in mechanization. Pre-seeding and transplanting of seedlings is obviously a very labour intensive exercise. At the same time there is no transplanting in wheat. Since we intend to explain a change of cropping patterns over time, the simple difference in labour input cannot be a cause because this disadvantage of rapeseed production relative to wheat has been in place from the beginning. However, in case the economic value of this difference in working hours increased over time, it seems reasonable to assume that the increasing difference in labour cost has caused farmers to move away from rapeseed cultivation.

As can be seen in Figure 5, wage rates in rural areas did indeed increase significantly from 1.2 US$/day[3] in 2000 to 3.1 US$/day in 2008. This change equals more than 150%. Only the smaller part of that increase in US$ terms is caused by the depreciation of the US$ relative to the Yuan: Expressed in national currency, wage rates went up roughly 100%. It should be noted that the

[3] In early October US$1 was approximately equivalent to £0.62 and €0.77 (www.xe.com).

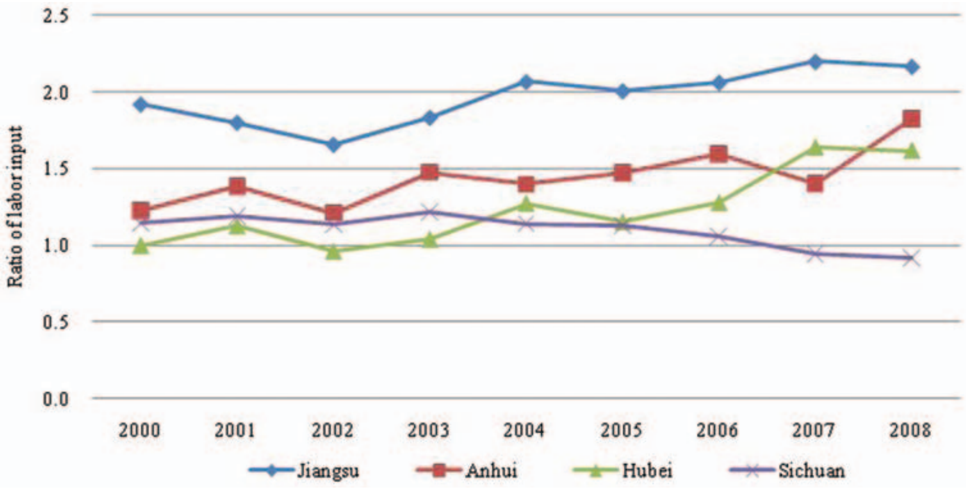

Figure 4: Ratio of labour input in rapeseed production relative to wheat
Sources: Compilation of National Cost-Benefit Data of Farm Products & own calculations

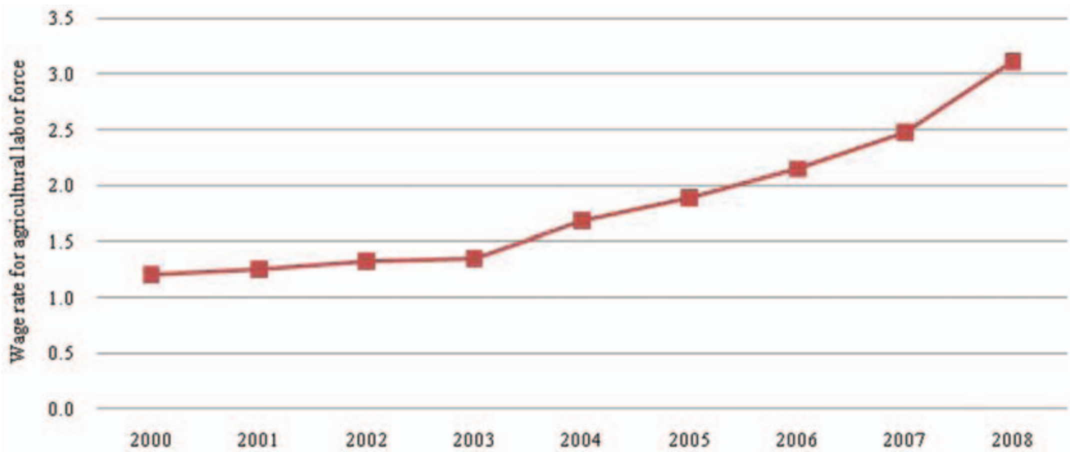

Figure 5: Wage rate for agricultural labour force (US$/day)
Sources: Compilation of National Cost-Benefit Data of Farm Products & own calculations

decrease of rapeseed acreage started in 2004 – exactly the same period in which a particularly sharp increase in wage rates occurred: More than 90% of the entire increase in wage rates took place from 2003 onwards. Based on this information, it seem very likely that increasing opportunity cost has caused farmers to move away from a rather labour intensive crop such as rapeseed to a less labour demanding one such as wheat.

The impact of gross margin changes

Besides changes in labour cost, the evolution in gross margins could be a driving force for changes in cropping patterns. The gross margin (defined as gross revenue minus direct operating inputs which include cost of fertilizer, plant protection, and contractors) are displayed in Figure 6 for both crops and each of the regions analyzed.

Over time a steep increase in gross margins took place for both, rapeseed and wheat grown in all regions analyzed. Values went from 200 US$/ha in 2000 to 1,000 US$/ha and more in 2008.

From 2001 and 2002 respectively onwards wheat gross margins tend to be as high as or even higher than rapeseed gross margins in most of the cases.

In 2007 - and even more pronounced in 2008 - a strong rebound of rapeseed gross margins occurred.

4. Specification of an econometric model and results

Model

As explained above, economic theory suggests that farmer's decision regarding cropping patterns are driven by the incentive to maximize profits from the scarcest factor, which is land. Under the assumption that there is no major difference between different crops in terms of machinery and labour inputs required, gross margins are considered to be a reliable proxy for profitability of land use. As long as it can be assumed that crop production in general is profitable – resulting in a more or less stable total land use – it is not the absolute value of gross margins that matter but rather the ratio. Changes in relative profitability of crops will ultimately lead to changes in cropping patterns; hence the ratio between gross margin for wheat and rapeseed (GMR) is used as one independent variable. The expectation is that the higher (lower) the value of 'GMR', the higher (lower) the competitive position of rapeseed relative to

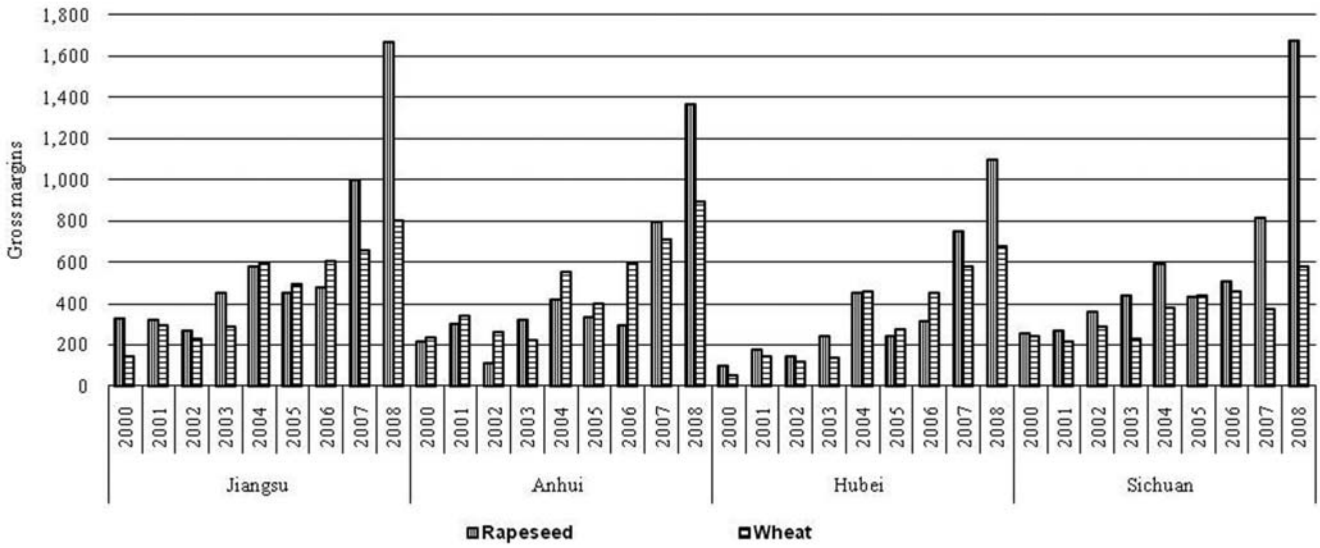

Figure 6: Evolution of gross margins from Rapeseed and Wheat in four key provinces (US$/ha)
Sources: Compilation of National Cost-Benefit Data of Farm Products & own calculations

wheat. A low (high) competitive position of rapeseed will lead to a decrease in the share of rapeseed in total acreage (CR).

Since there is strong evidence that the assumption regarding uniform non-cash cost across relevant crops is not true at all, the differences in labour input and respective cost have to be taken into account. In an ideal situation differences in labour cost would be used to set up an econometric model. However, there is no such data available for a broad range of farms in key rapeseed producing regions of China. And since the majority of farms use family labour, there is no easy access to labour cost anyhow. Therefore the model uses the ratio between labour input in rapeseed and in wheat (LIR) as a proxy for differences in labour cost. The economic hypothesis is that the higher (lower) the ratio the lower (higher) the incentive to grow rapeseed relative to wheat.

Against this background the econometric model is specified by using the log-log regression model. $\log(CR)=\alpha+\beta\log(GMR)+\gamma\log(LIR)+\varepsilon$. Where CR is the share of rapeseed acreage in the total acreage, GMR is gross margin of rapeseed/gross margin of wheat, LIR is ratio of labour input in rapeseed production relative to wheat production, α is intercept coefficient, β and γ are slope coefficients, and ε is the error term. In order to reduce the effect of co-linearity, a double logarithmic model is used.

Due to the lack of relevant future markets the growers' decision making process is most likely described best as a 'naive expectation behaviour' (Wang Q. 2011): Crop profitability in a given year is used as an indicator for profitability of crops in the following year. Therefore the model is using t-1 values to explain CR_t data.

Data

The subsequent analysis is based on data from the following sources: 1) *China Statistical Yearbook* (Zhongguo Tongji Nianjian) from 2001 to 2008, edited by National Bureau of Statistics of China. 2) *National Compilation Cost-Benefit Data of Farm Products* (Quanguo Nongchanpin Chenben Shouyi Ziliao Huibian) from 2001 to 2009, edited by National Development and Reform Commission People's Republic of China . These data have been generated by price monitoring authorities at all national levels and the National Operating Department. This department surveyed about 1,500 counties in which 60,000 farmers have been interviewed in total.

Since panel data are used in this model it has to be tested for random effects. Panel data models are based on the assumption that random effects are uncorrelated with the explanatory variables. One method for testing this assumption is to employ a Hausman (1978) test to compare the fixed and random effects of coefficients (Software used: E-Views). The probability is 0.96 which is well above the 0.1 threshold, consequently statistics provide evidence to accept the null hypothesis that there are correlated random effects (see table 3).

Results

Results in Table 4 suggest only limited evidence for the hypothesis that gross margin ratios and labour input ratios have an impact on rapeseed production in the top four rapeseed producing Chinese provinces. While the impact of the labour input ratio is significant on a 5% level the gross margin ratio impact is statistically not significant. Moreover, the low R^2 for the gross margin ration has to be mentioned; it indicates that other factors than those measure here influence growers decision. However, the magnitudes as well as the signs

Table 3: Correlated Random Effects - Hausman Test

Test cross-section random effects			
	Chi-Sq. Statistic	Chi-Sq. d.f.	Prob.
Test Summary Cross-section random	0.084	2	0.96

Table 4: Pooled EGLS (Cross-section weights) Parameter estimates for share of rapeseed in selected provinces.

Variable	Coefficient	t-Statistic
Constant	2.44	10.22***
$\log(GMR_{t-1})$	0.09	1.31
$\log(LIR_t)$	−0.45	−2.63 **
Random Effects (Cross)		
JS_C	−0.09	
AH_C	0.01	
HB_C	0.37	
SC_C	−0.29	
R^2	0.27	

Sources: Own calculations. ***, ** and * represent statistical significance at 1%, 5% and 10% level respectively. JS, AH, HB and SC are abbreviations for Jiangsu, Anhui, Hubei and Sichuan province.

of the estimated parameters make economic sense: (a) an increase in the gross margin ratio by 1% causes the share of rapeseed acreage in the subsequent year to go up by 0.09%. (b) An increase in the relative labour input in rapeseed compared to wheat by 1% in a given year will cause a reduction of the share of rapeseed acreage in the subsequent year by 0.45%.

The lack of statistical significance of gross margin ratios may be caused by the fact that the hypotheses that previous gross margin ratios influence growers cropping decisions in the subsequent year is too simple. Alternatively a possible explanation is that grower's decisions are to a large degree caused by non-economic factors. The strong impact of relative labour input does match with the fact that current production systems in rapeseed are rather labour intensive and at the same time opportunity cost for growers went up significantly. According to the eleventh National People's Congress at the fifth meeting of the government work report (2012), more than 36% of Chinese growers are working also outside the agricultural sector.

5. Summary and conclusions

Statistical data show that Chinese rapeseed production is not only important in terms of acreage but is also rather concentrated: Only the four provinces Hubei, Anhui, Jiangsu and Sichuan account for more than 50% of the entire rapeseed production. Furthermore a significant and more or less uniform decrease in rapeseed acreage from 2004 to 2007 can be detected. Only in 2008 a limited recovery in rapeseed production was realized.

In order to explain said evolution, driving factors for microeconomic decision making at farm level are tested as a main cause. In a first step the relevant alternative crop from an agronomic perspective is defined, which happens to be wheat. Since on Chinese smallholder farms labour input is much higher for rapeseed compared to wheat and opportunity cost for labour increased significantly in previous years, labour cost can be seen as a driving factor for the decrease in rapeseed acreage.

The specified regression model provides only limited evidence for the suggested impact of changes in the gross margin ratio while of the impact of labour input ratios on the share of rapeseed acreage turned out to be significant. However, the signs of both estimated parameters do make economic sense.

Based on the data available, it seems reasonable to assume that Chinese smallholders' decision making – even though heavily influenced by the grain regulation polices of the state – is also driven by labour cost. Furthermore, it seems likely that wage rates for migrant workers are a realistic proxy for the opportunity cost of family labour in the regions analyzed.

In turn that means that Chinese rapeseed production not only needs higher yielding rapeseed varieties and/or higher rapeseed prices relative to wheat, but also less labour intensive seeding technologies in order to return to former levels of acreage. Whether the relatively strong growth in rapeseed yields which have been realized in the past and improving mechanization of rapeseed will continue and hence eventually offset some of the recent economic shortcomings of rapeseed production as analyzed here, remains to be seen.

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Does the single farm payment affect farmers' behaviour? A macro and micro analysis

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ABSTRACT

Using Ireland as a case study, the overall aim of this paper is to determine if decoupled payments affect farmers' behaviour. Using a dynamic, multi product, partial equilibrium model of the EU agricultural sector, this paper first compares levels of production that would be expected if decoupled payments had no impact on farmers' activity with actual observed outcomes. Second this paper compares cereal and cattle farmers' profitability prior to decoupling with that observed after the introduction of decoupled payments. The analysis presented here would suggest that decoupled payments do still maintain a significant effect on agricultural activity with farmers using this new form of support to partly subsidise unprofitable farm production.

KEYWORDS: single farm payment; CAP; farming attitudes; farmers' behaviour

1. Introduction

European agricultural policy underwent significant changes with the Mid-Term Review (MTR) of the Common Agricultural Policy (CAP) in 2003, where with some exceptions, member states agreed to implement a system of single farm payments (SFP) which were decoupled from production. Decoupled payments were introduced in order to curb over-production and to reduce the trade-distorting and inefficiency effects of the CAP (Falconer and Ward, 2000; Swinbank and Daugbjerg, 2006). These payments were defined in the Uruguay Round Agreement on Agriculture (URAA) as payments that are financed by taxpayers rather than by consumers, are not related to current production, factor use or prices and for which the eligibility criteria are defined by a fixed historical base period, whereby actual production is not needed to receive payments. Decoupled payments are in the World Trade Organisations (WTO) 'green box' of agriculture related subsidies and thus must adhere to the fundamental requirement that the policy has no, or at most minimal, trade-distorting effects (Swinbank and Tranter, 2005). That said, it is often argued that decoupled payments could still have an impact on farmers' behaviour due to factors such as risk aversion, wealth effects and also the presence of non-pecuniary benefits associated with farm work (Bhaskar and Beghin, 2009 and O Donoghue and Whitaker, 2010).

To determine if decoupled payments do in fact affect farmers behaviour, this paper using a dynamic, multi product, partial equilibrium model of the EU agricultural sector will first compare projections of agricultural activity that we would expect to observe if decoupled payments did not affect farm activity with what was actually observed since the introduction of full decoupling in Ireland in 2005. With the introduction of full decoupling in Ireland a single farm payment is made to farmers based on payments they received in a historical reference period (2000–2002 inclusive). Second, this paper uses data from a National Farm Survey (NFS) collected as part of the Farm Accountancy Data Network of Europe (FADN) to examine the profitability of cattle and cereal farms as these were the sectors that were most reliant on coupled payments in Ireland. Specifically we examine the level of production on cattle and cereal farms that earns a positive market-based net margin.

In a European context, previous research (such as Hennessy and Thorne, 2005; Gorton et al., 2006 and Lobley and Butler, (2010)) examined future farmer intentions in the light of changes in policy such as the move towards decoupling. This research highlighted that farmers planned to make very little change to their farming activities post decoupling. However, as Tranter et al. (2007) notes there might be a difference in how farmers say they will react to a hypothetical change in policy as opposed to how they act in reality when that policy measure is in force. This paper should, therefore, provide a more reliable guide to short term decision making in the wake of the 2003 CAP reform by comparing levels of production that would be expected if decoupled payments had no impact on production with actual observed behaviour. In terms of overall structure this paper will in the following section explore

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previous literature relating to the impact of decoupling of farm support measures on agricultural activity. Next a description of the modelling framework used in this analysis is provided. This is followed with a discussion of the empirical results. Finally this paper concludes with a discussion of its major findings and their implications for agricultural policy.

2. Background: The effect of decoupled payments on production

The European Commission has declared that decoupled payments fall under the World Trade Organisations (WTO) category of 'green box' subsidies that result in none, or at most, minimal trade distortions of agricultural markets. Previous research has shown that the new CAP mechanisms will result in a significant reduction of gross profit margins in comparison to the previous support system and an associated risk of activity cessation (Onate et al., 2007). As production is not needed to receive subsidies, the recent policy reform could therefore potentially lead to land abandonment particularly in marginal rural areas (Osterburg and van Horn, 2006). However, it has also been reported that the actual effect is unlikely to be as drastic as farmers engage in production for non-economic as well as economic motivations. That is, in contrast to 'homo-economicus' strategies which assume that farmers behave absolutely rationally and only have profit-maximisation in mind, there are likely to be a variety of non-monetary benefits from farming that can influence their activities (Kantelhardt, 2006; Key and Roberts, 2009).

Increasingly research, for instance, has demonstrated that farming may be a vocation that may be valued in itself (Ackerman, et al., 1989; Herrmann and Uttitz, 1990; Willock et at. 1999a; 1999b). Vanclay (2004) asserts that farmers seek to make a reasonable income with each farmer defining what is reasonable for themselves and that the additional lifestyle factors associated with farming compensate farmers for those times when income may be less that what they could achieve in other endeavours. Key and Roberts (2009) and Key (2005) describe how attributes associated with farming such as independence and pride associated with business ownership are valuable to farmers and these attributes may not be observable in other types of employment. Outside of agriculture it has been widely reported that the self employed, all things being equal, report much greater levels of satisfaction with their jobs (Hamilton, 2000). The variety of non-pecuniary benefits associated with farming mean that farmers may have an incentive to use decoupled payments as a means of maintaining a farming lifestyle irrespective of any financial returns.

A number of other arguments for the supply inducing effect of decoupled payments have also been advanced. For example Tielu and Roberts (1998) and Hennessy (1998) assert that decoupled payments distort production by increasing a farm operator's overall wealth. The argument here is that with increased income from these risk free decoupled payments, farmers can more easily invest in their farm operation as their overall risk exposure is decreased thus increasing production. Furthermore, farmers with higher guaranteed incomes are more likely to be granted access to capital and this increase in capital availability may also facilitate agricultural production. One additional reported potential impact of decoupled payments is that the increase in wealth may decrease a farmers risk aversion, consequently making farmers more likely to engage in certain production activities that otherwise they may not have made. Finally farmers may use decoupled payments to increase production as a result of expectations that future payments will be reassessed and based on current production levels (Coble et al., 2008; O Donoghue and Whitaker, 2010).

To date, previous research at least from a European perspective, concerned with determining if decoupled payments affect farmers' behaviour has been limited. This is because the recent reform represents such a new and radical policy shift that no previous experience exists with its application and, in addition, its application in the EU has been gradual. The work that does exist in this area has generally examined farmers' intentions in the light of the introduction of decoupled payments. Hennessy and Thorne (2005) compared survey data on farmers production plans post decoupling with outputs predicted by a farm-level profit maximisation model. In this study it was shown that a significant number of farmers plan to use their decoupled payments to continue or expand non-viable production. Similarly in a study of the UK dairy sector, Colman and Harvey (2004) outline how many farmers are determined to remain in farming despite low returns. They report that given the stated commitment of a majority of dairy producers to continue and even expand production, it seems likely that they will treat their direct payments as coupled in order to achieve their ambitions. Likewise Tranter et al. (2007) in a survey of farmers in Germany, Portugal and the UK found that only 30% stated they would alter their mix of activities in response to decoupling.

Gorton et al. (2008) examined farmers' attitudes towards agricultural production and policy support in the context of the 2003 CAP reform among five Member States in the EU. They note that while agricultural policy has shifted from one focused on maximizing production to more decoupled forms of payment, there is little evidence that farmers' attitudes have also adjusted. The study highlighted how farmers still overwhelmingly retain a productivist mindset and reject the idea that they can be competitive without the aid of policy support. In addition, farmers expressed preferences for the full utilization of agricultural land for agricultural production and wished to concentrate on farming. Similarly, Lobley and Butler (2010) examined farmers' intentions following the implementation of the 2003 CAP reforms. The study which was based on a large sample survey of farmers in the South West of England found that CAP reform is not stimulating rapid agricultural restructuring. Lobley and Butler (2010) notes that while the 2003 CAP reform agreement may have radically alerted the policy environment within which farmers operate there is little evidence that farmers are reacting in an equally radical manner. This mirrors earlier findings by Walford (2003) and Burton and Wilson (2006) who found that productivist tendencies prevail amongst English farmers.

3. Research Design

Twenty three teams from EU Member States as part of project called AGMEMOD funded under the European Commission 6th framework and by contributions from the partners institutes throughout the EU have built country level models that reflect the specific situation of the agricultural sectors in their individual country. The maintenance of analytical consistency is achieved via adherence to a common model template across all the partners involved in the model. In all country models, agricultural supply and use data as well as policy data for the years 1973–2005 have been collected. The CAP budget and national ceilings remain at the levels set out in Regulation EC 1782/2003. For each commodity modelled, and in each country, agricultural production as well as supply, demand, trade, stocks and domestic prices are derived by econometrically estimated equations.

The national level models have been combined into a composite EU model. Each country model contains the behavioural responses of economic agents to changes in prices, policy instruments and other exogenous variables. One element of the supply and demand balance (usually exports), for each commodity modelled, is derived as a closure variable to ensure that the supply and use identity holds for all EU markets throughout the projection period. This condition implies that production plus beginning stocks plus imports will always equal domestic use plus ending stocks plus exports (see figure 1 and figure 2 for a visual illustration of the structure of the AGMEMOD model).

A commodity country model is linked to the other countries through a price transmission relationship, where an EU key-price drives price formation in any domestic market. The EU key-price is usually set as the price observed in the most important national market within the EU for that commodity. In the key price country, the commodity model includes a price formation equation. This equation aims at capturing all exogenous variables affecting price formation within the EU and, in particular, the world market price, price policies (intervention prices, for instance), trade agreements, etc. In addition, the lagged EU self-sufficiency rate is also included as an explanatory variable, thus making the key-price recursively respond to the previous year's outcome. The key-price is then transmitted into any other domestic market such as Ireland, through a price transmission (or price linkage) equation that makes the domestic price a function of the EU key-price and other possible explanatory variables, e.g., the own country self sufficiency rate (or net exports) for that commodity.

Projections of exogenous data relating to macroeconomic series such as exchange rates and GDP taken from research institutions within each individual Member State have been incorporated into the model. In addition, projections of world prices from the Food and Agricultural Policy Research Institute (FAPRI) have been incorporated into the model structure. The development of specific country models has allowed for the capture of the inherent heterogeneity of agricultural systems existing within the EU, while simultaneously maintaining analytical consistency across the estimated country models. Within this

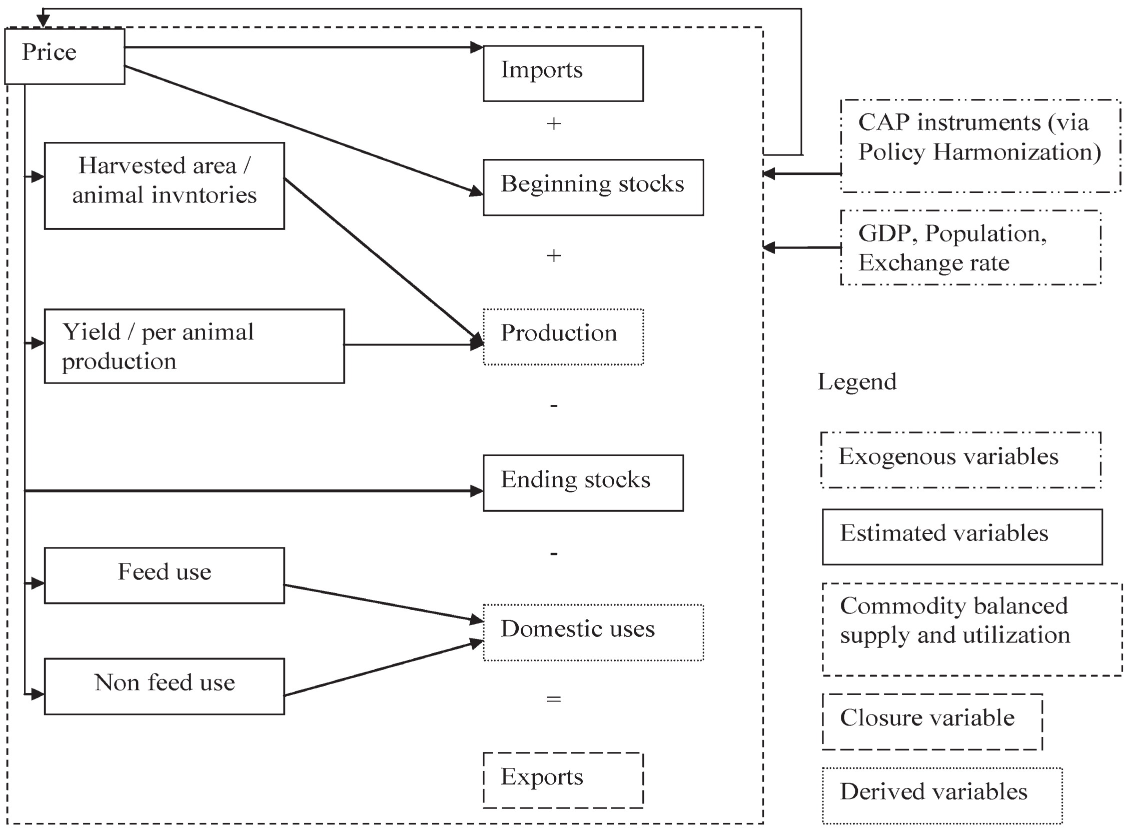

Figure 1: Commodity modelling structure

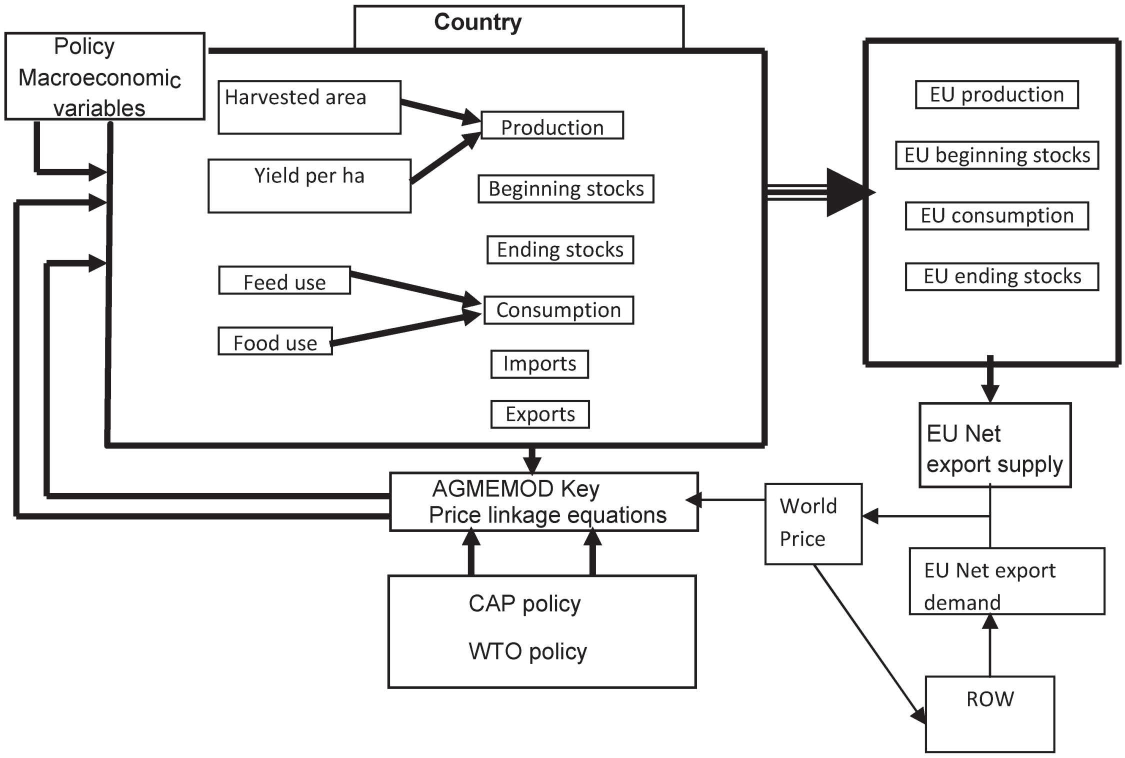

Figure 2: AGMEMOD combined model

combined model environment all EU prices, as well as all elements of agricultural commodity supply and demand in each member state, are modelled endogenously. Hence, the final dynamic, multi-market, multi-country, composite model developed, allows us to generate projections for each Member State, under the assumption of exogenous world prices[4].

In order to analyse the impact of policy reform, data on all of the different types of direct payments that are and were part of the CAP were collected for each member state. This was used to create a database which in a coherent manner across all the member states incorporated the total budgetary envelopes, the different types of the EU CAP direct support elements, and their allocation from the total budgetary envelopes. Using this policy data a set of country specific variables were developed which calculated the impact of policy instruments on the supply and use of various agricultural commodities. In particular, in the case of Ireland an adjusted gross return figure for grains and a reaction price for beef were calculated. In other words in the AGMEMOD modelling approach, all direct payments are recalculated as a policy price add-on to the relevant producer price to form a reaction price or expected gross returns. Thus, when entered into the model structure these variables will lead to responses by farmers that are analogous to farmers' responses to changes in agricultural output prices.

As discussed earlier, there are a variety of reasons why decoupled payments could still influence agricultural activity. The actual supply inducing effect of the reaction price for beef and adjusted gross return for grains can be altered in the model structure by multiplying them by a multiplier between 0 and 1. The closer the multiplier is to one then the greater are the assumed impacts of decoupled payments on production. For instance, setting the multiplier as equal to 1 assumes that the reaction price for beef which captures the effect of policy instruments on the beef sector has the same impact as output prices. Setting the multiplier as equal to 0 assumes that the reaction price does not have any impact on production (i.e. fully decoupled from production) which would be in keeping with its status as a green box policy.

Data from the NFS was also examined in order to ascertain the prevalence of loss-making cereal and cattle production amongst Irish farmers. The NFS is collected annually as part of the Farm Accountancy Data Network requirements of the European Union (Farm Accountancy Data Network (FADN), 2005). It determines the financial situation on Irish farms by measuring the level of gross output, costs, income, investment and indebtedness across the spectrum of farming systems and sizes and provides data on Irish farm income to the EU Commission in Brussels and a database for economic and rural development research and policy analysis. The sample is weighted to be representative of farming nationally across Ireland. In the 2006 NFS survey, 1,159 farmers were surveyed representing 113,068 farmers nationally.

4. Results

The following analysis aims to provide some guidance as to the actual impact of decoupled payments by comparing actual observed market data (CSO, 2009) with projections from the partial equilibrium (PE) model under the two different assumptions relating to

[4] For more details in relation to the structure of this model the reader is referred to Erjavec et al. (2006; 2011)

Table 1: Impact of decoupled payments 2005–2009

	2005	2006	2007	2008	2009	% change
Grain area harvested *(1,000 ha)*						
Zero coupling		258	247	244	244	−12
Actual area harvested	276	280	279	314	293	6
Full coupling		308	327	341	351	27
Suckler cows (1,000 head)						
Zero coupling		1132	1102	1060	1020	−11
Actual numbers	1150	1129	1117	1115	1069	−7
Full coupling		1168	1160	1136	1112	−3

the supply inducing impact of decoupled payments between 2005 and 2009. As can be seen in Table 1, the projected levels of grain area harvested for the years 2005–2009 under the zero coupling assumption are significantly below what was actually observed over this period. Under the assumption that decoupled payments maintain the same effect on farm behaviour as output prices the projections are significantly above that observed. With the exception of 2006 which was the first year post decoupling a similar situation is evident in relation to suckler cow numbers. In the model results, the extent to which the real figure for suckler cow numbers and grain area harvested is closer to the projected figure for full coupling or zero coupling depends in part on external developments in agricultural markets. For instance, a larger than expected increase in cereal prices in 2007 due to, among other things, an increase in biofuel demand and diminished supplies as a result of drought from major grain exporters such as Australia led to a larger than expected market return for the production of cereals. This resulted in a significant jump in the area harvested in 2008 to the extent that the actual area harvested in 2008 was closer to the full coupling scenario. By 2009 the actual figure for grain area harvested was much closer to the midpoint of these two scenarios as cereal prices had fallen back to pre 2007 levels. Therefore while we can see a clear path emerging whereby production is significantly above what would be expected if payments were in fact truly decoupled, suggesting that decoupled payments affect farm behaviour, it is not possible to precisely quantify this impact.

To provide a further illustration of the impact of decoupled payments on farmer's activity table 2 outlines the proportion of production in the cattle and cereal sectors that make a positive market based net margin post decoupling. The market based net margin is calculated as market based gross output less direct costs (such as concentrate feed costs and outside hired labour (farmers own labour is not included as a cost)) and the share of overhead costs attributable to the sector under examination. Market based gross output is simply sales less purchases plus any coupled premia payments that were in existence. It does not include decoupled payments. Focusing on the market based net margin allows us to examine the profitability of suckler cow and cereal production.

As shown in Table 2 even after assuming zero labour costs on the part of the principal farm operator less than 30 percent of suckler cows within the NFS for the five years examined are raised on farms, which earned a positive market-based net margin from cattle production. In relation to cereal production the proportion showing a positive market based net margin increased from 54 percent in 2006 to 88 percent in 2007. The proportion showing a positive market based net margin declined substantially in 2008 and 2009 and finally increased again in 2010. This variability is due to the considerable variation in cereal prices and the cost of cereal inputs, most notably the high prices recorded in 2007 and 2010 for cereals compared with the very low cereal prices of 2009. As we saw in table 1 the number of suckler cows fell by 7 percent between 2005 and 2009 whereas total cereal production increased by 6 percent during this period. If farmers treated decoupled payments as being 'truly' decoupled, then given the negative market farm incomes observed in table 2 it seems reasonable to expect much larger reductions in agricultural activity.

Table 2 also reports the proportion of cereal and suckler cow production that occurs on farms with a positive family farm income which includes all decoupled payments in its calculation. It can be seen that when decoupled payments and the returns to other farm activities are considered there would be a significant increase in the proportion of cereal and cattle production that would be on farms earning a positive family farm income. More specifically, under this scenario a total of 87 percent of suckler cow production in 2008 would be on farms earning a positive family farm income. A similar situation would be observable in relation to cereal production as 94 percent

Table 2: Proportion of production with a positive market based net margin 2006–2008

	2006	2007	2008	2009	2010
Suckler cows (%)	29.2	25.6	27.2	20.7	23.5
Suckler cows (% with a positive family farm income – includes the SFP as a component of farm income)	92	91.6	87	87.3	87.0
Grain area (%)	54.2	88.3	25.5	14.7	70.3
Grain area (% with a positive family farm income – includes the SFP as a component of farm income)	98.3	99.7	94.2	84.6	97.7

Source: National farm survey

Table 3: Proportion of cattle production with a positive market based net margin 2004 (Euro per hectare)

Adjusted Farm GM Quintile	Family farm income	Market Net Margin	Production FC	Other FC	Adjusted Farm Market GM	Subsidies	Has part time Job
1	−25	−500	100	276	−224	475	0.58
2	158	−269	77	262	−7	427	0.56
3	241	−136	64	202	66	377	0.44
4	380	−46	70	214	168	425	0.44
5	530	108	80	315	423	423	0.37
Total	253	−174	79	256	82	427	0.48

Source: National Farm Survey
Note: in late September 2012 €1 was approximately equivalent to US$1.29 and GB£0.80

of cereal production would be generating a positive family farm income, with figures of 98.3 and 99.7 percent in 2006 and 2007 respectively.

In table 3 and 4 we categorise cattle farms and cereal farms by quintile in the year just before the introduction of decoupling. Here farms are broken into groups according to their level of adjusted gross margin which is simply market net margin less all coupled and decoupled payments and any non production related fixed costs such as depreciation, maintenance costs and interest payments etc. First it can be seen that farms within each quintile group in the cereal sector had on average positive family farm incomes (market net margin plus subsidy payments). Interestingly, cattle farmers in the bottom quintile had on average negative family farm incomes. We can see, therefore, that even prior to the introduction of decoupled payments a significant proportion of cattle farmers albeit to a much smaller extent than presently were using non-farm income to subsidise loss making agricultural production.

When we calculate market net margin which excludes subsidy payments such as the special beef premium, only the top two quintiles in relation to the cereal sector and the top quintile in relation to the cattle systems make an average positive market return. This highlights the large dependency of farmers on subsidy payments to make profits prior to the introduction of decoupling. As illustrated in table 2 even though these payments are since 2005 not linked to production (save for some cross compliance obligations) farmers still rely on these supports in order to subsidise what would otherwise be loss making agricultural activity. Table 3 and 4 also reports the proportion of farmers with an off-farm job in each quintile. We can see a trend whereby the farms in the lowest quintiles have the largest proportion of farmers with off-farm jobs. For instance, 58 and 72 percent of cattle and cereal farmers respectively in the bottom quintile have off-farm jobs. These farmers may not be dependent on farming to make a living and therefore profit maximising behaviour may be very different to that which would maximise their utility in that they may wish to maintain a farming lifestyle irrespective of any financial rewards.

5. Discussion

Traditionally, direct payments in Europe and elsewhere have linked payments to production. This has had the effect of substantially altering the market for particular agricultural commodities as farmers could receive more payments simply by producing more of the supported commodity irrespective of any consumer needs (Ackrill, 2008; Swinbank and Daugbjerg, 2006). In addition to a large budgetary cost, the policy of price support in the EU created significant tensions between the EU and other agricultural exporters. As a result, since the MacSharry reforms in 1992 the EU has moved from a policy of price support towards measures that are decoupled from production. The most significant move in this regard was the Mid Term Review (MTR) of the CAP in 2003 where member states agreed to implement a system of payments which were not related to actual production. Decoupled payments are in the 'green box' of domestic support defined by the World Trade Organisation (WTO) and thus are assumed to have none, or at most, minimal trade distorting effects. Decoupled payments have, however, generated considerable international debate as to whether they do in fact alter the behaviour of farm operators.

In order to provide some guidance as to the actual effect of decoupled payments, this paper compared projections from a PE model under the alternate assumptions of full and zero coupling with observed market outcomes between 2005 and 2009. The results suggest that decoupled payments do still maintain a positive impact on farmers' production levels, albeit less

Table 4: Proportion of cereal production with a positive market based net margin 2004 (€ per hectare)

Adjusted Farm GM Quintile	Family farm income	Market Net Margin	Production FC	Other FC	Adjusted Farm Gross Margin	Subsidies	Has part time Job
1	153	−358	167	234	−124	511	0.72
2	220	−200	140	338	138	420	0.37
3	248	−202	113	510	308	450	0.41
4	554	97	99	328	425	457	0.47
5	631	148	126	662	810	483	0.31
Total	358	−108	130	403	295	466	0.47

Source: National Farm Survey

than what would be expected if payments were still fully coupled to production. This viewpoint was supported by the analysis of a National Farm Survey which showed that a large proportion of cattle and cereal farms are operating at a market loss and appear to be using decoupled payments to subsidise unprofitable production.

Traditional economic theory suggests that individuals make decisions based on the expected change in their level of 'well-being', where the technical term used for well-being or welfare is utility (Edwards-Jones, 2006). Given that utility is a difficult concept to measure economists have often made the simplifying assumption that money can act as a substitute for utility. This has lead to the situation observed in many agricultural economic models where it is assumed that all farmers are rational profit maximisers (Edwards-Jones, 2006). This approach may not account adequately for the farming behaviour of individuals as it fails to recognise the large and increasing literature which suggests farmers' behaviours result from complex processes influenced by a range of socio-economic and psychological variables (see Willock et al., 1999a; 1999b and Howley and Dillon, 2012 for a review of this literature). It could be that farmers are perhaps not just driven by financial goals but are also influenced by goals in relation to the satisfaction associated with farming. In other words, as a result of non-pecuniary benefits associated with farm relative to non-farm work, many farm operators may be using decoupled payments to subsidise what would otherwise be unprofitable farm production in order to maintain a farming lifestyle. Farmers may fear a possible diminution in the lifestyle and social benefits associated with traditional farm work if they make significant reductions on their level of farm activity.

There have also been a number of other reported potential influences of decoupled payments on farm activity. This includes issues such as risk aversion, wealth effects and increase in accessibility to loans from lenders that could also result in decoupled payments having a positive impact on farm activity (see Bhaskar and Beghin, 2009 and O Donoghue and Whitaker, 2010 for a review of this literature). Furthermore, through cross compliance obligations, farmers are required to maintain their land in good agricultural and environmental condition in order to receive their full payment. This is likely to result in some compliance costs and may make it optimal for certain farmers to keep land in agricultural use where without this requirement it would otherwise be left idle or converted to non-agricultural use.

6. Conclusion

The results presented in this paper would suggest that cereal and cattle farmers in Ireland do not treat the new single farm payment as being 'truly' decoupled from production. Decoupled payments appears to still elicit a behavioural response from farmers in that it encourages production at levels above that which would be optimal from a market perspective. In effect many farmers are using decoupled payments to at least partly subsidise what would otherwise be unprofitable farm activity. It could be that for many farmers maximising income may not be the most important objective with benefits such as social interaction with other farmers or simply the enjoyment of farming also important considerations. Also, the single farm payment despite being decoupled from production might still affect farmers' behaviour via wealth or risk reducing incentives. It is also important to note that the presence of a large amount of sunk costs that exist regardless of production levels can mean that it may be optimal for some marginally unproductive farmers to maintain production (O Donoghue and Howley, 2012)

While decoupled payments still appear to influence agricultural production, this impact is less than what would be expected if these payments were still coupled to production. From this perspective, the move towards decoupled payments is a step in the direction of a less trade distorting policy. Moreover decoupling is both a new and radical shift in the CAP and it is conceivable that farmers may get closer to treating these payments as truly decoupled in time. For example, it may take some time before the breeding stock of cows can be adjusted. Additionally, multiple generations of farmers have adapted and become used to payments being coupled to production and therefore it may take time for farmers to realise that they are both losing money and that actual production is not needed to receive payments. In relation to future work, further micro-econometric and behavioural analysis will be needed at the farm level to ascertain the differential impact of decoupled payments. In addition, a better understanding of the motivational profiles of farmers could aid efforts to understand and predict farmers' response to policy changes as it seems likely that farmers will consider a wide variety of factors in addition to financial considerations in determining their levels of farm production.

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farm production plans, farm incomes and the viability and sustainability of farm households.

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BOOK REVIEW

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Keeping it in the Family: International Perspectives on Succession and Retirement on Family Farms

Edited by: Matt Lobley, John R. Baker and Ian Whitehead

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Part of Ashgate's *Perspectives on Rural Policy and Planning* series, *Keeping it in the Family* represents an edited collation of 13 chapters drawing upon international perspectives, research and experiences of retirement and succession across the globe. The result is a well-researched book that has been thoughtfully edited, with chapters 1 and 13 respectively providing an overview and discussion which draws together the main themes. For anyone with a personal or professional interest in farmer retirement and succession, this will provide considerable insight, both in terms of what can be gained to ensure more balanced and planned retirement and succession, but also to place in context the commonality of the issues that run through the book as it draws on its international experiences. Much of the research draws upon the international FARM TRANSFERS programme, drawing upon, and developed from, the late Professor Andrew Errington's research. This provides real context to the overall messages that emanate from the book, such as the issue of the aging farmer being reluctant to hand over the reins, the lack of planning for both retirement and succession, the emotional attachment to land and family businesses, the conflict arising from inter- and intra- generational expectations, and the difficulty for new entrants and successors in securing capital to engage in commercial agriculture on scale sufficient to provide a family income.

Chapter 1 sets the scene for the book, discussing the definition of the family farm, the policy support for the family farm and giving an overview of the FARM TRANSFERS project. Australian agriculture is the focus for Chapter 2, noting that whilst Anglo-Saxon traditions remain, Australian farmers are more likely to view the farm and land as a commodity to support retirement, with climatic and economic pressures forcing a realisation that leaving the family farm to the next generation is neither viable nor desirable in some contexts. Australia also forms the basis for Chapter 3, but within the specifics of Australian Woolgrower farms. Drawing upon a case-study based approach, this chapter explores the lack of succession in the sector, driven by poor financial returns, contrasted by new-entrants to woolgrowing who bring in outside capital. In Chapter 4, succession and retirement in Japan brings the reader characteristics of Japanese agriculture and food production; new entrants in Japan are frequently over 60 years old, albeit that off-farm income plays a major role in supporting the small-scale farming activities in the country. Switzerland forms the basis for Chapter 5 and highlights include the influence of social security payments on retirement and succession decisions and planning, together with the influence of successors *wanting* to take over, rather than feeling under an obligation to do so. Chapter 6 has a large focus on patrilineal transfer (from father to son), set in the context of Northern Ireland. This chapter focuses upon the wider social context of farm transfers, titled "keeping the name on the land" aspects of gender and non-succession sibling interaction and acceptance of patrilineal transfers provide fascinating insights.

Chapter 7 provides a different perspective, focusing upon new entrants to farming from non-farming families, drawing upon experiences from the County Farm Estates, largely in Eastern England, and the Fresh Start initiative in Cornwall; social factors, lack of capital and rural housing all raise to the fore in the challenge of enabling new entrants in to the sector. Chapter 8 provides international perspectives again drawing upon the FARM TRANSFERS results, highlighting the need for communication, planning and decision making about succession outcomes. Following a similar approach, Chapter 9 presents findings from Nebraska, additionally providing a four-phase succession plan. Staying with the USA, Chapter 10 provides aspects of the (potentially) retired farmer perspective, noting that there are more farmers citing a desire to 'never retire' than 'fully retire' – a result not confined to Nebraska, but also common in other countries. New Zealand provides the focus for Chapter 11, placing retirement, succession and new-entrant aspects in context of a country that underwent radical agricultural policy change in the mid-1980s. The chapter discusses new-entrant arrangements not often seen in other countries, exploring various share-farming agreements that have arguably brought innovation and a source of rejuvenation to New Zealand agriculture. Chapter 12 represents the final subject-specific chapter, and provides an in-depth academic exposition of retirement and succession planning.

Given the nature of the book, there are instances of several chapters drawing upon similar literature providing the reader with a sense of repetition, however, this is only apparent when reading the book in entirety and for readers wishing to dip in to a few chapters, this should not detract from its overall quality. Key messages from the book come out very strongly - farmers not wishing to retire or even plan for retirement, lack of communication in farming families despite the importance of succession as an issue, lack of capital for new entrants and challenges of family succession with respect to equity of treatment for all the farm family children. At the very heart of the book are the emotional ties, commitment and desire from both the retiring farmer and the successor to keeping the land and farming business in the family. The inseparable nature of family ties to business activities in these cases, coupled with the emotional and economic difficulties that farmers face when considering retirement, make this book both a valuable academic contribution that will be of interest to range of subject areas, and also a fascinating insight to this complex issue as faced by thousands of farm families across the globe.

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The US Farm Bill: Lessons for CAP Reform?

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ABSTRACT

In an analysis first posted on his blog at http://capreform.eu, the author considers differences between the agricultural support programmes of the United States of America and those of the European Union, in terms both of levels of support and of institutional processes. The likely content of the forthcoming US Farm Bill is discussed, including the likelihood of a rebalancing of direct and indirect farm support away from 'decoupled' payments. One possible consequence is reinforcement of the arguments of those who feel that the CAP should move back towards more product-specific subsidy and away from environmental support – as many emerging countries are already doing. Bad economic ideas, such as recoupling or making payments countercyclical, will gain influence in the EU if it becomes the only 'country' sticking to the spirit of the WTO discipline.

KEYWORDS: Farm Bill; agricultural policy; CAP; institutional differences; subsidies; decoupling

The current CAP reform debate and the US Farm Bill debate have been taking place in parallel for several months. There are some interesting contrasts between the two procedures, which are explored in a note for the European Parliament (Bureau 2012). The note also describes the current situation of the Farm Bill negotiations, based on the proposals tabled by the Senate and by the Committee of Agriculture of the House of Representatives (not endorsed by the House as a whole, so far).

It is difficult to compare the proposed €370 billion for 7 years in the CAP (a crude estimate based on recent budget proposals) with some US$ 690 billion, i.e. €523 billion budget projected in the US Senate Farm Bill proposal for an equivalent period of time[2]. Indeed, almost 80 percent of the US Farm Bill budget is devoted to nutrition programs such as food stamps and school lunches that benefit primarily to the urban poor and the unemployed. Nutrition programs do benefit farmers by raising demand for food products, but the transfers are much more indirect and diffuse than with the EU direct payments (US nutrition programs also benefit EU farmers by raising global demand). The fact that the main US welfare program is included in the agricultural legislation is puzzling. It results from the progressive expansion of food aid in the US. For decades, farm interests insisted for maintaining this welfare program within the Farm Bill, since it ensured that urban areas Representatives would support legislation that also included generous farm payments. Ironically, the current opposition of conservative Representatives to welfare transfers now hampers the adoption of a Farm Bill. As a result, the 2012 Farm Bill has been delayed. Some provisions of the 2008 Agricultural legislation expired on September 30 2012, threatening a variety of programs in an immediate future. And because of the automatic budget stabilizers voted by Congress, even a temporary extension of the 2008 Farm Bill is problematic.

As shown in another report for the European Parliament (Butault *et al.*, 2012), the EU provides more subsidies to its farmers than the US. This holds in absolute value as well as in percentage of production[3]. The proposals tabled in the US and the EU will not change this situation. However, EU farm support under the CAP proposal relies more on production neutral instruments than the US ones. Indeed, the proposals currently discussed in Congress show that future US support will rely more on market conditions and that it is likely to induce distortions for third countries.

Institutional differences

US and EU farm policies moved together in the 1990s, with a shift away from price support and towards decoupled direct payments. They have now taken diverging paths. Institutional differences, and in particular the fact that Congress has all power on US farm policy, are part of the explanation. Within the European Parliament, there are voices calling for the EU to follow the new US orientation that focuses on protecting farmers from adverse situations (e.g. countercyclical payments, insurance, etc.). The new powers of the European Parliament could mean that the CAP setting procedure will be more US like in the future. This would not be a good thing.

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[2] The US Senate schedules nearly US$1 trillion for 10 years in its Farm Bill version.

[3] Supporters of farm programs point out that there are more farmers in the EU, though. For more details on the measurement of support and a EU-US comparison see Butault *et al* (2012).

The US Farm Bill procedure is hardly a worthy source of inspiration for the EU. The cleavage between Republican and Democrats in an election year has turned the debate on the Farm Bill into a partisan battlefield, with little attention paid to the general interest and even less to international commitments. In the Senate proposal, every vested interest seems to get its share of the taxpayer's money. Both the Senate and the House proposals maintain and even expand the budget for the most cost-inefficient policies, in particular the insurance subsidies whose ratio of the benefits for the farmers to the cost for taxpayers is particularly low as shown by Bruce Babcock (2011) in a recent report.

In the EU, the decision making process is not satisfactory, as shown by decades of petty bargaining for maximizing budget returns within the Council. However, the specific role of the EU Commission, co-decision with the Council and the way the Parliament is elected make the procedure less subject to short term clientelism. For example, in the US House of Representatives, members are elected for two years from a local constituency and are therefore in permanent electoral campaign. The US procedure of working on scenarios as a difference with a 'baseline' is also a source of bias in Congress' decisions compared to the Commission's impact assessment. It leads to focus, somewhat artificially, on the fixed decoupled payments and conservation programs for budget cuts[4].

The US Farm Bill proposals

As we write this article[5], the content of the future US Farm Bill is still uncertain. Some of the disagreements within Congress regarding the overall budget and the cuts in the nutrition program will be hard to solve. Within the House of Representatives, the Farm Bill proposal by the agricultural committee is not consistent with the budget cuts adopted by the budget committee. However, on the farm support issue, the House Committee and the Senate proposals share many common points and show the likely content of the future Bill.

The main budget cuts will take place in the nutrition programs (food stamps) and in conservation programs, especially those that rely on a 'land sharing' approach, i.e. on which conservations relies on land retirement. Most of the farm support programs will be maintained and the multiple layers of payments, some of them overlapping, will persist. The 'direct' (i.e. the decoupled) payments will be eliminated in both proposals. However, claims by Congress that "direct payments will be cut" are largely bogus: among the many different layers of direct payments, i.e. the marketing loans program, the countercyclical payments, the fixed direct payments, the insurance payments, the Average Crop Revenue Election payments, the disaster payments, etc. It is only the most decoupled and production neutral ones that will be cut. A paradox is that the measures that will be cut are part of the World Trade Organisation 'green box' measures, which are the ones that generate the smallest international distortions.

At the same time, schemes that isolate farmers from adverse conditions will be reinforced. Both the Senate and House Committee proposals include some enlarged insurance programs, as well as some 'shallow loss' payments that are triggered by a fall in income. The Senate Bill is particularly ambitious in this area, with revenue targets that adjust with market prices, countercyclical payments that are increasingly coupled to current production through higher target prices, and updated yields and base acreages. If, under the next Farm Bill, payments are made on planted acres instead of historical base acres as proposed by the Senate this would involve some 'recoupling' as benefits would be more closely tied to producer loss. This will create the potential for market-distorting behaviour and might also lead to larger payments under the WTO 'amber box'. Already, preliminary figures for 2012 suggest that if the US does not exceed its WTO commitments on domestic support, it is thanks to particular (and questionable) conventions used to notify crop insurance payments[6].

Consequences for the EU

The Congress proposals for the US Farm Bill have been criticized by most of the prominent US economists who think that many of the proposed payments are either useless, inefficient or encourage perverse behaviour (see for example Goodwin, Smith and Sumner (2012)). In the EU, recent declarations by some European Parliament's COMAGRI heavyweights suggest that they look at the US Congress proposals as a source of inspiration. Some of them propose making direct payments more countercyclical, which would require going back to product specific payments and giving up any attempt for environmental conditionality. Many want to water down the Commission's proposal for greening the CAP. Others press for more ambitious insurance programs. The example of the US situation, where the insurance system is such that each dollar of insurance net payment costs twice as much to the taxpayer, and where the layers of countercyclical payments means that the budget could vary by some US$15 billion from one year to the other, should warn against such temptations.

Another consequence of the US Farm Bill debate for the EU is on the diplomatic side. In the 1990s, both the EU and the US found a source of inspiration in the other party's reforms. The move to decoupled payments in the 1985 and then 1996 Farm Bill was followed by the EU. This dynamics played a considerable role in the achievement and respect of a multilateral discipline, which helped the recovery of world prices and soothed international relations. In the 2000s, the US experienced

[4] The US procedure is differs from the Impact Assessment carried out by the European Commission. Rather, the Congressional Budget Office establishes a budgetary baseline which corresponds to the perpetuation of the current law over ten years, and estimates the costs of the reforms proposed as deviations to this baseline. A flaw of this procedure is that the CBO has based its 10 year projection on the current market situation. That is, all the impressive arsenal of payments that depend on market prices appear at almost zero cost over the 10 year period. This results in the largely artificial image that in the future, the fixed decoupled payments are the only ones that will use taxpayers' money. It may have played a role in the fact that Congress cuts mostly those payments that are seen as the most 'virtous' by economists.

[5] November 2012

[6] See Box 4 and Box 6 in Bureau (2012)

a turnaround by shifting to countercyclical payments. With the Congress proposals, the US will most likely depart further from production neutral payments. At the same time, many emerging countries are also expanding their coupled payments (Russia, China, India, Turkey in particular). Countries, like the EU, that stick to cooperative policies and take care to the preservation a rule based multilateral discipline tend to become exceptions.

The EU takes pride in remaining a leader in the promotion of more neutral support and respect of WTO commitments. But being a leader that no one follows is not a sustainable status. Bad economic ideas, such as recoupling or making payments countercyclical, will gain influence in the EU if it becomes the only 'country' sticking to the spirit of the WTO discipline. The orientation of the US Farm Bill shows that the stalling of the Doha negotiation has far reaching and damaging implications.

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Options from life-cycle analysis for reducing greenhouse gas emissions from crop and livestock production systems

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ABSTRACT

Options for reducing greenhouse gas emissions (GHGE), measured as global warming potential, in twelve crop and seven livestock systems were explored using a systems model-based life-cycle analysis of environmental burdens and resource use. Differences between crops in GHGE per kg product reflected differences in yield per hectare. Technological changes found to reduce GHGE per kg of crop were: (i) 20% decrease in total N (all crops except legumes); (ii) no-till (cereals and legumes only) and (iii) no straw incorporation (cereals and rape). Reductions in GHGE ranged from 2% (sugar beet) to 15% (cereals). GHGE per kg crop were also reduced by increasing crop yields by 20%. The maximum potential to reduce livestock GHGE was estimated by identifying for each livestock sector the system which gave the greatest reduction in GHGE per kg of product. Alternative systems were associated with reductions in GHGE of between 7% (beef from the dairy herd) and 21% (sheep meat). Nitrogen use efficiency (NUE) ranged from 48% for oilseed rape to 85% for sugar beet, and from 5.8% for sheep meat to 33% for poultry meat production. The results indicate that improvements in productivity and efficiency of resource use result in lower GHGE per unit of product and increased NUE.

KEYWORDS: Life-cycle analysis; resource use; greenhouse gases; crops; livestock

1. Introduction

Governments have made international commitments to reduce greenhouse gas emissions (GHGE) and the United Kingdom government has set a target of an 80% reduction in emissions of GHGE by the year 2050 compared to the baseline of 1990 (Office of Public Sector Information, 2011). Reductions in GHGE in food production largely involve reducing emissions of nitrous oxide from agricultural soils and manures, and emissions of methane from enteric fermentation and livestock manures (IPCC, 2006).

Total GHGE from UK agriculture are estimated to have decreased by 21% in the period 1990 to 2009 (DEFRA, 2011). Although some progress has been made towards the achievement of the UK government's target, the decrease in GHGE has been driven by reduced amounts of fertiliser nitrogen applied per hectare of land and by reductions in the populations of dairy cattle and sheep (DEFRA, 2011). Other factors, such as improvements in efficiency of resource use, are not currently captured in the national inventory (MacCarthy et al., 2011). In future decades, the rising world human population will increase the pressure to produce more edible food crops from finite areas of cultivatable land (Godfray et al., 2010). The ability of ruminant livestock to convert grasslands and forage crops into human-edible food of high biological value will continue to make a significant contribution to higher total food output. The challenge is to produce more food with lower GHGE per unit of product, focussing attention on more efficient use of agronomic resources in crop production, on increased efficiency of breeding females in livestock production, and on improved efficiency of feed use in all systems of milk and meat production. Technological options to achieve these objectives need to be explored at the individual system level, to support the activities of farmers, by examining systems through life-cycle analysis in which the GHGE attributed to each component is assessed in a fully authenticated methodology (Williams, 2006). In this way, the impact of variations in management strategies can be quantified theoretically.

Previous research has concentrated on determining the environmental burdens of existing systems of food production (Williams et al., 2006; Ledgard et al., 2010; Nemecek et al., 2008). In this paper we have taken the work a stage further to assess the effects on GHGE, of implementing theoretically a range of technological options in conventional systems of crop and livestock production operated on farms in northern Europe and America, with the objective of determining the potential reductions in GHGE which might be feasible in each system without reducing the total production of food or changing the national diet. Other studies have considered the scope from making changes to the national diet

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(Audsley et al., 2009). Organic options are not considered here because they have been explored elsewhere (e.g. Olesen et al., 2006; Williams et al., 2006; Weiske and Michel, 2007). Given the importance of nitrous oxide emissions from agricultural soils as a source of non-CO_2 GHGE (MacCarthy et al., 2011), the potential effects of alternative options on NUE (N in product as a percentage of total N input) are also explored.

2. Material and methods

Typical northern European crop and livestock production systems were studied using the Cranfield system model-based life-cycle analysis (LCA, Williams et al., 2006), available online at www.agrilca.com. LCA is a holistic analysis and the methodology specifically includes GHGE not only from the farm, but also from industries that produce inputs such as fertiliser, feeds, machinery and fuel, including overseas production and by-products. Critically, burdens are expressed in terms of the functional unit, in this case per kg of product fresh weight, per MJ of edible energy or per kg edible protein at the farm gate, not the GHGE of whole farms. This approach focuses attention on options linked to both technical and financial efficiency (Evans, 2009). GHGE are expressed as a global warming potential (GWP_{100}) in tonnes CO_2 equivalent (CO_2e) per unit of product, using a 100 year time frame and the GWP values for gases from the Intergovernmental Panel on Climate Change (IPCC, 2006). The methods and data inputs to the LCA model have been described in detail for the production of bread wheat, oilseed rape and potatoes in England and Wales by Williams et al. (2010).

The production systems studied in the Cranfield LCA represent all the main methods of producing each commodity such as for example for wheat: organic, conventional, ploughed, reduced tillage, direct drill; for pigs: indoor or outdoor sows or weaners, light or heavy pigs; for beef, suckler or dairy-bred calves, intensive cereal, extensive grass, upland or lowland, spring or winter calving. The systems modelling approach includes equations defining the interactions between yield-fertiliser-crop N-long term soil N and leaching, yield-feed energy-manure-crop response, as well as the effect of different soil type and rainfall across the UK. This approach calculates the impact of changes within the farm system, for example a decrease in fertiliser input reduces crop yield per hectare and crop nitrogen content and long-term soil nitrogen (Williams et al, 2010). Equally, an increase in the crop yield from plant breeding (with no reduction in crop N content) requires additional fertiliser input.

For each system emissions of nitrous oxide (N_2O) were calculated using the IPCC Tier 1 methodology (IPCC, 2006). Other emissions such as those from energy use, from manure storage and use, or nitrate leaching were calculated systematically by considering each aspect of the system in turn. A calculated change in GHGE therefore represents the total effect of a change in the farming system. The output of each system is defined as the product at the farm gate – grain, seed, forage, whole milk, whole eggs or meat bone-in carcase weight. Two major crops grown in America – soya beans and maize grain were included for comparison with UK cropping systems. The current combination of systems and their emissions were considered as baseline (2005) values for agricultural GHGE.

Based on analyses of the impact on GHGE of making changes to the systems, alternative technological options for each production system were developed in the present study using Release 3 Version 48 of the model (July 2009). Percentage reductions in GHGE for the alternative options were expressed relative to the values for 2005 for the typical systems. The GHGE from post farm gate processing of crops and livestock products are not included in this analysis.

Ten UK and two American cropping systems were included in the present study to cover the range of major agricultural food crops except rice, the range in soil types, and a range of contrasting agronomic practices. Typical cropping systems were defined in relation to soil texture, soil cultivation technique, straw incorporation, irrigation, and the average total input of nitrogen (N) per hectare (Table 1). The analysis determined the new long-term steady state for the soil, but as the soil was in steady state, no contribution was assumed for changes in the concentration of soil carbon and the proportion of soil types nationally (Table 1) was unchanged. The typical composition of each crop product in terms of concentration of dry matter, energy and crude protein is shown in Table 2.

Alternative cropping management options were studied in the model by varying three major characteristics described for each system in Table 1: Type of cultivation (ploughing versus no-till or direct drilling), straw incorporation (zero versus 100%) and level of fertiliser N. Stepwise reductions in total N input were analysed to determine an appropriate level which might reduce GHGE by more than crop yields to give a net environmental benefit per unit of crop produced. Irrigation (zero versus 100%) was studied for potatoes alone. The effect on GHGE of a theoretical increase in crop yield of 20% compared to current average yield (Table 4) was also explored.

The LCA model considers the full range of alternative livestock rearing systems; high and low intensity, spring and autumn calving, indoor and outdoor, hill, upland and lowland. Typical details of European livestock systems are described in Table 3, comprising milk production from autumn-calving dairy cows housed for six months of the year, semi-intensive beef from calves born in dairy herds, spring-calving suckler beef production, sheep meat production from crossbred ewes, indoor heavy bacon production, poultry meat from housed broiler chickens, and egg production from housed layers. Inputs of concentrate and forage DM refer to the complete system and include both the dam and her offspring. Emissions associated with imported feeds and fertilisers were calculated in the inventories of the country of origin and were included in the analysis. No account was made of post-farm gate GHGE, such as energy use in the processing of milk and carcases, and in product packaging and distribution.

The range of options available to reduce livestock GHG was discussed by Gill et al. (2009), who identified improved fertility, health and genetics as the major factors contributing to decreasing the number of

Table 1: Typical values for soil composition, cultivation and nitrogen input for crop systems (from Williams et al., 2006)

Crop	Soil type (%)			Cultivations (%)			Straw incorporation (%)	Irrigation (%)	Total N (kg/ha)	Type of N fertilizer (% of total)	
	Clay	Loam	Sand	Plough	Reduced tillage	No-till				Ammonium nitrate	Urea
Winter bread wheat	34	48	18	57	41	2	75	0	219	80	20
Winter feed wheat	34	48	18	57	41	2	75	0	204	82	18
Winter barley	22	54	24	57	41	2	15	0	163	82	18
Spring barley	9	75	16	57	41	2	0	0	123	82	18
Winter oilseed rape	43	29	28	50	45	5	100	0	204	69	31
Sugar beet	7	82	12	100	0	0	–	0	122	96	4
Main-crop potatoes	7	82	12	100	0	0	–	56	191	96	4
Second-early potatoes	7	82	12	100	0	0	–	48	171	96	4
Field beans	39	33	28	57	43	0	100	0	0	–	–
Soya beans[1]	30	28	42	27	53	20	–	0	0	–	–
Maize grain[1]	30	28	42	30	58	12	100	0	134	90	10
Forage maize	55	16	29	57	41	2	0	0	212[2]	90	10

[1]America. [2]A significant proportion of the total N input to forage maize is from manure, but the reduction in fertiliser use is credited to the animal and not to the crop. The same principle applies to the other crops but to a lesser extent.

animals required per kg of product. In addition, feeding strategies to reduce methane and nitrous oxide emissions were considered to be particularly valuable in terms of increasing efficiency of livestock systems. The conversion of human-edible and inedible animal feeds into animal products has been reviewed elsewhere (Wilkinson, 2011) and is not considered here.

Alternative systems in terms of reduced GHGE compared to the equivalent typical system were explored, using the Cranfield model, for each livestock sector by varying those system components associated with technological efficiency, described above, which were considered most likely to reduce GHGE (e.g. fecundity, longevity, feed conversion ratio). Alternative systems were defined using the model with the most extreme feasible improvement in each factor in order to estimate the maximum potential for reducing GHGE.

3. Results and discussion

Crops

Fresh weight yields for the typical cropping systems and for the options to reduce GHGE are shown in Table 4. The options found to reduce GHGE also reduced crop yields but to a relatively small extent ranging from 5% or less for potatoes, field beans, soya beans and forage maize to between 7 and 11% for the other crops.

Typical GHGE, expressed as tonnes CO_2e/tonne product fresh weight at the farm gate are shown in Table 5. The range in GHGE between crops was considerable, with oilseed rape and sugar beet having the highest and lowest emissions per tonne of crop fresh weight, respectively. Standardising potato and sugar beet yields to 860 g DM/kg fresh weight to make them comparable with the cereal crops produced values of 0.59, 0.44 and 0.20 kg CO_2e kg^{-1} for main-crop potatoes, second early potatoes and sugar beet, respectively. Forage maize had the lowest GHGE per kg of the cereal crops because, being harvested in its entirety, it had a substantially higher yield per hectare than the other crops, though of lower quality (Table 2).

No-till or direct drilling (cereals and legumes) reduced GHGE. Although no-till was associated with reduced crop yield compared with ploughing (Table 4), there was a reduction in GHGE, mainly as a result of lower primary energy use. The restrictions of applying the IPCC Tier 1 emission factors meant that the model assumed there were no changes in soil N_2O emissions for different cultivation techniques. However there may be an increase in N_2O compared to the typical system which comprised ploughing and reduced tillage in approximately equal proportions because of increased soil anaerobic conditions (Robertson et al., 2000). The extent to which any increase in N_2O emissions might offset the reduction in primary energy use is not known. The reductions in GHGE due to no-till alone ranged from 0.01 kg CO_2e kg^{-1} for wheat and maize (a 2% reduction) to 0.07 kg CO_2e kg^{-1} (10% reduction) for soya beans. An exception was oilseed rape where the change to 100% no-till was associated with an increase in GHGE of 0.04 kg CO_2e kg^{-1} because the relatively high yield penalty (13%) outweighed the saving on primary energy. No-till was therefore excluded as an agronomic option for oilseed rape. The typical proportion

Table 2: Typical concentrations of dry matter, metabolisable energy and crude protein in crop products (from Thomas, 2004 and Williams et al., 2006)

Crop	Dry matter (DM) ($g\ kg^{-1}$ fresh weight)	Metabolisable energy (ME) ($MJ\ kg^{-1}$ dry matter)	Crude protein (CP) ($g\ kg^{-1}$ dry matter)
Winter bread wheat grain	860	13.6	130
Winter feed wheat grain	860	13.6	116
Winter barley grain	860	13.2	123
Spring barley grain	860	13.2	116
Winter oilseed rape seed	930	23.1	212
Sugar beet roots	220	13.2	31
Main-crop potatoes	200	13.3	93
Second-early potatoes	200	13.3	93
Field bean seed	860	13.3	298
Soya bean seed	860	14.5	415
Maize grain	860	13.8	102
Forage maize (whole plant)	280	11.0	101

of no-till in America for soya bean and maize grain production was markedly higher than in the UK (Table 1), reflecting lighter soils and the need to preserve soil moisture.

Not incorporating straw reduced GHGE. The main source of GHGE due to incorporating straw into soil is N_2O emission from soil during the winter. No use was assumed for the straw made available by not incorporating it into the soil. The GHGE associated with the removal of straw (baling and transport) are assumed to be an environmental burden associated with the use of straw as a product of cereal grain production, not with the production of grain itself. If the straw were to be used to replace other sources of energy this would mitigate the GHG burden of its production and disposal as a waste product of cereal grain production. The model determines the long-term steady state system for all processes. This includes nitrogen from the rotation, nitrate leaching and soil organic matter. Thus incorporating or not incorporating straw continues for a long time, so that the soil is in steady state. There is thus no contribution from the change in the soil organic matter. In the transition period of not incorporating, soil organic matter would be reduced giving a release of CO_2 which the benefit of reduced N2O would take some years to counteract, and *vice-versa*. The magnitude of the effect of a change away from straw incorporation depended on the typical proportion of straw incorporated for each crop (Table 1). Reductions in GHGE due to no straw incorporation alone were zero, 0.01 (2% reduction), 0.04 (8%) and 0.06 kg $CO_2e\ kg^{-1}$ (2%) for spring barley, winter barley, wheat, and oilseed rape, respectively (Table 4).

Irrigation of main-crop potatoes was associated with a progressive reduction in GHGE, from 0.14 kg $CO_2e\ kg^{-1}$ without irrigation to 0.13 kg $CO_2e\ kg^{-1}$ with 100% irrigation – a 6% decrease. As the majority of potato crops are either irrigated or do not need irrigation, the overall potential reduction in GHGE is probably only about 1%.

A reduction in the total quantity of N input was associated with decreased primary energy use and reduced emissions of N_2O since under the Tier 1 IPCC methodology the emission factor for N_2O was a fixed percentage (1%) of total N applied (IPCC, 2006). Progressive decreases in total N not only reduced crop yields and soil nitrate concentrations but also reduced emissions of ammonia. However, small reductions in N were reflected in relatively small decreases in crop yield which were more than compensated by greater reductions in N_2O emissions and by reductions in primary energy use in the production of the fertiliser in the first place. An average reduction of 20% in total N input was found to produce a net GHGE benefit for all crops and was therefore considered to be the most appropriate option (Table 5). Kindred et al. (2008) found a similar optimal reduction in fertiliser N input to UK wheat of 43 kg ha^{-1} (a 22.5% reduction) to minimise GHGE,

Table 3: Main components of typical livestock systems (from Williams et al., 2006)

Sector	Milk	Dairy beef	Suckler beef	Sheep meat	Pig meat	Poultry meat	Eggs
Days housed	190	180	182	0	126	42	385
Concentrates (kg DM)	2047	960	579	76[5]	366	4.9	52
Forage[1] (kg DM)	6792	2281	4982	1018	–	–	–
Live weight gain (kg/day)	–	0.90	0.88	0.17	0.56	0.06	–
Output (kg/year)	7850	285	232[3]	60[6]	–	–	14.8[8]
Live weight at slaughter (kg)	–	565	565	41	109	2.4	–
Age at slaughter (months)	–	19	20	7 to10	6.3	1.5	–
Feed conversion ratio (kg feed DM/kg milk or live weight gain)	1.13[2]	6.23[4]	10.7[4]	18.2[7]	2.89	1.76	3.06[9]
Longevity of breeding females (years)	3.2	–	7	4.2	2.5	–	1.1
Manure as slurry (%)	88	18	0	0	35	0	25[10]

[1]Grazing and conserved forage. [2] kg total feed DM/kg milk. [3] Live weight of calf at weaning. [4] kg total feed DM/kg total live weight gain (slaughter weight minus 45 kg birth weight). [5] Includes concentrates for finishing store lambs. [6] Per ewe. [7]kg total feed DM/kg output. [8] 295 eggs/layer, 50g/egg. [9]kg feed/kg eggs. [10] Proportion with belt-cleaned cages, remainder on deep cages.

Table 4: Predicted yields for typical crop systems and for agronomic options to reduce greenhouse gas emissions

Crop	Typical yield[1]	Predicted yield with agronomic options[2] to reduce GHGE	Reduction in yield (%)
	(tonnes fresh weight ha^{-1})		
Winter bread wheat	7.7	7.0	9
Winter feed wheat	8.1	7.2	11
Winter barley	6.5	5.9	9
Spring barley	5.7	5.2	9
Winter oilseed rape	3.2	2.9	9
Sugar beet	63.0	58.1	8
Main-crop potatoes	52.0	49.6	5
Second-early potatoes	48.0	46.1	4
Field beans	3.4	3.3	4
Soya beans	2.4	2.3	2
Maize grain	7.2	6.7	7
Forage maize	11.2[3]	10.8[3]	4

[1]Systems as described in Table 1. [2] See text for details of options. [3] tonnes dry matter ha^{-1}

after accounting for land-use change to maintain grain output.

An effect of reducing total N input is that the concentration of N in the crop is also reduced (Rothamsted Research, 2006). This reduces the likelihood of bread wheat grain being of a suitable quality for bread-making and thus a greater proportion is assumed to be only suitable for animal feed. Alternatively, a switch to a variety with a higher inherent protein content might be feasible, but these varieties are lower-yielding (HGCA, 2011) and thus GHGE per kg product would be similar. Reduced concentrations of N are unlikely to be consequential in the case of potatoes and sugar beet as it is not a quality criterion in these crop products. The decreases in GHGE due to reduced N input (Table 5) were relatively small for sugar beet and potatoes (2 to 3% reduction), but were of greater significance for the cereal crops and oilseed rape: 0.03 kg CO_2e kg^{-1} (7 to 8% reduction) for feed wheat and barley, 0.04kg CO_2e kg^{-1} for bread wheat (7%) and forage maize (13%), and 0.05 kg CO_2e kg^{-1} for oilseed rape (5%) and maize grain (11% reduction).

Where all three agronomic options were appropriate to the crop, reduced N had the greatest effect on GHGE (Table 5). The combined effect of the options on the percentage reduction in GHGE was lowest for sugar beet (2%) and highest for the cereal crops (average 15% reduction). The percentage reduction in GHGE was similar for the two potato crops (3%), and was also similar for the two grain legumes (9%).

Typical yields per hectare of metabolisable energy (ME), crude protein (CP) and GHGE per unit of ME and CP are in Table 6. Yields of ME were low for the two legume crops, but they contained more CP per kg DM than other crops (Table 2) and yields of CP for field beans and soybeans were comparable with those of wheat. Forage maize yields of both ME and CP were relatively high reflecting the fact that this crop is harvested in its entirety for livestock feed. GHGE per MJ of ME generally reflected yield of ME, ranging from 0.015 for sugar beet to 0.056 for soya beans. GHGE per kg CP were higher than average for potatoes and sugar beet and lower than average for field and soya beans and forage maize.

The output of the major grain crops has increased steadily over the years and there is undoubtedly scope for them to be increased further - for example through improved plant breeding and crop health (see review by Godfray et al., 2010). GHGE per kg product were

Table 5: Greenhouse gas emissions (GHGE) from typical crop systems and from options to reduce GHGE

Crop	Typical system	No-till	No-till + no straw incorporation	No-till + no straw incorporation + 20% reduced N	20% increase in crop yield per hectare
	GHGE (kg CO_2e kg^{-1} product fresh weight)				
Winter bread wheat	0.51	0.50	0.46	0.42	0.48
Winter feed wheat	0.46	0.45	0.41	0.38	0.43
Winter barley	0.42	0.40	0.39	0.36	0.39
Spring barley	0.38	0.35	–	0.32	0.36
Winter oilseed rape	1.05	–	1.03	0.97	0.95
Sugar beet	0.043	–	–	0.04	0.04
Main-crop potatoes[1]	0.14	–	–	0.13	0.13
Second-early potatoes[2]	0.10	–	–	0.10	0.09
Field beans	0.51	0.46	–	0.46	0.46
Soya beans	0.70	0.64	–	0.64	0.61
Maize grain	0.38	0.37	–	0.33	0.36
Forage maize	0.30	0.29	–	0.26	0.29

[1]Cool-stored until May: weighted cooling energy applied. [2] No storage.

Table 6: Typical yields of metabolisable energy (ME) and crude protein (CP) and GHGE per unit of ME and CP from crops

Crop	Yield		GHGE	
	ME (GJ ha^{-1})	CP (kg ha^{-1})	kg CO_2e MJ^{-1} ME	kg CO_2e kg^{-1} CP
Winter bread wheat	90	859	0.044	4.56
Winter feed wheat	94	803	0.039	4.61
Winter barley	74	687	0.037	3.97
Spring barley	65	570	0.033	3.81
Winter oilseed rape	69	631	0.049	5.33
Sugar beet	183	434	0.015	6.24
Main-crop potatoes	138	967	0.053	7.53
Second-early potatoes	128	893	0.038	5.38
Field beans	39	882	0.045	1.99
Soya beans	30	867	0.056	1.96
Maize grain	85	632	0.032	4.33
Forage maize	124	1100	0.027	2.97

significantly reduced by increased crop yields, as illustrated in Table 5 for a theoretical increase in yield of 20% above those shown in Table 4. The analysis requires the fertiliser N input to the crop to be increased to balance the increased N off-take (and P and K). For crops other than cereals and forage maize the effect on GHGE of a 20% increase in yield alone was greater than the combined effects of the agronomic options, ranging from a 5% reduction for main-crop potatoes to a 14% reduction in GHGE for soya beans (Table 5). This raises the exciting prospect that sizeable reductions in GHGE might be achieved by exploiting simultaneously both agronomic and plant breeding strategies, without at the same time suffering a reduction in crop output.

The scope for reducing GHGE per unit of product is markedly less for the grain legumes than for other crops. In part this is simply a reflection of the fact that these crops do not receive fertiliser N. However, it is also a reflection of relatively low crop yield - as is also the case for oilseed rape. On a protein versus energy yield basis compared to wheat, the protein-equivalent yield of beans should be 4.8 t ha^{-1} compared to the typical yield of 3.4 t/ha^{-1} (Table 4), so there would appear to be some scope for research to increase yields of grain legumes in the UK, including research into the genetic improvement of soya bean cultivars for use in the northern European climate.

The main GHGE from crop production is nitrous oxide, which accounts for about 50% of total UK agricultural GHGE on a CO_2 equivalence basis (MacCarthy et al., 2011). Of the total N_2O emissions from agriculture, about 90% is from the need to boost the fertility of soils – in any form (MacCarthy et al., 2011). Thus important areas for innovation and improvement are to increase the efficiency of use of both organic and inorganic N, to reduce the need by plants for N for growth in excess of off-take, and hence to increase NUE at constant or reduced N input. NUE is defined as off-take of N in the harvested crop as a percentage of total N input, excluding atmospheric N deposition. Estimates of NUE are in Table 7 for the typical cropping systems and also for the agronomic options to reduce GHGE described above, assuming that crop yield and composition could be maintained at typical levels *via* improved plant genetics and/or disease control at 85% of current total N input.

Typical values for NUE were in excess of 67% for all crops except oilseed rape. The agronomic options to reduce GHGE also gave increases in NUE, reflecting the fact that reductions in total N input by 20% of average levels did not produce decreases *pro-rata* in output of N in crop product (Rothamsted Research, 2006). NUE ranged from 48% for typical oilseed rape production to 97% for the 'best' system of sugar beet production (Table 7). The estimate of NUE for the best sugar beet system may be an overestimate because the nitrogen offtake estimated at the lower fertiliser N input may not have properly reflected the reduction of crop N concentration. On a long term view there must always be an excess of N supply over N off-take, since plant residues and roots contain N which break down in the soil and thus emit nitrous oxide to the atmosphere and nitrate to watercourses (Dobbie and Smith, 2003). There is also a demand for increased soil organic matter in order to store carbon in soil.

Livestock

There is a wide range between the different livestock sectors in the typical period of time the animals are housed, in feed inputs, in output of animal products and in feed conversion ratios (Table 3). It is important to note that large differences in efficiency have also been recorded *within* systems, reflecting differences in quality of land, type of livestock and management expertise (BPEX, 2008; EBLEX, 2009, 2010; QMS, 2011ab). The

Table 7: Nitrogen use efficiency (NUE, %) for typical crop systems and for options to reduce GHGE

	Typical system	No-till + no straw incorporation + 20% reduced N
	NUE (%)	
Winter bread wheat	70	79
Winter feed wheat	67	74
Winter barley	74	80
Spring barley	81	86
Winter oilseed rape	48	55
Sugar beet	85	97
Main-crop potatoes	74	93
Second-early potatoes	72	90
Forage maize	83	92

GHGE from livestock systems are shown in Table 8 in terms of kg CO_2e per kg product, per unit of edible energy and per unit of edible protein, assuming zero edible energy and protein in bone and egg shell.

Milk production has substantially lower GHGE per kg product fresh weight than the other livestock systems, but this is due to the fact that milk is largely water. On a dry matter basis GHGE from milk production is similar to that of poultry production, reflecting the energetic efficiency of converting feed into milk rather than live weight and the different chemistry of milk compared with poultry carcasses or eggs. GHGE per kg product are higher for suckled beef and sheep meat production than for beef produced from calves born in the dairy herd (dairy beef) and non-ruminant systems, reflecting the relatively high feed input to the breeding female (Table 3). Differences in GHGE between the meat production systems per unit of edible energy and edible protein are similar to those per kg fresh product, with suckler beef having the highest, and poultry meat the lowest GHGE per MJ of edible energy and per kg edible protein.

Three main technologies were found to reduce GHGE per unit of product: (i) Increased lifetime output of breeding females (fertility, fecundity and longevity); (ii) increased milk yield per year (dairy cows); and (iii) improved feed conversion ratio (growing animals). By increasing fertility (number of successful conceptions per female inseminated), fecundity (number of offspring per breeding female in sheep) and longevity (number of years in production), the annual number of herd and flock replacements were reduced. Genetic improvement of livestock was estimated to have resulted in reductions in GHGE per unit of product of about 1% per annum (Genesis-Faraday, 2008). Re-orientating livestock breeding programmes to include GHGE as selection traits was an appropriate strategy to achieve a sustained reduction in livestock GHGE. Increased fertility and resistance to disease were crucial factors in achieving increased longevity in breeding livestock. Increased fertility was achieved by feeding cows on a higher starch diet to stimulate the resumption of oestrous in early lactation, followed by a higher oil diet to encourage high conception rates (Garnsworthy, et al., 2009).

Increasing milk yield per year spreads the inputs to maintain the dairy cow over a greater output. This is not the same as breeding larger cows which have greater GHGE than smaller cows. Thus a 10% larger cow giving 10% more milk per lactation will have the same GHGE per kg milk. Increased annual milk output should also not be confused with yield per lactation, which can be increased by having a longer calving interval. Milk yield per cow life (longevity) is an important performance indicator because it affects the proportion of the total breeding herd replaced annually by first-calving heifers, and hence the total number of heifer calves reared (Garnsworthy, 2004).

A highly effective practical measure to reduce methane production by cattle is to increase the proportion of maize silage at the expense of grass silage (Tamminga et al., 2007, Weiske and Michel, 2007). Forage maize has a relatively low GHGE per kg of ME and CP of the arable crops analysed in this study (Table 6). However, the GHGE mitigation effect of forage maize may be offset by increased losses of soil

Table 8: Estimated GHGE for typical and alternative livestock systems

Sector	Typical system			Alternative system	GHGE from alternative system	Reduction in GHGE from alternative system
	kg CO_2e Per kg product	kg CO_2e Per MJ edible energy	kg CO_2e Per kg edible protein		kg CO_2e/kg product	%
Milk	1.0	0.4	30.6	Autumn-calving cows, housed 190 days/year. 8000 litres milk per year, 7 lactations per cow. 15% crude protein housed diet based on maize silage.	0.89	12
Dairy beef	8.5	1.0	49.5	Lower forage diet, housed throughout lifetime.	7.95	7
Suckler beef	15.9	1.9	90.0	Spring calving. High genetic merit cow for fertility and calf growth.	14.1	12
Sheep meat	14.6	1.6	69.3	Ewes of high genetic merit for fecundity and longevity. Low stocking rate. No housing.	11.5	21
Pig meat	4.0	0.7	19.7	High genetic merit for fertility and piglet growth. Sows and weaners outdoors. Finishing indoors on a slurry system, stored slurry immediately incorporated into land.	3.49	14
Poultry meat	2.7	0.3	14.2	Housed. Immediate incorporation of manure into land. FCR as for top 10% of sector.	2.54	7
Eggs	3.0	0.5	23.2	Housed, slurry, under-floor drying of manure, covering of manure store, immediate incorporation of manure into land. FCR as for top 10% of sector.	2.57	13

carbon if grassland is ploughed and substituted by maize crops (Vellinga and Hoving, 2011) – a factor which was not taken into account in this analysis.

There is a need to identify ways of reducing methane production in extensively grazed ruminants – possibly through plant breeding to incorporate natural methanogen inhibitory products in new herbage cultivars, or via the provision of dietary supplements which contain compounds to modify forage digestion. Higher sugar grasses may increase the capture of feed energy and protein by the rumen, improve the conversion of feed into useful animal product, and reduce methane and nitrogen emissions per unit of product (IBERS, 2011). Long chain fatty acids have also been shown to reduce methane production per unit of product in ruminants (Blaxter & Czerkawski, 1966). The mechanisms of these effects require clarification and confirmation on a larger scale.

Improving feed conversion ratio (FCR) – defined as kg feed (at constant dry matter) per kg weight gain, milk or eggs (at constant dry matter) – makes more efficient use of feed resources. Increased daily live weight gain can save resources in meat animals by reducing the total period of time needed to reach an acceptable weight and carcase composition at slaughter. However an animal that is simply larger may achieve a greater daily live weight gain but consume *pro-rata* more feed; and in this case there is no improvement in its feed conversion ratio. The analysis presented here does not distinguish between methods to improve FCR, which may be genetic, managerial, or nutritional. In some cases, diet formulations may need to be changed to achieve improved FCR. This could increase the environmental burdens of feed production and so reduce the GHGE benefit somewhat. Other improvements in animal performance, such as reducing lameness and endemic diseases, also result in better animal welfare.

The best alternative livestock systems are described in Table 8 together with the estimated percentage reduction in GHGE compared to the average for the sector (Table 8). The potential reductions in GHGE range from 7% for dairy beef and poultry meat to 21% for sheep meat. The major factors affecting GHGE per unit of milk are annual yield per cow, longevity and reduced protein diets. The alternative milk production system to reduce GHGE is therefore based on autumn-calving, cows yielding 8000 litres milk per year and given a reduced-protein diet (15% crude protein) during the housed period based on maize silage. Longevity is assumed to be 7 lactations per cow rather the current average of 3.2 lactations per cow, given that infertility is a major source of involuntary culling in the dairy herd, and that the best nutritional strategy is adopted for high fertility (60%, Garnsworthy et al., 2009). The GHGE from the alternative milk production system are 12% lower than the typical system (Table 9).

The alternative system to reduce GHGE in beef production from the dairy herd is one based on male dairy x dairy calves and beef x dairy calves in a housed system. The animals are fed on a high-energy reduced forage diet. The use of sexed semen in dairy herds was examined as a possible option. There was little effect on the total number of male and female dairy-bred calves available for beef, but its use increased calf beefing quality because a higher proportion of cows in the dairy herd were available for insemination with beef-breed semen. Sexed semen was not included in the best alternative dairy beef system. The reduction in GHGE for the best alternative system compared to the average for the dairy beef sector is 7%.

The scope for reducing GHGE from suckler beef systems is limited by the relatively high GHGE associated with the breeding cow and the relatively low output of beef per breeding female per year. Overall feed conversion ratio is substantially poorer than that of the monogastric livestock systems (Table 3). The alternative suckler system comprises spring-calving suckler cows with extended grazing (i.e. minimal housing) to minimise N_2O emissions from farmyard manure. The weaned calves are reared indoors and then finished at pasture. The GHGE from the alternative system is 12% lower than the average for the sector.

Inputs to the sheep sector are relatively low compared to other livestock sectors and the typical upland and lowland systems currently in operation in the UK are based on grazing (Table 3). The alternative sheep system is extensive, with outdoor lambing in late spring, using crossbred ewes of high fecundity and longevity. Ewes are not housed in winter. Stocking rate is relatively low −10 ewes and lambs per hectare. The reduction in GHGE of 21% compared to the average for the sector mainly reflects higher fecundity of 2 lambs per ewe compared to 1.4 lambs per ewe for the typical system, illustrating the same effect as for crops of higher 'yields'.

The best alternative pig production system comprised sows of high genetic merit for fertility and piglet growth. Sows and weaners are kept outdoors with an indoor finishing system with manure as slurry. Greater emissions of N_2O from the outdoor system are more than offset by the reduction in methane which would otherwise be produced from stored manure or slurry, giving a net reduction in global warming potential from the outdoor system compared to indoor housing of sows and weaners. There is, however, an increased risk of nitrate leaching from the outdoor system compared to fully-housed systems. GHGE from the alternative system are 14% lower than the average for the pig sector.

Poultry production is relatively efficient compared to other livestock sectors (Tables 3 and 8), and there was relatively little scope for reductions in GHGE compared to other sectors in this livestock sector, in agreement with more detailed studies of poultry meat and egg production systems (Wiedemann and McGahan, 2011; Leinonen et al., 2012a,b). The alternative system of poultry meat production is indoor-housed with immediate incorporation of manure into soil, which reduced GHGE by 4% compared to the average for the sector due to a potential saving in fertiliser for feed production. An additional 3% reduction was achieved through an improvement in FCR so that it was equivalent to that achieved by the top 10% of units, without feeding higher than average levels of dietary crude protein. The best alternative system of egg production is also indoors, with manure as slurry dried under-floor and incorporated immediately after being spread on land. This system was reflected in a reduction in GHGE of 10% compared with the average for the sector. An additional 3% reduction was achieved if the average

Table 9: Nitrogen use efficiency (NUE): Typical and alternative livestock systems

Sector	Typical system	Alternative system
	NUE (%)	
Milk	18.3	25.5
Dairy beef	16.9	18.8
Suckler beef	7.5	7.8
Sheep meat	5.8	6.8
Pig meat	26.8	28.3
Poultry meat	32.7	37.4
Eggs	24.5	28.3

FCR was improved to that currently achieved by the top 10% of units.

A continuing challenge in livestock nutrition is to define the requirement of the animal more accurately with respect to essential amino acids in order to meet requirements without over-supplying N in the diet, and to reduce excreted N, particularly as urea in urine (Weiske and Michel, 2007). Estimates of livestock NUE, defined here as N in animal product as a percentage of total N intake, for the typical and alternative systems are shown in Table 9. Values for the NUE of livestock systems were substantially lower than those for crops (Table 7). However, in calculating NUE no credit is given to nitrogen in manure, most of which is recycled into the production of crops for animal feed either directly or indirectly and which could result in longer term efficiency values considerably higher than those quoted in Table 9. Comparing different livestock sectors, the ranking of NUE is in broad agreement with that for GHGE, i.e. poultry meat has the highest and sheep meat production the lowest NUE.

There is clearly potential for improvement in livestock NUE, though it is evident from the NUE values for the alternative systems that the scope for improvement is relatively low for suckler beef, sheep meat and pig meat production. Possibly some of the alternative technologies chosen by the model for their potential effects on reducing GHGE are incompatible with others which might be selected for increasing NUE since they have relatively more impact on methane than on nitrous oxide emissions. Research is needed to confirm the extent to which diets lower in crude protein are effective in increasing NUE and in reducing GHGE in all livestock sectors without compromising animal performance. Thus at pasture the grazing animal is offered high-protein herbage which is associated with low NUE (Beever et al., 1978; Dewhurst, 2006) and novel approaches are needed to increase capture of N by the grazing animal. One reason for the apparent over-use of protein in diets for livestock is that reductions in animal performance are often seen when livestock are given diets of reduced crude protein concentrations. There is an inverse relationship between crude protein concentration of the diet and feed conversion ratio, even when (in the case of chickens) diets are given which provide essential amino acids in excess of the requirement of the bird (Ferguson et al., 1998). Thus it is often the case that animals are given diets which contain more protein than is optimal in order to maximise daily growth and minimise days to slaughter.

4. Conclusions

The main conclusion from this study was that reductions in GHGE per unit of product and increases in NUE were theoretically possible with the same technological strategies. Thus options which reduced GHGE per kg product also increased NUE, in some cases (e.g. sugar beet) apparently to values close to 100%. Differences between crops in GHGE reflected differences in yield per hectare. Thus sugar beet and forage maize had the lowest GHGE per tonne of crop and per MJ of energy because of their relatively high yields per hectare. Of the options found to reduce crop GHGE, reduced fertiliser N and increased yield per hectare were the most significant, giving reductions in GHGE of between 5% and 15% compared to typical systems.

Livestock GHGE per unit of product were an order of magnitude higher than those from crops. Values for NUE were substantially lower for livestock than for cropping systems. These results pose major challenges to those involved in livestock research, development and production in the light of likely increased future demand for milk and meat (Godfray et al., 2010).

Options found to reduce GHGE in livestock production were increased fertility, fecundity and longevity of breeding females, increased annual milk yield per dairy cow, improved FCR in meat animals and immediate incorporation of slurry following its application to land. Alternative systems were associated with reductions in GHGE of between 7% (poultry meat) and 21% (sheep) compared to the average for the sector. Small increases in NUE were also seen in the alternative systems compared to the average for the sector.

Uncertainties in the estimation of agricultural GHGE (IPCC, 2006) may make it difficult, if not impossible, to measure emissions directly on farms. Indirect indicators of GHGE, such as the technologies described in this paper, may have to be used as an alternative approach to the estimation of GHGE mitigations (DEFRA, 2011).

The results of this theoretical study show that improvements in productivity and efficiency of resource use are likely to result in lower GHGE per unit of product and increases in NUE. However the best that is likely to be achieved overall is around a 10% improvement, in agreement with the aspiration of the UK Greenhouse Gas Action Plan (Agricultural Climate Change Task Force, 2010). There is scope to reduce GHGE in all sectors by applying existing knowledge. Given the importance of nitrous oxide as an agricultural greenhouse gas, a major environmental challenge for future agricultural research is to increase NUE without compromising output or methane emissions.

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Typology of farm management decision-making research

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ABSTRACT

A review of 183 papers published between 1990 and 2006 led to development of a typology of farm management decision-making (FMDM) research. An existing model which categorises decision research according to purpose as being either *Analytical* (descriptive), *Normative*, or *Prescriptive* was blended with a second form of categorisation based on six emergent decision domains: (1) *factors*; (2) *processes*; (3) *events*; (4) *evaluation*; (5) *patterns*; and (6) *aids*. The result was a typology of seven main discernible types of FMDM research with four being Analytical in purpose (Factors, Processes, Events and Patterns), two being Normative (Event and Evaluation), and the last being Prescriptive Aid. Each of these types is outlined and examples of representative publications listed. Finally, some trends in publication patterns, in accord with this typology, are presented. This work is presented in the hope it helps readers to navigate more easily though a large and complex literature.

KEYWORDS: Farm management; research; typology; decision-making

1. Introduction

Understanding how farmers make decisions is of great interest to many stakeholders including researchers, extension workers, policy makers, input suppliers, product marketers and supply chain managers. The field of farm management decision-making (FMDM) research has a long history, and now is represented in a vast and multi-faceted literature which can be seemingly impenetrable to the casual reader and even to the experienced researcher. This paper attempts to address the maze of FMDM research literature by providing a guide or 'road map' based on the type and purpose of research. It was developed as part of doctoral research into decision making by farmers of the Republic of South Korea. Our aim is to share with others what we believe is a useful typology of decision theories and research methods used in FMDM research. We also report on several trends apparent in recent FMDM literature.

2. Materials and methods

The review of FMDM research was conducted in two steps with an initial broad overall review being followed by an in-depth review. The overall review was focused on establishing a general profile of FMDM from the research publications to allow categorisation, and the in-depth review was conducted to deal with the more detailed characteristics of FMDM, such as the research methodology employed.

FMDM research was reviewed through the following procedures:

(1) For ease of electronic access, it was decided that the review would include all articles published since 1990 and listed on two powerful databases: 'CAB abstracts®' and 'Science Direct'. 'CAB abstracts®' was selected because at the time this study commenced, it had been reported to be the most comprehensive of all available applied life sciences bibliographic databases emphasising agricultural literature (Kawasaki 2004). 'Science Direct' is another comprehensive database with a strong agricultural coverage that was available through University of Queensland (UQ) Library resources at the time. This review yielded a total of 183 journal articles. Although much useful FMDM research had also been published prior to 1990, it was considered impossible to review all of these articles within the time constraints of this research. Furthermore, it was also difficult to gain electronic access to the full text of these earlier articles. The key words for searching the databases were 'farm* and decision*' which captured any articles including the words 'farm' (e.g. farmer or farm management) and 'decision' (e.g. decision-making, decision process or decision support) within their title.

(2) Full length text articles available in English were obtained and reviewed in full, whereas for those published in other languages the review depended on their abstracted text.

(3) The initial broad review focused on comparing the aims and area of each study, and resulted in the identification of two main categories and nine subcategories. The second, in-depth review resulted in the consolidation of these into seven types of FMDM research.

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3. Categorisation of FMDM research

During the 15 year period of publication under review, it was found that much research dealing with farmers' decision-making had been conducted in various farm management research areas (e.g. production, marketing, financial, resources, environmental management and so on) and for various purposes. As a result, these different areas of FMDM research were broken into two main categories according to: (1) research aim or purpose (Purpose Category); and (2) the domain of FMDM research (e.g. decision factors, decision processes) on which the research was focused (Domain Category). By establishing these two main categories, seven types of FMDM research were consolidated.

Purpose Category research

For Purpose Category**,** three subcategories relating to research purpose were adopted and included descriptive (D), normative (N) and prescriptive decision research (P), in accordance with the analysis provided by Bell, Raiffa and Tversky (1988) and Rapoport (1989). The Purpose Category and its three subcategories are illustrated in Table 1. For greater consistency with standard economics terminology, the Descriptive subcategory was renamed Analytical in this study.

Analytical decision research (subcategory A), which is typically studied in psychology (especially social psychology) and the other behavioural sciences, deals with questions pertaining to how people really *do* make decisions. Analytical decision research begins with observations of how decision makers (e.g. farmers selected to be observed) make choices in given situations (e.g. financial issues that need to be tackled) and attempts to describe systematically (inductively) the decision processes or social phenomena resulting from their decisions (e.g. causes and effects of observed events described in terms of psychological states (motivations, preferences, satisfaction, disappointment etc)). The purpose of analytical decision research is to identify the rules determining the decisions of certain classes of decision makers and to predict decisions or their consequences.

In contrast, normative decision research (subcategory N), which is usually studied in the context of economics, statistics and mathematics, is aimed at addressing the question of how people *ought to* (*should*) make decisions in given decision situations. Normative decision research relies upon the use of mathematical language in which the precise definitions of terms, deductive analysis and assumptions of idealised conditions (rationality) are essential. This is the reason why normative studies are considered both formal and optimal (Bell *et al*., 1988; Einhorn and Hogarth, 1988). Thus, the main objective of normative decision research is to reveal the logical essence of an idealised decision problem (Rapoport, 1989).

Prescriptive decision research (subcategory P) is focused on *how* to help people to make good decisions or *how* to train people to make better decisions. Thus, prescriptive research, which is usually studied in the disciplinary area of operational research or management science, uses elements of both logical consequences (normative study) and empirical findings (descriptive study), but also draws on a level of prescriptive analysis which differentiates it from normative and descriptive (analytical) approaches (Bell *et al*., 1988). One good example of a prescriptive study is the development of decision support systems (DSS).

Category II research

Category II (the domain of decision research) is made up of six subcategories. These were the main subcategories that emerged in this review and were identified as: (1) the decision factors affecting farmers' decision-making; (2) decision processes; (3) decision events; (4) decision outcomes evaluation; (5) decision patterns; and (6) decision aids (see Table 2).

Identifying these six subcategories was difficult and somewhat arbitrary because the majority of the previous studies addressed more than one subcategory, and also because the subcategories themselves cannot be neatly separated by explicit definition. This is a weakness in categorising FMDM research and it was found that some of the previous studies could be included, at least to some extent, in every subcategory. However, in spite of the difficulties and weaknesses associated with classification, the decision research area was ultimately classified by considering elements of the FMDM research that had been emphasised by previous researchers because the purpose of classifying the previous studies was not to define them by rigorous criteria.

Subcategory 1, the decision factors, includes studies that deal mainly with the factors influencing farmers' farm management decision-making such as economic, environmental and social factors (external factors) and farmers' goals, motivations, attitudes, personality, and biography (internal factors). Studies that deal with farmers' full decision-making process from detecting problems through to implementing decisions are categorised into subcategory 2, the decision process. Studies focusing on farmers' decisions about a specific event in a decision situation, such as uncertain or risky situations, are grouped into subcategory 3, the decision event. Studies attempting to evaluate decision outcomes or identify the relationship between farmers' decision-making and their performance are classified into subcategory 4, the decision outcome. Subcategory 5, the decision pattern, includes studies with a focus on the identity and roles within the farm household of the main

Table 1: Classification of farm management decision research by purpose

Categories	Subcategories	Main focus
Category I: The aim of FMDM research	Analytical (descriptive) study Normative study Prescriptive study	Understanding how farmers actually make decisions Providing solutions for how farmers should (ought to) make decisions Developing decision support systems to help farmers make better decisions

Table 2: Classification of farm management decision research by domain

Categories	Subcategories	Concepts
Category II: FMDM research domain	Decision factors (1)	Factors affecting farmers decision-making
	Decision processes (2)	Farmers' decision-making process from detecting problems to implementing decisions
	Decision events (3)	Farmers' decision on the specific event under the special situation (uncertainty, risk, or multi objectives)
	Decision evaluation (4)	Evaluation of decision outcome or relationship between D-M and performance
	Decision patterns (5)	Major roles of main decision-maker within family members
	Decision aids (6)	Decision support system (DSS) or other helpful means to improve farmers' decision-making

decision makers. Finally, subcategory 6, the decision aid, is strongly related to studies developing decision support systems (DSS) or extension services for the purpose of assisting farmers' decision-making.

Consolidated typology of FMDM research

The review of these two forms of categorisation allowed for their consolidation into a single scheme to identify seven main types of FMDM research (see Table 3). This was achieved by combining the purpose of FMDM research (Category I) and the FMDM research domain (Category II) as illustrated in Figure 1. This figure shows that with three types of research purpose (analytical, normative and prescriptive) and six research domains (factors, processes, events, evaluation, patterns and aids) an 18 cell (6X3) matrix may be created. However, only seven of these cells have been populated by the categorisation of research reported. Each of these seven types of FMDM is briefly described in Table 4 with some examples of key references relating to each type. Explanatory notes and discriminating features for each type of FMDM research are set out below.

Analytical Factors (AF): Studies that describe and analyse the factors influencing farmers' decision-making

Analytical factors decision research is focused on identifying and analysing the factors that affect farmers' decision-making in either day-to-day management decisions or in given decision situations. Many studies similarly conclude that the factors influencing farmers' decision behaviour tend to differ among farmers due to differences in their goals, resources, level of knowledge, environment and their approaches to confronting uncertainty. Therefore, researchers agree that given these variations it can be quite difficult to identify the key determinants affecting farmers' decision behaviour. However, these types of studies tend to be carried out with the purpose of identifying the diverse variables that are needed to build farmers' decision models or to identify the implications related to the provision of extension services or policy making.

Various factors influencing farmers' decision-making have been studied. With respect to internal aspects, farmers' attitudes and objectives, which are generally believed to depend on their beliefs, values or personalities, are thought to strongly affect farmers' behaviour (Tassell and Keller, 1991; Farinos Dasi, 1994; McGregor *et al*., 1996; Willock, J. *et al*., 1999). Many decision studies have found that farmer characteristics such as age, education, farm size or farm income level have very close relationships with decision behaviour (Featherstone and Goodwin, 1993; Fox *et al*., 1994; Stirm and St-Pierre, 2003; Bragg and Dalton, 2004; Chianu and Tsujii, 2004; Selvaraju *et al*., 2005; Iqbal *et al*., 2006). Solano *et al*. (2006) analysed the impact of farmers' biographical variables and decision-making profiles on farm management and performance and concluded that among the biographical characteristics, education level and age most strongly affected the majority of management practices (decision-making). However, it was found that education level affected these practices positively, while age affected them negatively.

With regard to the external factors associated with farmers' decision behaviour, environmental and economic factors (Kolodinsky and Pelch, 1997; Illukpitiya

Table 3: Categorisation of FMDM research published between 1990 and 2006

Farm Management Decision-making Research Domain	FMDM Research Purpose		
	Analytical (n=95)	**Normative (n=26)**	**Prescriptive (n=62)**
DM Factors	Analytical Factors (n=28)		
DM Process	Analytical Process (n=14)		
DM Event	Analytical Event (n=29)	Normative Event (n=21)	
DM Evaluation		Normative Evaluation (n=5)	
DM Pattern	Analytical Pattern (n=24)		
DM Aid			Prescriptive Aid (n=62)

(n=number of papers categorised)

Table 4: Typology of farm management decision research

Types	Description	Examples
Analytical Factors (AF)	Studies on the understanding or analysis of **factors** influencing farmers' decision-making	(Featherstone and Goodwin, 1993; Kolodinsky and Pelch, 1997; Willock, Joyce *et al*., 1999; Solano *et al*., 2003; Stirm and St-Pierre, 2003; Bragg and Dalton, 2004; Iqbal *et al*., 2006)
Analytical Process (APr)	Studies on the understanding of the farmers' **decision processes**	(Gonzales-Intal and Valera, 1990; Murray-Prior, 1998; Ohlmer *et al*., 1998; Murray-Prior and Wright, 2001; Dounias *et al*., 2002)
Analytical Event (AE)	Studies on certain farm management **decision issues** by the way of descriptive approach	(Mistry, 1998; Bandong *et al*., 2002; Vaarst *et al*., 2003; Matshe and Young, 2004; Blackett *et al*., 2006)
Analytical Pattern (APa)	Studies dealing with **decision patterns** or decision makers' **decision styles**	(Timsina *et al*., 1992; Rogers and Vandeman, 1993; Kalinda *et al*., 2000; Ozkan *et al*., 2000)
Normative Event (NE)	Studies dealing with rational **decision models** on specific issues especially under uncertainty or risk	(Piech and Rehman, 1993; Juan *et al*., 1996; Backus *et al*., 1997; Strassert and Prato, 2002; Humphrey and Verschoor, 2004; Pritchett, 2004)
Normative Evaluation (NEval)	Studies on **evaluation** of the outcomes of decision behaviour	(Varela-Ortega *et al*., 1998; Buysse *et al*., 2005; Qiu, 2005)
Prescriptive Aid (PA)	Studies aimed at developing decision **support systems** or useful means to help farmers make better decisions	(Gauthier and Neel, 1996; Attonaty *et al*., 1999; Morag *et al*., 2001; Pomar and Pomar, 2005); (Dorward, 1991; McCown, 2001; Swinton *et al*., 2002; Coleno *et al*., 2005)

and Gopalakrishnan, 2004; Lindgren and Elmquist, 2005) and government policies (Hollick, 1990) have significant impact on farmers' decision-making. It is also clear that farmers' preferred information sources (Solano *et al*., 2003), the role of information or knowledge (Casey *et al*., 2002), and information systems (Streeter, 1992; Verstegen *et al*., 1998) have played a very important role in farmers' decision-making.

Analytical Process (APr): Studies focusing on farmers' decision processes

Analytical Processes and ***Analytical Factors*** types of decision research are usually predicated on the belief that the main reason for the failure of polices or programs that are launched with the purpose of improving farm management is a lack of understanding of farmers' decision behaviour or decision processes (Ohlmer *et al*., 1998; Murray-Prior and Wright, 2001; Bekele and Drake, 2003; Illukpitiya and Gopalakrishnan, 2004). Therefore, both types of decision research share a similar research purpose.

The decision research included in type ***APr*** attempts to describe and predict farmers' decision-making behaviour through developing an understanding of the process of decision-making. The work of Ohlmer *et al.* (1998) is a good example of this type of decision research. They initially used the traditional model of the decision-making process (i.e. values and goals, problem detection, problem definition, observation, analysis, development of intention, implementation and responsibility bearing) in order to describe the farmers' full decision-making process. They subsequently used this approach to revise a conceptual model of the decision-making process.

In an another example of type ***APr***, a hierarchical decision model (Gladwin, 1980; Gladwin, 1989) employs a two stage decision process, which can be represented as a decision tree, to describe and predict farmers' decisions. Such a model is based on an ethnographic approach for building the decision models. Gladwin (1980) has claimed that hierarchical decision models studied in many cultures have a high level of predictability with these models predicting around 85 to 95% of actual decisions. In the first stage, decision makers are assumed to quickly narrow down the possible alternatives to a small set by eliminating all those that fail to pass a set of criteria or aspects. This is a form of 'elimination by aspects' theory (Tversky, 1972). This first step, called 'a pre-attentive process' (Murray-Prior, 1998), is used to simplify the problem rapidly and often unconsciously. Once two or three alternatives remain, decision makers take the conscious or 'hard core' step of entering the decision process, which can be further divided into six steps for more comprehensive analysis. Thus, this stage, called 'a conscious stage' (Murray-Prior, 1998), is 'essentially an algebraic version of maximization subject to constraints and may be represented by an algorithm, decision tree or table, or set of decision rules' (Gladwin, 1980).

Similarly, Gonzales-Intal *et al.* (1990) employ a three stage crop decision model that is a modified version of Gladwin's (1980) hierarchical decision model. In the first stage, the family's rice consumption requirement is considered before an elimination process of alternatives is undertaken in the second stage. Gonzales-Intal *et al.* (1990) postulate that after the first stage of the decision process, farmers will choose to plant the diversified crop by moving into the same process as described in Gladwin's hierarchical decision model.

In addition to the hierarchical decision model, many studies (Kirchner *et al*., 2004; Le Quang and Mensvoort, 2004; Pritchett, 2004) both in the descriptive and normative traditions, have employed decision tree techniques to build up the decision model and to test its effectiveness by visualising complex decision processes and their relationships.

However, most ***APr*** decision research concludes that the process of farmers' decision-making is very complex and does not follow a linear process. Thus, in order to understand farmers' decision processes, they need to be considered within a broad context.

Analytical Event (AE): Studies focusing on decision issues with descriptive approaches

Type ***AE*** decision research is focused on the alternatives that farmers tend to choose rather than the decision-making factors (type ***AF***) or the full decision-making process (type ***APr***). This study type attempts to describe or analyse which alternatives are chosen by farmers in response to certain decision issues so that researchers can develop a better understanding of farmers' decision-making with regard to specific issues related to farm management, for example, allocation of land use, pest management, water management, and so on.

However, ***AE*** research typically has a broader research boundary than types ***AF*** and ***APr.*** This is because some AE research considers both decision factors and decision processes in order to achieve research objectives (Mistry, 1998; Bekele and Drake, 2003; Blackett *et al*., 2006). Some ***AE*** research also employs decision tree models to depict the process of choosing between the alternatives or to describe farmers' decision behaviour (Gonzales-Intal and Valera, 1990; Bhuiyan *et al*., 1995; Le Quang and Mensvoort, 2004).

Analytic Pattern (APa): Studies dealing with decision patterns or decision styles

Most ***APa*** research deals with the roles of farm family members, especially women, in decision-making about both on and off-farm activities. This is due to the increasing recognition of the importance of women's participation in farming, especially in developing countries, such as India, where women are increasingly becoming involved in almost all stages of farming. Thus, this type of decision research attempts to seek answers to the following research question: To what extent and in what kinds of farm management decision-making do women participate?

Many studies concerning women's participation in decision-making processes (Timsina *et al*., 1992; Kalinda *et al*., 2000; Masur, 2000; Ozkan *et al*., 2000; Debasish *et al*., 2005) have found that male family members tend to dominate decision-making about farm management, especially in relation to matters of financial management. Despite this, it has also been observed that in decisions relating to production or marketing management, men and women tend to make decisions jointly.

However, these studies do not place a strong emphasis on whether women's participation in the decision-making process is beneficial to farm management decision-making or examine why women's role in decision-making is important. Therefore, in terms of family members' partnership and better decision-making, the importance of women's participation in the decision process needs further study.

Normative Event (NE): Studies dealing with rational decision models especially under conditions of uncertainty and risk

Although both ***AE*** and ***NE*** research deal with decision issues or decision events, ***AE*** is very different from type ***NE*** due to the different approach that is adopted to the research problem. This difference can best be described as the former type entailing a descriptive study whereas the latter type is normative in its approach.

In the studies on a particular decision event, especially in normative decision studies, decision makers are assumed to have profit-maximising or cost-minimising intentions amongst their multiple objectives. In these cases, the decision makers' goals, objectives and values are also assumed to be known. Further, the consequences of alternative decisions may be known, probabilistically known or unknown depending on the decision issues under consideration.

Type ***NE*** decision research aims for an optimal and rational decision model which farmers *should* consider when they choose one alternative over another, especially in uncertain or risky situations. Type ***NE*** research is typically carried out on the basis of economic theory, for example, subjective expected utility theory (Backus *et al*., 1997) or multiple criteria decision models (Piech and Rehman, 1993; Strassert and Prato, 2002).

Normative Evaluation (NEval): Studies focusing on the evaluation of the outcomes of decision behaviour

The main purpose of type ***NEval*** decision research is to assess or evaluate the consequences of decision-making on the basis of the assumption that the farmer as a decision maker tries to maximise his/her profit function. However, this type of research concerning the evaluation of decision outcomes was found to be relatively rare in both the normative and descriptive decision research that was published during the period under review.

To evaluate the economic or environmental impact of decision-making, a multi-criteria decision-making (MCDM) model (Martinez-Cordero and Leung, 2004; Qiu, 2005) or a farm household optimisation model (Bernet *et al*., 2000) is employed. Buysses *et al*. (2005) and Varela-Ortega *et al*. (1998) have used this approach to evaluate the impact of decision-making on the nutrient balance of dairy farms and the impact of the changes of policies on decision-making respectively.

From an examination of type ***NEval*** research, it is evident that decision outcomes can be evaluated in various ways such as by economic performance, environmental benefit, or the impact of policies. The evaluation of decision outcomes is critical to recognising the importance of farmers' decision-making. However, other aspects like farmers' values or preferences also need to be considered because the outcome of decisions can also be evaluated in a subjective manner. For example, the level of the decision-makers' satisfaction could be varied according to their values on different aspects of farming, from leisure time to profit.

Prescriptive Aid (PA): Studies aimed at developing decision tools or means to help farmers make better decisions

In type ***PA*** research, a number of web-based or computer-based systems and software programs have been developed to help farmers or advisors collect and analyse various types of information effectively and use it to inform their decision-making (Kerr *et al*., 1999; Bracke *et al*., 2001; Morag *et al*., 2001; Pomar and Pomar, 2005).

However, as the use of computers and access to the Internet has increased among farmers, PA research generally focuses on the development of new decision support systems (DSS). In spite of their potential usefulness, DSS remain unavailable or unhelpful to many farmers, particularly those who are relatively poor, old or less educated, even in developed countries. Therefore to be effective, ***PA*** research should not only deal with the development of user-friendly DSS but also be accompanied by the appropriate delivery of education or extension programs to train and equip farmers to make better decisions.

Trends in FMDM research

Further analyses were conducted as part of the process of reviewing the FMDM publications since 1990. The initial stage of analysis was directed at detecting any noticeable trends in the type of research being published, the second stage at identifying patterns of publication by the country of origin, and the third stage focused on the aspect of the research. The results are presented and briefly discussed below.

Trends by year and country

The number of FMDM research publications increased significantly from 39 articles during the period 1990–1994 to 79 articles during the period 2000–2006 (see Table 5). As the circumstances surrounding farm management have become more complex and also increasingly affected by unpredictable variables, it is evident that researchers' concerns about farmers' behaviour and decision-making have also been increasing. FMDM research has been consistently dominated by Prescriptive Aid (PA) research, representing one third of all publications, followed in order of frequency by AE, AF, APa, NE, Apr and finally NEval.

Further, there have been an increasing number of publications within the categories ***Analytical Event (AE), Analytical Pattern (APa)*** and ***Prescriptive Aid (PA)*** during the first half of the 2000s compared to those published in the first half of the 1990s. It was also observed that there has been a decrease in category Analytical Process ***(APr)*** publications since the second half of the 1990s. The number of normative decision studies ***(Normative Event (NE)*** and ***Normative Evaluation (NEval))*** has continued to increase steadily over time.

Four nations dominate the publication of research in this area, with half of all publications coming from the USA (35), India (29), the UK (17) and Australia (11). It is noteworthy that India has played such a significant role in publication, and also that a large proportion of its publications are of type ***Analytical Pattern (APa)***. This is a domain relatively neglected elsewhere that deals with family management patterns and more specifically, the role of women in farm management.

Trends by aspect of farm management

Only 68 of the 183 FMDM research articles that were reviewed dealt with farmers' decisions across the whole span of farm management, while the remaining articles focused on decision behaviour in particular farm management areas such as production or resource management (Table 5). As environmental issues (e.g. soil or water management) and production management (e.g. issues related to organic products) have increasingly become matters of social concern in terms of sustainable farming or consumer-oriented agriculture, the need for decision-making studies on these farm management areas has increased in recent years.

On the other hand, in spite of the importance of marketing and financial management in farmers' business performance, relatively few studies have been published on these aspects of FMDM research. In particular, as shown in Table 6, few ***Analytic Process (APr)*** and ***Analytic Event (AE)*** studies have been carried out in the financial management research area.

Consequently, it is apparent that one trend in the FMDM research has been a move away from a broader understanding of farmers' decision-making (e.g. types ***AF*** and ***APr***) to a more detailed analysis of the specific decision matters (e.g. types ***AE*** and ***NE***) leading to the development of decision support systems (type ***PA***).

4. Research methods used in descriptive FMDM research

Research methodology can normally be divided into two main categories. These categories are qualitative and quantitative research. These two approaches to research methodology have markedly different philosophical backgrounds, use different research questions and styles of research design, including the ways data are collected and analysed, and apply very different modes of interpretation and description to the resultant findings. Generally, the aim of qualitative research is to add to the body of knowledge through improved understanding of the nature and meaning of social phenomena on their own terms, while that of quantitative

Table 5: Farm management decision-making research by year and by country

Type	By year			By country					Total
	1990–94	1995–99	2000–06	USA	India	UK	Australia	Others	
AF	9	7	12	8	2	6	1	10	28
APr	1	10	3	2	1	–	3	8	14
AE	2	13	14	5	4	3	–	17	29
APa	5	8	11	1	17	–	–	6	24
NE	4	8	9	4	3	1	–	13	21
NEval	–	1	4	1	–	1	–	3	5
PA	18	18	26	14	1	6	7	34	62
Total	39	65	79	35	29	17	11	91	183

Table 6: Farm management decision-making research by aspect of farm management

Type	Whole farm management	Managerial ability	Production management	Marketing management	Financial management	Resource management	Environmental management	Total
AF	7	9	2	1	2	4	3	28
APr	6	4	3	–	–	–	1	14
AE	6	3	8	1	–	7	4	29
APa	20	1	–	–	2	1	–	24
NE	8	–	7	1	2	1	2	21
NEval	3	–	2	–	–	–	–	5
PA	18	13	9	2	5	11	4	62
Total	68	30	31	5	11	24	14	183

research is to add to the body of knowledge by building on formal theory that explains, predicts and controls the phenomenon of interest (Morse, 1994; Merriam, 1998b; Golicic *et al*., 2005). Qualitative research often incorporates numeric data such as descriptive statistics, and may employ sampling procedures based on principles fundamental to quantitative research.

Analytical FMDM research tends to use qualitative methods more frequently than normative or prescriptive research, and it was observed that only 6% of normative and prescriptive research studies reviewed for this study used qualitative methods to collect data. This difference tends to be because of the nature of analytical FMDM research. Among the analytical FMDM research papers reviewed, 73% used both qualitative and quantitative methods to collect data concerning farmers' decision behaviours by surveying large numbers of farmers using structured questionnaires and analysing this data using simple statistical methods. The remainder of these studies reported collecting data through qualitative methods such as in-depth interviewing or participant observation, and analysing this data by using 'thick' description. Furthermore, almost all analytical FMDM researchers visited the field to collect qualitative and quantitative data by meeting with farmers personally, while only 5% of studies relied on the use of a mail survey for the purpose of surveying large numbers of subjects.

Qualitative methods in analytical FMDM research

In analytical FMDM research, the most commonly reported method of collecting data was by communicating with farmers personally in the field (e.g. in-depth interviewing or participant observation). In order to determine farmers' beliefs, values and actual decision behaviour, most researchers also expressed a preference for going into the field.

The case study is one of the most common qualitative methods used in descriptive FMDM research. Researchers conducting case study research tended to use non-random samples in specific study areas (Bandong *et al*., 2002; Bohnet *et al*., 2003; Le Quang and Mensvoort, 2004) or specific study groups (Streeter, 1992; Ohlmer *et al*., 1998; Murray-Prior and Wright, 2001; Vaarst *et al*., 2003; Blackett *et al*., 2006) in accordance with their research purposes, and interviewed their subjects using open-ended or semi-structured questionnaires. For example, with respect to conducting research with a specific study group, Streeter (1992) carried out in-depth interviews with four farmers and one grain purchaser to explore the impact of electronic information systems on decision-making, and Vaarst *et al*. (2003) used similar techniques to survey 20 farmers who had converted to organic farming within the last two years. Murray-Prior *et al*. (2001) also selected two groups of farmers, a development group and a test group, to develop models of Australian wool producers' production and marketing decisions and to test the refined models.

Some researchers also visited farmers several times over several years (Ohlmer *et al*., 1998; Bandong *et al*., 2002). Ohlmer *et al*. (1998) undertook 18 case studies of individual farmers to determine how they made decisions, and they studied two cases longitudinally for three years through repeated interviews. Bandong *et al.* (2002) carried out surveys in four irrigated rice sites in the Philippines over a span of eight years (1984–1991) to explore farmers' insecticide decision-making protocol. They also visited farmers who were selected randomly across the four sites to interview them and record field notes.

In analytical FMDM research, the data collected through the above qualitative methods were analysed by 'thick' description (Streeter, 1992) and using the decision tree method (Murray-Prior and Wright, 2001; Le Quang and Mensvoort, 2004). Vaarst *et al.* (2003) used a grounded theory approach to categorise the data they collected.

Quantitative methods in descriptive FMDM research

Most of the analytical FMDM research using quantitative methods employed a combination of qualitative and quantitative data obtained in three main ways: the structured interview; mail surveys; and statistical data sets. Quantitative data were analysed through various statistical methods (e.g. from the simple mean, variance or factor analysis through to complicated empirical analysis) to test the decision model or to explore the relationships that existed among various factors.

The first method of data collection, and the most common method used in descriptive FMDM research, involved going into the field and conducting structured interviews with large numbers of farmers who had been selected randomly (Gonzales-Intal and Valera, 1990; Willock, J. *et al*., 1999; Solano *et al*., 2003; Chianu and Tsujii, 2004; Selvaraju *et al*., 2005). For example, Gonzales-Intal *et al.* (1990) collected data on crop diversification from six case studies in the Philippines by conducting structured interviews with 266 farmers who had been selected randomly to test cropping decision tree models. Similarly, Chianu *et al.* (2004) interviewed 160 Nigerian farmers in four villages using a structured questionnaire to investigate the factors affecting farmers' decisions to adopt or not adopt inorganic fertiliser.

The second method of data collection involves undertaking a mail survey that can sample a larger number of farmers with various characteristics from a wider range of study areas. This method also requires less time and expenditure than conducting surveys in the field (Tassell and Keller, 1991; McGregor *et al*., 1996; Stirm and St-Pierre, 2003; Bragg and Dalton, 2004). Nevertheless, a mail survey may face some problems. These relate to the quality of the data as well as the response rate. Most researchers conducting mail surveys express some concerns about these issues. In some cases, respondents may leave questions blank or skip over them, and they may misunderstand the meaning of questions. These problems can cause the data quality to be compromised, with consequences for both the accuracy and the value of analyses.

The third method of data collection relies on the use of statistical data, for example, data generated through livestock breeding data sets or farm accounting systems (Woldehanna *et al*., 2000; Kirchner *et al*., 2004). Some studies have employed secondary data or accessed databases relating to their research goals as a complementary method (Timsina *et al*., 1992; Rogers and Vandeman, 1993; Lindgren and Elmquist, 2005). Although this method allows cross-sectional data or time-series data to be collected that allow statistical analysis, the scope for the analysis of various and complex situations (e.g. complicated decision behaviour or processes) may be limited.

Consequently, it can be concluded that qualitative methods, in which researchers typically go into the field, for example to conduct interviews with farmers using semi-structured or open-ended questionnaires, are a common and useful method for analysing diverse decision situations, processes and patterns. In addition, the quantitative approach, in which data are analysed by statistical methods, is also useful for exploring relationships between the variables and factors that affect the decision-making process.

5. Conclusion

In this paper, FMDM research has been reviewed to document the kinds of research that has been published since 1990 and a scheme for its categorisation proposed. Prescriptive FMDM research (***type PA***) that aims to support farmers' decisions by developing various computer systems or software dominates FMDM research. However, it could be argued that studies that improve understanding of decision processes should be conducted prior to development of decision support systems because better understanding can be the foundation of developing more useful decision support systems. A notable feature of this analysis is the relative paucity of studies into marketing, financial and environmental aspects of management (respectively 5, 11 and 14 of 183 studies) despite the growing evidence of the importance of these dimensions to sustained success of farm businesses.

About the authors

Jong-Sun Kim is a researcher at the Korea Rural Economic Institute, South Korea. His main research areas are agricultural management and rural development. He has recently finished a research project that aims to suggest effective ways of using registered farmers' managerial information for implementing agricultural policies. He is now conducting a project regarding setting up plans for building an agricultural complex in a certain rural area for the purpose of boosting the local economy.

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ways in which to improve outcomes from human activity systems based on agriculture.

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REFEREED PAPER

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Predicting Malaysian palm oil price using Extreme Value Theory

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ABSTRACT

This paper uses the extreme value theory (EVT) to predict extreme price events of Malaysian palm oil in the future, based on monthly futures price data for a 25 year period (mid-1986 to mid-2011). Model diagnostic has confirmed non-normal distribution of palm oil price data, thereby justifying the use of EVT. Two principal approaches to model extreme values – the Block Maxima (BM) and Peak-Over-Threshold (POT) models – were used. Both models revealed that the palm oil price will peak at an incremental rate in the next 5, 10, 25, 50 and 100 year periods. The price growth level in Year-5 is estimated at 17.6% and 44.6% in Year-100 using BM approach. Use of the POT approach indicated a growth rate of 37.6% in Year-5 and 50.8% in Year 100, respectively. The key conclusion is that although the POT model outperformed the BM model, both approaches are effective in providing predictions of growth in prices caused by extreme events. The results could serve as a useful guide to farmers, exporters, governments, and other stakeholders of the palm oil industry informing strategic planning for the future.

KEYWORDS: Price forecasting; Extreme Value Theory; Block Maxima model; Peak-Over-Threshold model; Malaysian palm oil

1. Introduction

The past few years have seen an increase in the production of renewable fuels because of rising crude oil prices, limited supply of fossil fuels and increased concerns about global warming. The increase in oil price has caused many countries to consider using alternative renewable energy from the agricultural sector, particularly vegetable oils such as soybean, rapeseed, sugarcane, corn and palm oil. This increase in production reflects rising global demand for vegetable oils dominated by palm oil production (Carter, 2007). However, there are regional differences in the choice of vegetable oils used for conversion to biodiesel. For example, in Europe, the primary production of biodiesel is based on the use of rapeseed oil, in Brazil and the USA, the base is soybean oil, and in Malaysia, palm oil is the main source (Yu et al., 2006).

In the international market, expanding trade, continuous rises in demand, irregular supply, and other related factors (e.g., weather variations) have caused the price of palm oil to fluctuate. Apart from the unpredictable fluctuations in the natural production environment, the other main source of palm oil price movement is driven by its demand. The world demand for palm oil depends on demand for food, as well as demand for biofuels in the industrial sector. These two types of demand are currently fluctuating due to small share of palm oil in food as well as a decline in usage for biofuels. Therefore, the price of palm oil remains uncertain in the future. Figure 1 illustrates the fluctuation in monthly Malaysian palm oil futures price over a 25 year period (1986–2011). The price was only $182.00[5] per metric ton in July 1986, rising to a high of $1,033.57 per metric ton in July 2011, an increase of 468%. Instability in palm oil prices can create significant risks to producers, suppliers, consumers, and other stakeholders. With production risk and instability in prices, forecasting is very important to make informed decisions. Forecasting price changes is however, quite challenging, as its behaviour is very unpredictable in nature (MPOB, 2010).

The forecasting of agricultural prices has traditionally been carried out by applying econometric models such as Autoregressive Integrated Moving Average (ARIMA), Autoregressive Conditional Heteroscedastic (ARCH) and Generalized Autoregressive Conditional Heteroscedastic models (GARCH) (Assis et al., 2010). These models assume that the data are normally distributed. Therefore, predicting future prices using such approaches ignores the possibility of extreme events. We believe, however, that palm oil price predictions involve determining the probability of extreme events. To this end, the application of Extreme Value Theory (EVT) enables the analysis of the behaviour of random variables both at extremely high or low levels (e.g., caused by financial shocks, weather variations, etc.).

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[5] In December 2012, 1$ (US) was approximately equivalent to £0.61 and €0.75.

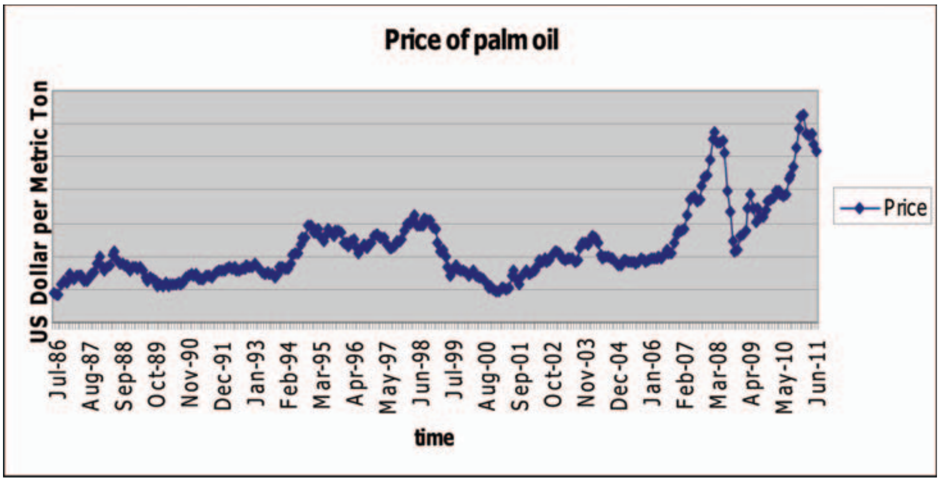

Figure 1: Palm oil monthly price, Jul 1986 - Jul 2011
Note: The Palm oil price of this paper is Malaysia Palm Oil Futures (first contract forward) 4-5 percent FFA, US Dollars per Metric Ton.
Source: www.indexmundi.com

Given this backdrop, the main objectives of this paper are: (a) to predict future prices of Malaysian palm oil, by applying EVT which takes into account the possibilities of extreme events; and (b) to compare two principal approaches to the modelling of extreme values – the Block Maxima (BM) and the Peak-Over-Threshold (POT) models – to predict the rates of growth of palm oil prices in the next 5, 10, 25, 50 and 100 year periods. The importance arises because forecasting future prices of palm oil using the most accurate method can help the government, buyers (e.g. exporters), sellers (e.g. farmers), as well as other key stakeholders of the palm oil industry, to plan strategically for the future.

The structure of the paper is as follows. Section 2 presents a brief overview of the major palm oil producers and production trends, a review of selected literature on forecasting palm oil prices and the application of EVT in forecasting future events. Section 3 presents the analytical framework and methods employed in this study. Section 4 presents the results leading to conclusions in Section 5.

2. Literature Review

Major palm oil producers and production trends

Palm oil is a type of fatty vegetable oil derived from the fruit of the palm tree. It is used in both food and non-food products. Palm oil is a highly efficient and high yielding source of food and fuel. Approximately 80% of the palm oil is used for food such as cooking oils, margarines, noodles, baked goods, etc. (World Growth, 2011). In addition, palm oil is used as an ingredient in non-edible products such as biofuels, soaps, detergents and pharmaceuticals. With such a wide range of versatile use, the global demand for palm oil is expected to grow further in the future (USDA, 2011).

Many countries plant oil palm trees to produce oil to fulfil their local consumption. World trade in palm oil has increased significantly due to an increase in global demand and the world production of palm oil has increased rapidly during the last 30 years, caused through the fast expansion of oil palm plantation in the south-east Asian countries. The world production of palm oil was 13.01 million tons in 1992, increasing to 50.26 million tons in 2011, a 286% increase in 19 years (USDA, 2011).

The major world producers and exporters of palm oil are Malaysia and Indonesia. For these countries, palm oil production for export purposes is found to be highly viable, and oil palm has become a favourite cash crop to replace other traditional crops such as rubber. Even here, the maintenance of high yields of the palm throughout the year is essential to achieve viability for the export market (MPOB, 2010). Indonesia is the largest exporter of palm oil in the world, exporting around 19.55 million tons a year during 2008–2011 (USDA, 2011). Malaysia is the second largest exporter nowadays and was the largest exporter of palm oil in the world until 2007, producing about 15 million tons of palm oil a year. Malaysia, has therefore, played an important role supporting consumption and remaining competitive in the world's oils and fats market (World Growth, 2011).

The main consumer and business market for palm oil is the food industry and, for this, the major importers are India, China and the European Union. India is the largest and leading consumer of palm oil worldwide, importing about 7.8 million tons in 2011. China is the second largest importer of palm oil importing about 6.65 million tons in 2011 (USDA, 2011). Current production of the world palm oil suggests an increase by 32% to almost 60 million tons by 2020 (FAPRI, 2010).

Forecasting palm oil prices

Previous works on forecasting palm oil prices and other agricultural prices were conducted by Arshad and Ghaffar (1986), Nochai (2006), Liew et al., (2007) and Karia and Bujang (2011) employing a range of forecasting techniques to predict palm oil prices. For example, Arshad and Ghaffar (1986) used a univariate ARIMA model developed by Box-Jenkins to forecast the short-run monthly price of crude palm oil. They found that the Box-Jenkins model is limited to short-term predictions. Nochai (2006) identified an appropriate set of ARIMA models for forecasting Thailand palm oil price, based on minimum Mean Absolute

Percentage Error (MAPE) at three levels. For farm level price, ARIMA (2,1,0) was seen to be most suitable, ARIMA (1,0,1) or ARMA(1,1) is suitable for wholesale price and ARIMA (3,0,0) or AR(3) is suitable for pure oil price. A further study on forecasting other agricultural prices using methods from the ARMA family was reported by Liew et al., (2007) which used the ARMA model to forecast Sarawak black pepper prices. This found that the ARMA model 'fits' the price and correctly predicts the future trend of the price series within the sample period of study. Assis et al., (2010) compared four methods – exponential smoothing, ARIMA, GARCH and mixed ARIMA/GARCH models – to forecast cocoa bean prices. They concluded that the mixed ARIMA/GARCH model outperformed the other three models within the sample period of study.

All of the above studies have used approaches from the ARMA family, which is widely known as the Box-Jenkins time series model. Karia and Bujang (2011) have attempted to forecast crude palm oil price using ARIMA and Artificial Neural Network (ANN). They concluded that the ARMA family works better with the linear time series data, whereas ANN performs better with the nonlinear time series data.

It should be noted that both the ARMA family and ANN approaches assume that the data is normally distributed. Therefore, all of the aforementioned studies suffer from this weakness of normality assumption. The next section briefly reviews the literature that has used EVT to analyse extreme events largely used in the finance and disaster studies.

Use of EVT in forecasting extreme events in finance and natural disasters

Extreme value methods have been used widely in environmental science, hydrology, insurance and finance. More often these have been used to forecast extreme events in finance. For example, Silva and Mendes (2003), as well as Bekiros and Georgoutsos (2004), used EVT to forecast Value at Risk (VaR) of stock and found that EVT provided accurate forecasts of extreme losses with very high confidence levels. Moreover, Peng et al., (2006) have compared EVT and GARCH models to predict VaR concluding that EVT method is superior to GARCH models in estimating and predicting VaR.

In disaster studies, Lai and Wu (2007), Lei and Qiao (2010) and Lei et al., (2011) have used EVT to evaluate and analyse the distribution of agricultural output loss and VaR is used to assess agricultural catastrophic risk. Lai and Wu (2007) have found that the distribution of loss data is heavy-tailed implying that it is also non-normal. Extreme value theory (EVT) describes the behaviour of random variables at extremely high and low levels of risk and provides the procedures to find distributions and quantiles for Maxima and to check models. Lei and Qiao (2010) used the extreme value methods, namely, Block Maxima (BM) and Peak-Over-Threshold (POT) models, to predict risk values and found that both of these models are significantly below the corresponding predictions. In addition, Lei et al., (2011) applied the POT approach to model distribution and assess VaR of agricultural catastrophic risk. They found that catastrophic risk negatively affects agricultural production and is severe within a 100-year scenario and thus expected to recur.

3. Analytical framework

As mentioned earlier, the main objective of this study is to forecast Malaysian palm oil prices accounting for extreme events. This is because palm oil price is characterized by a high degree of volatility and is subject to the occurrence of extreme events (see Figure 1). The extreme value method provides a strong theoretical basis with which one can construct statistical models that are capable of describing extreme events (Manfred and Evis, 2003). The use of EVT provides statistical tools to estimate the tails of probability distributions (Diebold et al., 1998) with evidence of substantial use in the financial sector. The closest application of EVT in agriculture has been for the forecasting of losses in the agricultural output due to natural disasters (Lei and Qiao, 2010; Lei et al., 2011). Thus far, EVT has not been applied to predict agricultural product prices, particularly, palm oil prices, although it is characterized with extreme events.

The next section explains the theory and presents the two principal approaches to modelling extreme values: the BM and POT models.

The Extreme Value Theory

The main idea of EVT is the concept of modelling and measuring extreme events which occur with very small probability (Brodin and Kluppelberg, 2008). It provides a method to statistically quantify such events and their consequences. Embrechts et al. (1997) note that the main objective of the EVT is to make inferences about sample extrema (maxima or minima). Generally, there are two principal approaches to identifying extremes in real data. The BM and the POT are central to the statistical analysis of maxima or minima and of exceedance over higher or lower thresholds (Lai and Wu, 2007).

Block Maxima model

The BM model studies the statistical behaviour of the largest or the smallest value in a sequence of independent random variables (Lei and Qiao, 2010; Lei et al., 2011). One approach to working with extreme value data is to group the data into blocks of equal length and to fit the data to the maximums of each block whilst assuming that n (number of blocks) is correctly identified.

Let Z_i (i=1,…,n) denote the maximum observations in each block (Coles, 2001). Z_n is normalized to obtain a non-degenerated limiting distribution. The BM approach is closely associated with the use of Generalized Extreme Value (GEV) distribution with cumulative density function (c.d.f) (Lei and Qiao, 2010):

$$G(z) = \exp\left\{-\left[1+\xi\left(\frac{z-\mu}{\sigma}\right)\right]^{-1/\xi}\right\}$$

Where μ, $\sigma > 0$ and ξ are location, scale and shape parameter, respectively. The GEV includes three extreme value distributions as special cases: the Frechet distribution is $\xi > 0$, the Fisher-Tippet or Weibull distribution is $\xi < 0$, and the Gumbel or double-exponential distribution is $\xi = 0$. Depending on the parameter ξ, a distribution function is classified as fat tailed ($\xi > 0$), thin tailed ($\xi = 0$) and short tailed ($\xi < 0$) (Odening and Hinrichs, 2003). Under the assumption that $Z_1, \ldots, Z_n$ are independent variables having the GEV distribution, the log-likelihood for the GEV parameters when $\xi \neq 0$ is given by (Coles, 2001):

$$\ell(\xi,\mu,\sigma) = -\mathrm{n}\log\sigma - (1+1/\xi)\sum_{\mathrm{i=1}}^{\mathrm{n}}\log\left[1+\xi\left(\frac{\mathrm{Z_i}-\mu}{\sigma}\right)\right] - \sum_{i=1}^{n}\left[1+\xi\left(\frac{Z_i-\mu}{\sigma}\right)\right]^{-1/\xi}$$

provided that $1+\xi\left(\frac{z_i-\mu}{\sigma}\right) > 0$, for i=1,….,n

The case $\xi = 0$ requires separate treatment using the Gumbel limit of the GEV distribution (Coles, 2001). The log-likelihood in that case is:

$$\ell(\mu,\sigma) = -\mathrm{n}\log\sigma - \sum_{\mathrm{i=1}}^{\mathrm{n}}\left(\frac{\mathrm{Z_i}-\mu}{\sigma}\right) - \sum_{\mathrm{i=1}}^{\mathrm{n}}\exp\left\{-\left(\frac{\mathrm{Z_i}-\mu}{\sigma}\right)\right\}$$

The maximization of this equation with respect to the parameter vector (μ, σ, ξ) leads to the maximum likelihood estimate with respect to the entire GEV family (Coles 2001; Castillo 1988).

Peak-Over-Threshold model

The POT approach is based on the Generalized Pareto Distribution (GPD) introduced by Pickands (1975) (cited in Lei and Qiao, 2010). The GPD estimation involves two steps, the choice of threshold u and the parameter estimations for ξ and σ which can be done using Maximum Likelihood Estimation (Bensalah, 2000). These are models for all large observations that exceed a high threshold. The POT approach deals with the distribution of excess over a given threshold wherein the modelling is to understand the behaviour of the excess loss once a high threshold (loss) is reached (McNeil, 1999). Previous studies have shown that if the block maxima have an approximate distribution of GEV, then the excesses from the threshold have a corresponding Generalized Pareto Distribution (GPD) with c.d.f. (Lai and Wu, 2007, Lei and Qiao, 2010):

$$\mathrm{H(y)} = 1-\left(1+\frac{\xi y}{\sigma}\right)^{-1/\xi}$$

defined on {y: y > 0 and $\left(1+\frac{\xi y}{\sigma}\right) > 0$}, where y (growth rate price exceeds) is random variable, σ ($\sigma > 0$) and ξ ($-\infty < \xi < +\infty$) are scale and shape parameters, respectively. The family of distributions defined by this equation is called the GPD family. Having determined a threshold, the parameters of GPD can be estimated by log-likelihood.

Suppose that the values $Y_1, \ldots, Y_n$ are the n excesses of a threshold u. For $\xi \neq 0$, the log-likelihood is (Coles 2001)

$$\ell(\sigma,\xi) = -\mathrm{n}\log\sigma - (1+1/\xi)\sum_{i=1}^{n}\log(1+\xi y_i/\sigma)$$

provided that $(1+\xi y_i/\sigma) > 0$ for i=1,…,n

The maximum likelihood procedures can also be utilized to estimate the GPD parameters, given the threshold (Lei and Qiao, 2010).

4. Empirical results

In this paper, the monthly palm oil price data from July 1986 to June 2011 from the indexmundi website was utilized. Monthly prices are computed as growth rate of price relatives: $Gr = (p_t - p_{t-1})/p_{t-1} * 100$, where p_t is the monthly Malaysian palm oil futures at time t. A test was conducted to check whether the palm oil price growth rate (PPGR) has a non-normal distribution. The Jarque-Bera test, which summarizes deviations from the normal distribution with respect to skewness and kurtosis, provides further evidence about the non-normality of the distribution (Odening and Hinrichs, 2003). The Jarque-Bera test rejects normality, at the 5% level for the PPGR distribution (see Table 1). Thus the test results provide evidence that the PPGR distribution is non-normal and, therefore, justifying the use of EVT and the estimation of an extreme value distribution.

Results from the BM model

The data in this study are 300 observations of monthly Malaysia Palm Oil Futures price, covering a 25 year period (Jul, 1986 to Jul, 2011). In the case of the BM model, we focus on the statistical behaviour of block maximum data. Therefore, the source data is a set of 26 records of maximum annual palm oil price growth rates (PPGR). Figure 2 shows the scatter plot of annual maximum PPGR. These data are modelled as independent observations from the GEV distribution.

Maximization of the GEV log-likelihood for these data provides the following estimates of the necessary parameters: $\hat{\xi} = 0.2106$, $\hat{\sigma} = 4.5000$, $\hat{\mu} = 9.6435$. Figure 3 shows various diagnostic plots for assessing accuracy of the GEV model fit the PPGR data. The plotted points

Table 1: Descriptive statistics of the Malaysian palm oil price growth rate (July 1986 – June 2011)

	PPGR
Mean	0.88208
Median	0.800682
Maximum	33.68552
Minimum	−27.08083
Std. Dev.	7.842985
Skewness	0.324795
Kurtosis	4.915701
Jarque-Bera	51.14846
Probability	0
Observations	264.624

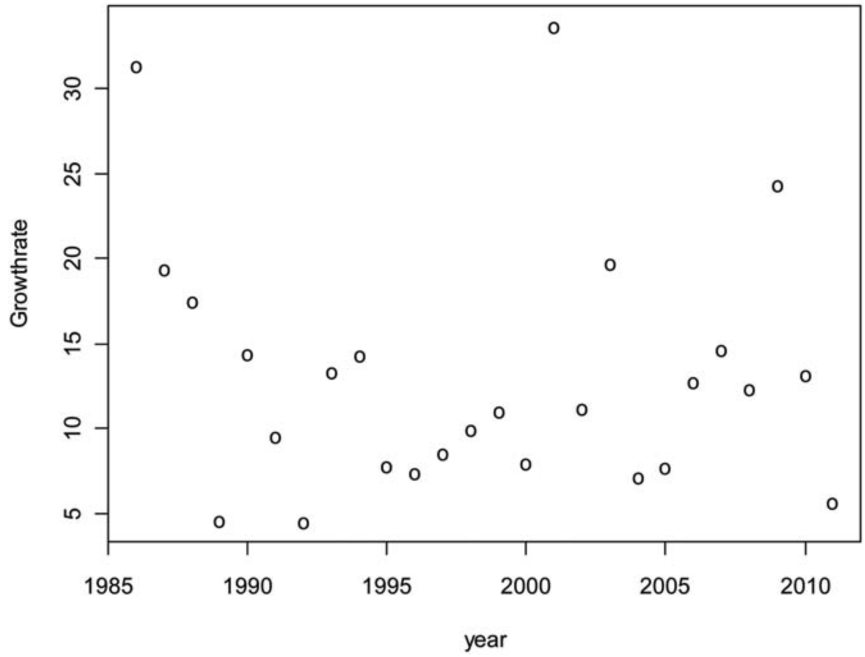

Figure 2: The scatter plot of annual maximum palm oil price growth rate (PPGR)

of the probability plot and the quantile plot are nearly-linear. The return level curve converges asymptotically to a finite level as a consequence of the positive estimate, although the estimate is close to zero and the respective estimated curve is close to a straight line. The density plot estimate seems consistent with the histogram of the data. Therefore, all four diagnostic plots give support to the fit of GEV model.

Table 2 presents the T-year return/growth levels based on the GEV model for the 25 year period, to forecast the extreme values in the PPGR for the next 5, 10, 25, 50 and 100 year in the future. The probability of 95% confidence interval (CI) for future 5-, 10-, 25-, 50-, 100-years growth levels, based on the profile likelihood method, is also provided. Empirical results show that the extreme values of the PPGR will increase in the future. Under the assumption of the model, the extreme value of PPGR will be 17.58% overall, with 95% CI (14.05–24.43%) in year-5. In year-10 the extreme value of PPGR will be 22.59%, with 95% CI (17.51–37.59%).

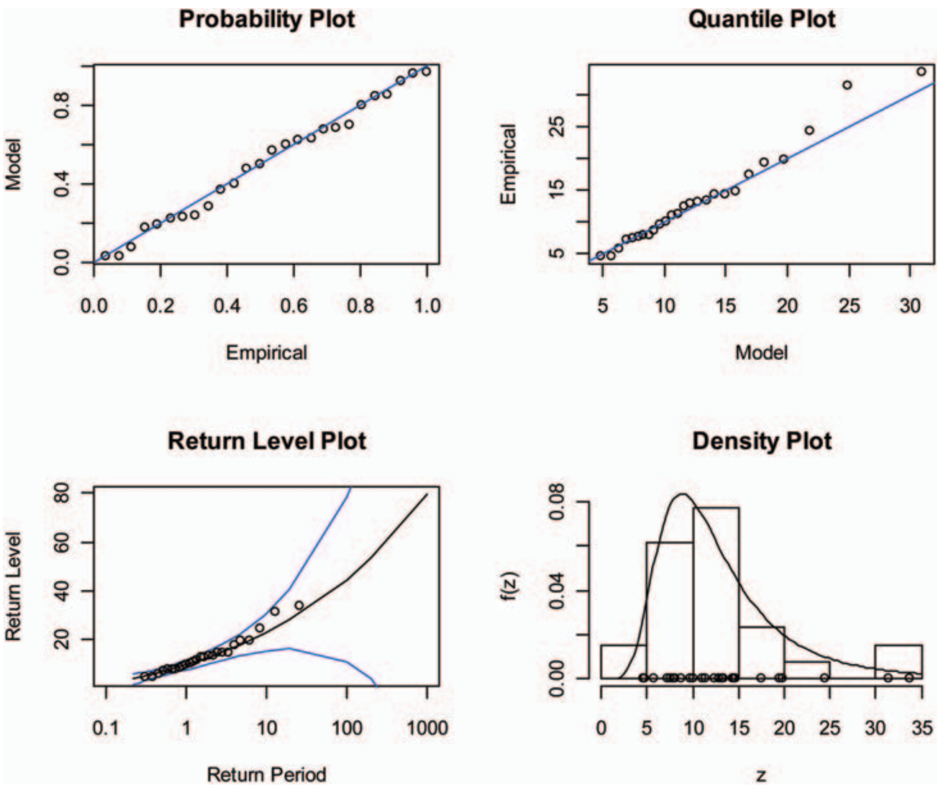

Figure 3: Diagnostic plots for GEV fit to the annual maximum PPGR

Table 2: T-year return/growth level based on GEV model (BM approach)

Item	GEV fit	95% CI
ξ	0.2106	
σ	4.5000	
μ	9.6435	
Year-5	17.5810	(14.0515,24.4286)
Year-10	22.5982	(17.5190,37.5984)
Year-25	30.1837	(21.8648,67.3767)
Year-50	36.8748	(24.9560,105.3495)
Year-100	44.5726	(27.8615,165.6797)

Finally, in year-100, the extreme value figures for PPGR are 44.57%, with 95% CI (27.86–165.68%). These figures reveal that the PPGR values are going to be incrementally higher further in the future. For instance, the value of PPGR increases from 17.58% in year-5 to 44.57% in year-100.

Results from the POT model

In this section, although the same data is used, the model focuses on the statistical behaviour of exceedances over a higher threshold. The data is analysed by modelling exceedances of individual observations over a threshold according to the following method. The scatter plot of PPGR data is presented in Figure 4 and the mean residual life plot is presented in Figure 5. In the POT model, the selection of a threshold is a critical problem. If the threshold is too low, the asymptotic basis of the model will be violated and the result will be biased. If the threshold is too high, it will generate few observations to estimate the parameters of the tail distribution function, leading to high variance (Gilleland and Katz, 2005). The assumption, therefore, is that GPD is the asymptotically correct model for all exceedances. The mean residual life plot for these data suggested a threshold of u=6. The vertical lines in Figure 6 show the 95% confidence intervals for the correct choice of the threshold value u=6. This gives 61 records of PPGR. The parameters of GPD using the MLE approach, with the threshold value of u=6 was then estimated. The parameters of GPD are estimated at σ =6.0619 and $\xi = -0.0435$. Figure 7 shows the diagnostic plots for GPD fit to the PPGR data. Neither the probability plot nor the quantile plot presents any doubt on the validity of the model fit.

In Table 3, the probability of 95% confidence intervals, based on the profile likelihood method to forecast the extreme value of growth rate of palm oil price for the next 5, 10, 25, 50 and 100 years into the future, is provided. Table 3 exhibits T-year return level based on the GPD model. In year-5, the extreme value of PPGR will be 37.62%, with 95% CI (29.19–76.97%). In year-10 the extreme value figures are 40.82%, with 95% CI (30.76–94.33%). Finally, in year-100 the extreme value of PPGR are 50.78% with 95% CI (34.48–180.54%). Again the value of PPGR increases at an incremental rate further into the future. For example, the value of PPGR increases from 37.6% in year-5 to 50.78% in year-100.

Discussion

The previous sections have explained that the Malaysian PPGR has a non-normal distribution, shown in Table 1. Past studies (e.g., Arshad and Ghaffar, 1986; Nochai, 2006; Karia and Bujang, 2011) that predicted palm oil price using ARMA family methods, assuming normal distribution of the data, and, therefore failed to recognize that actual palm oil prices tend to exhibit extreme values.

The quality of the EVT enhances the data movements toward the tail of a distribution (Odening and Hinrichs, 2003). Using the BM and the POT approaches of extreme value modelling, both GEV and GPD models

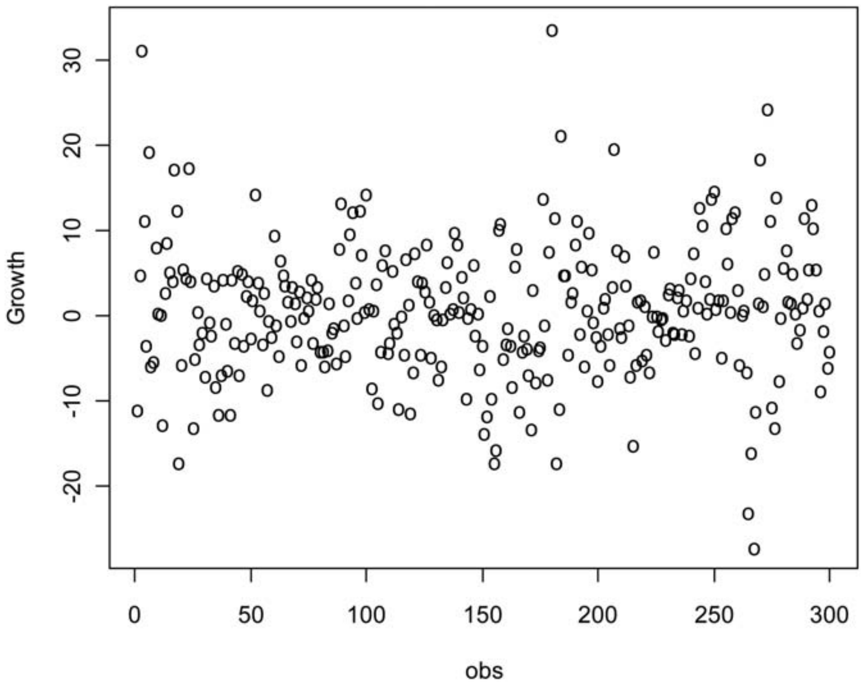

Figure 4: The scatter plot of monthly PPGR

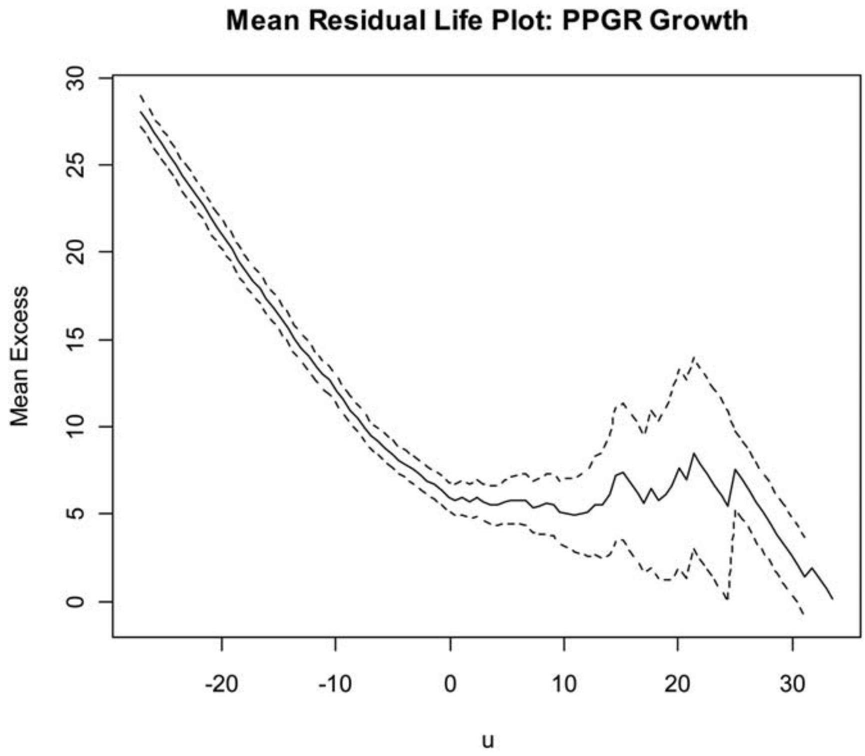

Figure 5: Mean Residual Life Plot of PPGR

were applied to PPGR covering a 25 year period to predict growth rate of palm oil prices in the next 5, 10, 25, 50 and 100 year periods (Tables 2 and 3). The results presented in Tables 2 and 3 show that the BM method provides lower estimates than the POT method. The discrepancy in forecasts, however, narrows as the forecasting horizon expands. For example, the difference in PPGR for Year-5 is 20% whereas it is 14.7% for Year-25 and only 6% for Year-100 between the two methods of forecasting. Overall, the POT approach 'outperformed' the BM approach. This is because BM only considers the largest events. The most common implementation of this approach is to take a block of data from the PPGR and treat the maximum from that block as single observations for one year. The approach becomes 'incapable' if other data on the tail of the distribution are available. On the other hand, the POT approach can compensate for such weaknesses and can

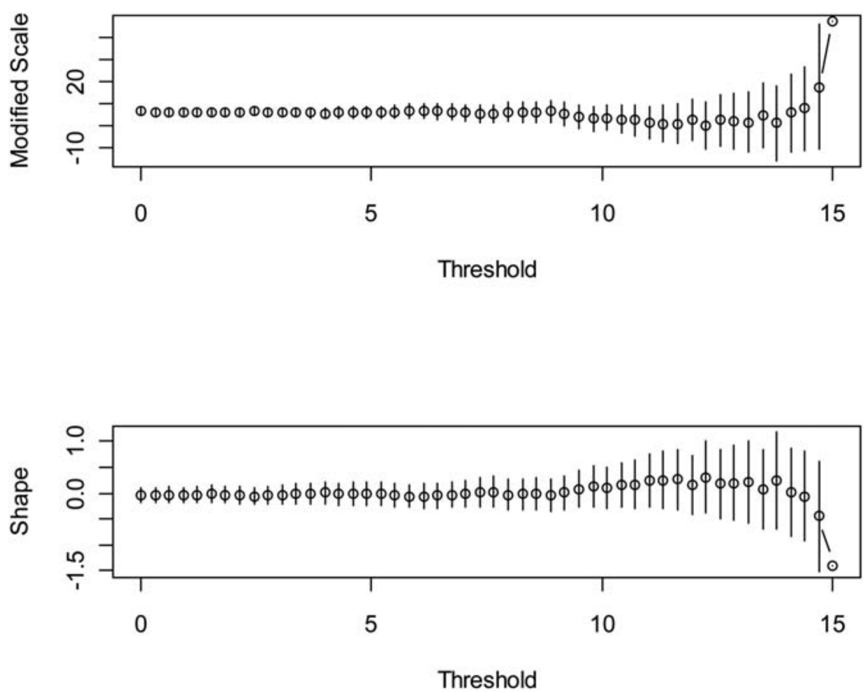

Figure 6: Parameter stability plots for PPGR

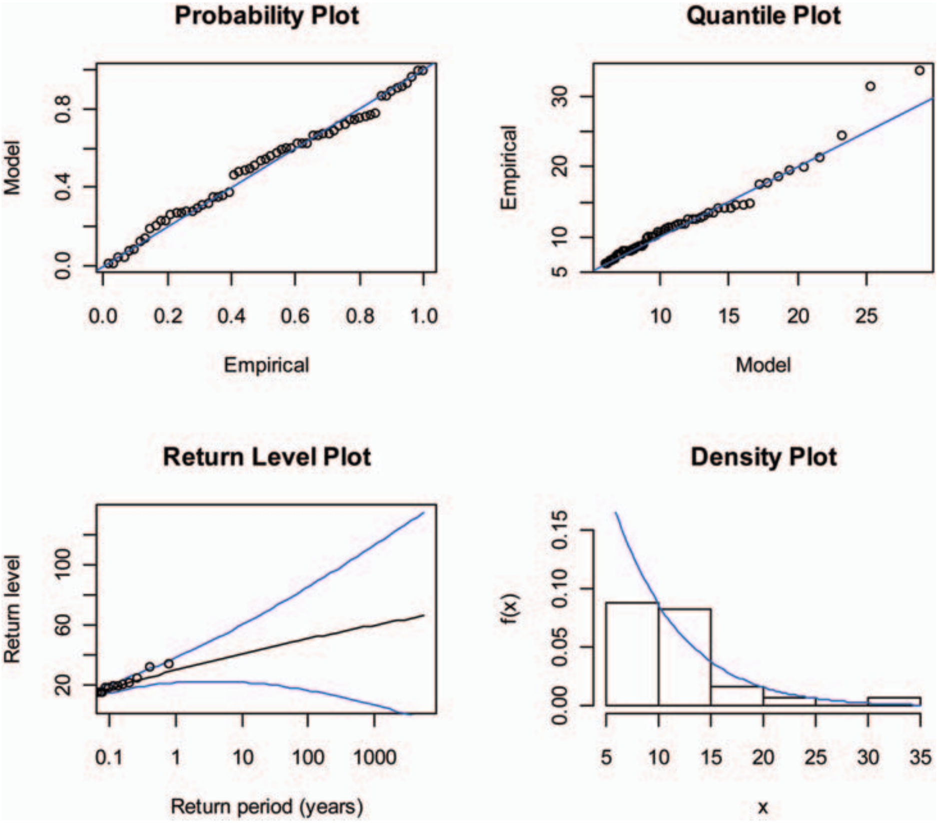

Figure 7: Diagnostic plots for GPD fit to PPGR

be used to model all large observations that exceed a high/given threshold. Similar conclusions on the superiority of the POT approach over the BM have been observed by previous researchers (e.g., Lai and Wu, 2007; Lei and Qiao, 2010).

5. Conclusion

This paper applies extreme value methods to the prediction of Malaysian palm oil prices in the future, using monthly futures price data for the 25 year period (July 1986 – June 2011) which is characterized by non-normal distribution caused by extreme events. The diagnostic test confirmed that the Malaysian palm oil price is characterised by non-normal distribution, thereby justifying the use of EVT. This is a major improvement on the forecasts of palm oil prices based on the assumption of normal distribution, as seen in the literature. Both the BM and the POT approaches were used which revealed that the Malaysian palm oil price will have higher extremes in the next 5, 10, 25, 50 and 100 year periods, with acceleration in growth further into the future. The discrepancy in forecasting between the two methods decreases as the forecasting horizon expands. Although the POT approach outperformed the BM approach, both of them are effective in predicting prices caused by extreme events. The results could be useful for the farmers, exporters, governments, and other key stakeholders involved in the palm oil industry as it will enable them to undertake better strategic planning and mitigate against risk and instability.

Table 3: T-year return/growth level based on GPD model (POT approach)

Item	GPD fit	95% CI
ξ	−0.0435	
σ	6.0619	
Year-5	37.6226	(29.1853,76.9672)
Year-10	40.8219	(30.7610,94.3344)
Year-25	44.9058	(32.4901,122.6481)
Year-50	47.8887	(33.5656,149.0050)
Year-100	50.7830	(34.4789,180.5439)

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REFEREED PAPER

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Gold, black gold, and farmland: should they all be part of your investment portfolio?

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ABSTRACT

Can traditional investors improve financial performance by adding a farmland real estate investment trust (F-REIT), gold and oil to their investment portfolios? This study shows that for the period 1972–2011, financial performance was significantly improved with the addition of F-REIT, gold and oil to a portfolio of traditional investments of T-bills, bonds, stocks and REITs. A Canadian F-REIT is considered relatively low risk, enters the efficient portfolios at low to medium risk levels and adds the most financial improvement to medium risk portfolios. Gold and Oil are higher risk assets with no dividend yield but because of their low correlations with other assets, they are able to reduce portfolio risk and add significant financial improvement in all portfolios.

KEYWORDS: investment portfolio performance; farmland real estate investment trust

1. Introduction

In response to the worldwide recession of 2008, many governments, including those in the United States and the European Union, chose to borrow and spend in order to spur the economy. Many industrialized countries by 2012 had reached debt levels that were potentially unsustainable. Some countries in Europe, such as Greece, Spain, Portugal and Ireland were at risk of defaulting on their debts, which has started another economic panic similar to 2008. The United States was similarly spending far more than its annual revenues and its government debt was also becoming perilously large. In summer 2011, Standard and Poor's, a world-renowned bond rating agency, lowered the US debt rating from AAA (the top rating, which US held for over 100 years) to AA+. This sent shock waves to the financial markets around the world. In one week, stock markets had lost approximately 10% of their value based on fears of another world recession. The US Federal Reserve chairman announced that interest rates would be at near-zero levels likely until 2013. In 2012, the debt fears remained, with the European Union threatening to expel Greece (and possibly others) if it did not agree to austerity measures. Unemployment levels in Spain reached 25% and the banking system was near collapse. The new government challenge in industrialized countries is to lower expenditures and move towards balanced budgets, which could have a further dampening effect on economies and stock markets. The economic fear and worry has led investors to seek alternative investments to the traditional bonds and stocks that have been staples for so many years.

In the US, because of the 2008 housing crisis, real estate investment is still very risky as no one can predict when the industry might again be sustainably on the rise. Rather, there has been a flight to safety. Many investors have chosen government treasury bills (T-bills, which are discounted government short term bonds) and long-term bonds, even though interest rates are very low. Many investors who are willing to accept some risk have moved to commodities such as precious metals (gold, for safety) and energy (oil), as world demand for commodities has been growing. There is also growing interest in the food industry as worldwide population and food demand continues to grow. One way to invest in the food industry is by investing directly in food commodities; another is through farmland ownership. However, it is difficult and time-consuming for the average investor to purchase and manage farmland. To add liquidity and marketability to the farmland market, a number of farmland real estate investment trusts (F-REITs) have come onto the market in recent years. In general, the trust buys farmland using investor equity and bank debt and then leases the farmland to farmer operators (mix of cash and crop share rents). The F-REIT charges administrative and management fees, similar to a mutual fund that charges an MER (management expense ratio). The F-REIT can earn an operating profit based on the lease income, net of expenses, but the expected larger profit or return is from land value appreciation.

There are a number of North American F-REITs such as Hancock Agricultural Investment Group[2]

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[2] http://haig.jhancock.com/

(division of Manulife Financial Canada, a publicly traded company), which is a US $1.6 billion[3] farmland investment fund, managing 108,000 hectares in US, 400 hectares in Canada and 2,500 hectares in Australia. Bonnefield Canadian Farmland Fund[4], located in Ottawa, Ontario, launched LPI with a public offering in April, 2010 and holds a diversified Canadian farmland portfolio worth approximately $20 million (they have recently launched LPII). Agcapita[5] is a Canadian farmland fund based in Calgary, Alberta with $100 million in assets under management and has now launched its third fund. Assiniboia Capital Corporation[6], located in Regina, Saskatchewan, is a limited partnership publicly available for investment, was founded in 2005 and now manages approximately 45,000 hectares of Canadian farmland. Sprott Resources[7] is a publicly traded Canadian company that is targeting over 800,000 hectares in western Canada. HCI Ventures[8] and Prairie Merchant Corp.[9], both private, have also been investing in farmland.

As average farm size grows, farmers need more sources of equity financing as not all growth can be financed with debt. Over 50% of farmland in Canada and the United States is now leased by farm operators and the demand for leased land is growing as average farm size continues to increase, which points to a growing demand for farmland equity investment. The average investor needs to know whether an F-REIT is a good mix in their investment portfolios and whether it provides the investment qualities they are looking for, especially given current world-wide economic turbulence. Therefore, the main question in this paper is: Can Traditional investors improve financial performance by adding a farmland real estate investment trust (F-REIT), gold and oil to their investment portfolios? The research sub-questions are (a) what are the risk-return characteristics of F-REITs compared with financial assets, REITs, gold, and oil; (b) what is the impact on portfolio performance when an F-REIT, gold and oil are added to the portfolio, and; (c) is F-REIT a better diversifier than gold or oil? A diversified Canadian F-REIT along with bonds, stocks, REITs, gold and oil are assessed to determine their impact on the financial performance of a well-diversified international investment portfolio.

2. Background

Efficient investment is the basis for all portfolio decisions, considering the trade-off between risk and return for an individual investor. Markowitz (1959) developed the idea of efficient investment, which sought to combine the right assets into a portfolio such that it would dominate any other investment or portfolio for that given risk level. The result was an efficient frontier of dominant or efficient portfolios spanning the risk spectrum. The most important aspect of efficient investment is that the total risk of a portfolio will almost always be less than the sum of the risks of the individual assets held. Tobin (1958) and Treynor (1961) added to this with the two-fund separation theorem by including the risk-free asset in the mix, producing the Capital Market Line (CML). This very important contribution improved and simplified the investment decision because it showed that all efficient portfolios were some combination of the tangency portfolio (market portfolio) and the risk-free asset. Now investors only needed to choose what percentage they wanted invested in safe risk-free assets and what percentage in the risky market portfolio. This led to the development of the Capital Asset Pricing Model (CAPM) by Sharpe (1964), which applied efficient investment theory to individual asset pricing. Since all investors would only hold efficient portfolios, they should only be concerned about that portion of an asset's risk that is added to the total risk of a well-diversified portfolio, called systematic risk, as opposed to the portion of the asset's risk that is diversified away when included in the portfolio. An asset could have a high total risk level, but if most of that risk is diversified away within an efficient portfolio, then it would add little risk to the overall portfolio and would be considered a low-risk asset.

Figure 1 illustrates the concept of efficient investment. The efficient frontier (Markowitz) represents all those investments that dominate on a risk-return basis when the risk-free asset is not included in the mix. When the risk-free asset is added to the choice set, the Capital Market Line (Tobin and Treynor) becomes the efficient set of investment opportunities, where every investment on the CML is a combination of the risk-free asset and the tangency portfolio. Each investor mixes the risk-free asset and the market (tangency) portfolio to achieve the desired level of risk, which maximizes the expected return for that chosen level of risk. In Figure 1, the borrowing rate for investors is also added, which means there are two tangency portfolios, making the efficiency frontier ABCD. Selection of a portfolio on this frontier would be the result of an individual investor's risk-return preferences. A portfolio between B and C is a standard diversified portfolio of bonds, stocks and REITs without borrowing or lending (usually considered the market portfolio). Between A and B is where the investor reduces the amount invested in the market portfolio and transfers some funds into a risk-free investment (T-bills). Between C and D, the investor expands the market portfolio investment by borrowing.

A number of past studies have assessed farmland investment efficiency. Peter Barry (1980) applied the CAPM to farmland in eleven different regions in the United States and found that farmland added very little risk to a diversified portfolio of stocks and bonds because most of farmland risk is diversifiable (unsystematic risk). Kaplan (1985) found that farm real estate had two favourable attributes: high total return and low correlation with other assets, which meant that including farmland in a portfolio added a high return asset with very little risk added. Moss, Featherstone and Baker (1987) as well as Lins, Kowalski and Hoffman (1992) and Ruebens and Webb (1995), assessed efficient portfolios using US financial assets and farmland and concluded that the addition of farmland to stock and bond portfolios improved portfolio performance. Brown (1999) showed that farm returns are comparable

[3] In early January 2013, US $1 was approximately equal to GB £0.62, and €0.77.
[4] http://bonnefield.com/index.php
[5] http://www.farmlandinvestmentpartnership.com/
[6] http://www.assiniboiacapital.com/
[7] http://www.sprottresource.com/
[8] http://www.hciventures.ca/
[9] http://www.wbrettwilson.ca/pmc/contactUs.html

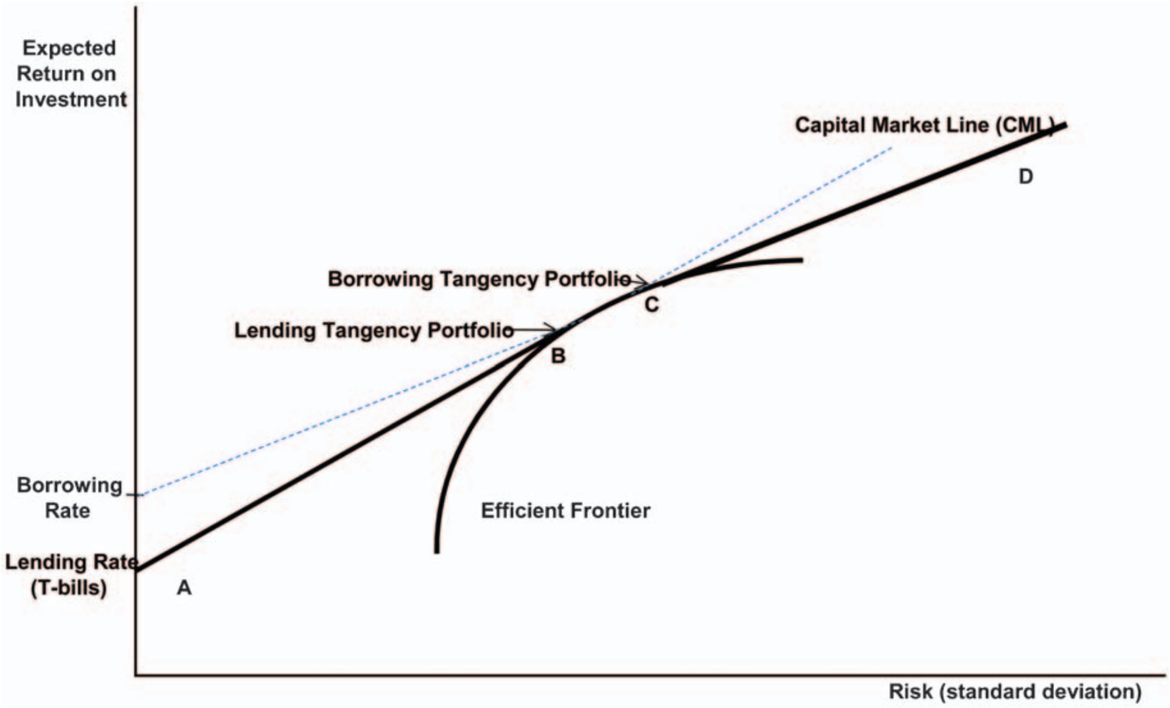

Figure 1: Efficient investment and the capital market line (CML)

to returns for stocks and bonds and correlations are low between farmland and financial assets, indicating the potential for efficient diversification by adding farmland to the investment mix. Bigge and Langemeier (2004) found that Kansas farmland's low level of systematic risk meant that farmers could improve overall portfolio performance with investment in the stock market. Libbin, Kohler and Hawkes (2004a and 2004b) suggest that farmers could improve financial performance by investing in financial assets and/or paying down their debt liabilities. Hardin and Cheng (2005) used a Markowitz semi-variance model to evaluate US farmland in a mixed-asset portfolio and found that farmland did not need to be a substantial part of an optimal portfolio; however, they suggested that more studies were needed using additional farmland data to fully assess direct investment in agricultural land. Shadbolt and Gardner (2006) found that returns to farming business investors are highly variable compared to the returns to farmland ownership based on rental agreements. Oltmans (2007) explains that with an appreciating asset like farmland, the capital gain return means that the asset itself need produce less operating income to make it economically desirable. This in part explains why farmers continue to purchase farmland even when it cannot cash flow itself because the operating return is only part of the total return; capital gain (expected growth) is the other part and needs to be addressed in the valuation assessment as well. Painter and Eves (2008) assessed farmland investments in United States, Canada, New Zealand and Australia and found that the low and negative correlation of farmland yields with stocks and bonds made it a good candidate for portfolio diversification. Waggle and Johnson (2009) added farmland and timberland to the choice set of assets. They employed a Markowitz portfolio optimization model and found widely varying allocations with farmland entering the optimal portfolios only at low risk levels and timberland at higher risk levels. Painter (2011) found that a Canadian Farmland Real Estate Investment Trust fared well in an efficient international investment portfolio and provided better diversification performance than gold, in medium risk portfolios. Noland *et al.* (2011) used the University of Illinois farmland portfolio and found that it frequently dominated the efficient asset allocation when other financial assets were included in the choice set. This paper can add to the literature in three ways; 1) by adding gold and oil to the asset mix, we can address the question as to whether we really need farmland as a diversifier, if it turns out that other assets, which are easier to invest in, can provide the diversification benefits we seek; 2) this paper is assessing the portfolio benefits of Canadian farmland whereas most previous research has been about US farmland; and 3) this is research that brings Canadian farmland portfolio assessment up to date by including 2011 market information.

3. The expected value-variance (E-V) model

An E-V model is used to assess whether an F-REIT would improve the financial performance of a diversified portfolio of financial assets, including REITs, gold and oil and to determine whether F-REIT is as good or a better diversifier than gold or oil. The E-V model is used to derive the efficient set of portfolios at all risk levels, by minimizing risk for various expected return constraints. The mapping of the minimum risk and corresponding return combinations provides the efficient set or frontier. The E-V model is as follows:

$$\text{Minimize } X' QX \quad (1)$$

X
subject to:
Rp=C' X
1.0=1' X
where:
X= vector of the wealth share invested in each asset, xi being the proportion of total wealth invested in asset i
Q= variance-covariance matrix of asset returns, Cov(ri, rj)
Rp= portfolio return on investment
C= Nx1 vector of expected return on investment for N choice assets

4. Calculating F-REIT, REIT, gold, oil and financial asset returns

Financial returns are calculated for each of the choice assets for the study period 1972-2011. The choice set of assets includes T-bills, long term bonds, F-REIT, gold, oil, United States REITs, and stock markets in Australia, Canada, Japan, United States, Europe, Hong Kong, and the MSCI World Stock Market Portfolio. For T-bills and bonds, average annual Canadian yields are calculated while for stock markets, average annual dividend, capital gain and total yields are calculated, using Morgan Stanley International stock market data. Average annual income and capital gain yields are calculated for REITs (FTSE NAREIT US Real Estate Index Series) and a Canadian F-REIT. Average annual gold and oil prices in USD were used to calculate annual investment yields for each.

Calculating income and capital gain yields for a Canadian F-REIT

The total return to an F-REIT is divided into two parts; income return and capital gain return. The income return is based on the net lease revenue obtained from renting the farmland in the trust to farm operators. The capital gain return is the change from year to year in the market value of the land. Canadian F-REIT returns are an average of the farmland ownership returns in the five major agriculture producing provinces: Alberta, Saskatchewan, Manitoba, Ontario and Quebec. A standard crop share approach is used where the F-REIT receives a percentage of the gross revenues produced (17.5% is a common crop share arrangement in North America, which compares closely with cash rents that are usually in the 5% - 7% of land values range). The F-REIT is then responsible for paying property taxes and building depreciation to arrive at a net lease amount or income return to the F-REIT. Hence, the annual income return per hectare to farmland ownership in a Canadian F-REIT is calculated as follows;

$$IR_t = LR_t - PT_t - BD_t \quad (2)$$

Where,
IR_t= \$ income return to farmland per hectare in year t;
LR_t=gross lease revenue per hectare in year t (17.5% of Gross Farm Revenues);
PT_t=property taxes per hectare in year t;
BD_t=building depreciation per hectare in year t;
The annual income and capital gain yields for a Canadian F-REIT are calculated as follows:

$$IY_t = \frac{IR_t}{V_{t-1}} \quad (3)$$

Where;
IY_t =% income yield per hectare in year t;
IR_t=\$ income return to farmland per hectare in year t;
V_{t-1}=average farmland value per hectare in year t-1.

$$CGY_t = \frac{V_t - V_{t-1}}{V_{t-1}} \quad (4)$$

Where;
CGY_t =% capital gain yield per hectare in year t;
V_t, V_{t-1}=average farmland values per hectare in years t and t-1, respectively.
The annual total investment yield for the F-REIT is the sum of the income and capital gain yields, calculated as follows

$$ROI_t = \frac{IR_t}{V_{t-1}} + \frac{V_t - V_{t-1}}{V_{t-1}} \quad (5)$$

Tax and Management Expense Adjustments to F-REIT and Bond Investment Yields

Before an efficient frontier of investments can be assessed, it must be recognized that there are tax differences between various financial assets and F-REITs and adjustments must be made to account for these differences. Also, an F-REIT requires management so a Management Expense Ratio (MER) must be included to account for management costs.

The first tax adjustment is to the F-REIT income return (net lease revenue earned). The F-REIT must pay corporate taxes on net lease income before any distributions to unit holders can be made, just as a stock market company must pay corporate taxes before distributing dividends. An average Canadian corporate tax rate of 27% is used to adjust the income return in the F-REIT (After Tax Income Return=Income Return x .73). The second tax adjustment is to T-bill and Long Bond yields. In Canada, the average personal tax rate on interest is significantly higher than on dividends or capital gains, which means that to an average investor, a 5% pre-tax dividend or capital gain yield is significantly better than a 5% pre-tax bond yield. Since the study is using before-tax average yields, a discount must be applied to T-bills and Long Bonds to adjust for the higher rates of taxation. This is not an adjustment for risk but recognizes that interest is taxed significantly higher and thus has less value to an investor on an after-tax basis. The average tax adjustment factor is calculated as follows:

$$T = \frac{1 - t_{interest}}{1 - t_{Dividend,CG}} \quad (6)$$

Where:

T= the tax adjustment factor for average T-bill and Long Bond yields;

$t_{interest}$= the average personal tax rate on interest income;

$t_{Dividend,CG}$= the average personal tax rate on dividend and capital gain income.

Using average 2012 personal tax rates in Canada, the adjustment factor T is 72%. Therefore, average T-bill and Long Bond yields are discounted to 72% of their calculated values to adjust for the fact that interest income is taxed higher than dividend and capital gain income.

An MER of 4% has been subtracted from the calculated F-REIT average yield to account for management expenses. A typical Canadian MER for equity funds such as Templeton Franklin, AIM Trimark, Investors Group and others is between 2% and 3% while segregated funds are up to 4%. Bonnefield states a 1.25% MER on their webpage, however it is unclear whether that includes all associated management expenses. Since an F-REIT would require active management, the upper end (4%) was chosen as a reasonable estimate.

5. Discussion of results

Table 1 provides average annual investment yields for the choice set of assets. The total yield results include all the tax adjustments and the F-REIT MER deduction. The borrowing rate is the average prime rate plus 2%, adjusted by the interest tax factor of 72%. The investment attraction of F-REIT appears to be reasonable investment yield with relatively low risk, as indicated by the lower coefficient of variation (standard deviation/yield=risk per unit of return) on F-REIT than on stocks, gold oil and REITs.

The important risk and return characteristics can be summarized as follows:

- FREIT total yields fall between long term bonds and REITS, Oil, Gold and Stocks.
- FREIT has a relatively low coefficient of variation at 1.31.
- The total REIT yield is almost entirely an income yield. When comparing coefficients of variation, REIT is higher than FREIT, but lower than Gold, Oil and most of the stock markets.
- Gold and Oil yields are the opposite of REIT yields in that there is no income yield at all; the yield is entirely from price movements. Gold and Oil yields are higher than F-REITs but the risk for each is almost three times that of an F-REIT, making gold and oil risk similar to stock market risk. Gold and Oil coefficients of variation are similar to stock markets.

The other attraction of F-REIT is its low and/or negative correlation with bonds, stocks, and REITs, which gives it significant diversification advantages for an investment portfolio. Table 2 illustrates the correlation coefficients between the choice assets. Some important implications are as follows:

- F-REIT is negatively correlated with REITs as well as with every stock market and has very low correlation with T-bills and bonds;
- Gold is negatively correlated with both T-bills and bonds, REITs and a number of stock markets, giving it diversification benefits;
- Oil is negatively correlated with REITs, every stock market, bonds and has a zero correlation with T-bills, which suggests that it will be an important diversifier in an efficient portfolio;
- F-REIT has high positive correlation with both gold and oil, implying that F-REIT, gold and oil may be interchangeable as diversifying agents in portfolios;
- F-REIT has been a better hedge against inflation than either gold or oil and almost as good as T-bills and bonds, as indicated by the positive correlation with inflation;
- F-REIT has been referred to as 'Gold with yield' because it has similar properties to gold such as safety of principal and inflationary hedge, but also offers a steady income yield;
- Simply diversifying across international stock markets may have worked for risk management at one time but with globalization, that is no longer a very good diversification strategy in itself, as can be seen by the high positive correlations amongst stock

Table 1: Average annual investment yields for T-bills, long bonds, F-REIT, gold, oil, REITs and stock markets (1972–2011)

	Income/Div Yield		Cap Gain Yield		Total Yield		Coefficient Of Variation
	Avg Yield	Std Dev	Avg Yield	Std Dev	Avg Yield	Std Dev	
T-bills	N/A	N/A	N/A	N/A	4.8%	0.0%	N/A
Long Bonds	N/A	N/A	N/A	N/A	5.8%	3.0%	0.52
Borrowing	N/A	N/A	N/A	N/A	7.4%	0.0%	N/A
Real Estate:							
F-REIT	3.9%	0.7%	7.3%	8.8%	7.0%	9.2%	1.31
REITs	8.7%	2.8%	0.8%	20.1%	9.5%	21.4%	2.25
Gold	0.0%	0.0%	9.6%	26.1%	9.6%	26.1%	2.72
Oil	0.0%	0.0%	8.3%	29.4%	8.3%	29.4%	3.54
Stock Markets:							
Canada	2.5%	1.0%	6.7%	22.2%	9.2%	22.5%	2.44
Australia	3.4%	1.2%	6.0%	26.2%	9.3%	27.1%	2.91
US	2.4%	1.1%	6.2%	17.8%	8.5%	18.2%	2.14
Japan	1.3%	0.8%	7.4%	33.0%	8.6%	33.5%	3.90
Europe	3.0%	1.0%	6.4%	21.8%	9.4%	22.4%	2.38
World	2.4%	1.1%	6.2%	18.1%	8.5%	18.5%	2.18
Hong Kong	4.2%	1.7%	10.7%	45.6%	13.2%	46.8%	3.55

Table 2: Correlation matrix for the choice set of assets (1972–2011)

	T-b	**LTB**	F-REIT	**Gold**	**Oil**	**REIT**	**Can**	**Aus**	**US**	**Japan**	**Eur**	**World**	**HK**	**Inflation**
T-b	1.0	.94	**.12**	–.13	.00	.02	–.12	–.13	.10	.07	.02	.06	–.01	.72
LTB		1.0	**.05**	–.13	–.10	.10	–.13	–.10	.13	.16	.06	.12	.03	.69
F-REIT			**1.0**	**.51**	**.55**	**–.12**	**–.06**	**–.10**	**–.15**	**–.17**	**–.22**	**–.23**	**–.02**	**.60**
Gold				1.0	.51	–.18	.10	.22	–.25	.09	–.13	–.11	.11	.26
Oil					1.0	–.21	–.03	–.25	–.35	–.29	–.36	–.41	–.14	.30
REIT						1.0	.47	.51	.57	.17	.39	.51	.43	.02
Can							1.0	.79	.66	.44	.64	.74	.60	–.13
Aus								1.0	.60	.45	.70	.77	.64	–.12
US									1.0	.35	.76	.88	.53	–.09
Japan										1.0	.47	.66	.59	.07
Europe											1.0	.89	.53	–.12
World												1.0	.64	–.08
HK													1.0	–.03

markets. REITs are also significantly positively correlated with stock markets.

FREIT appears to be an attractive investment, with similar diversification qualities displayed by gold and oil, but if gold and oil are available and easy to invest in, do investors need FREIT? The E-V model was applied to assess and compare performance of the following portfolios:

1. T-bills, long bonds, F-REIT (traditional farmer portfolio)
2. T-bills, long bonds, REITs, stocks (traditional investor portfolio)
3. T-bills, long bonds, gold, oil, REITs, stocks (traditional plus gold and oil)
4. T-bills, long bonds, F-REIT, gold, oil, REITs, stocks (all assets)
5. T-bills, long bonds, F-REIT, REITs, stocks (traditional plus F-REIT)

Figure 2 illustrates the kinked CML's for portfolios 1, 2 and 4. It shows that the traditional farmer and the traditional investor portfolios could both be significantly improved by adding FREIT, Gold and Oil.

This next section addresses the question of whether the portfolio improvement is from adding gold, oil or F-REIT, or all to the portfolio. Tables 3, 4, and 5 provide a comparison the five different portfolios. Table 3 compares performance in the low risk category (6% investment yield), Table 4 the medium risk (8% investment yield), and Table 5 the high risk (10% investment yield). The main performance measure is the coefficient of variation, which assesses the amount of risk in the portfolio for the chosen investment yield–the lower the coefficient of variation, the better the yield per unit of risk taken.

In Table 3 (low risk efficient portfolios), portfolio 1 (bonds and farmland only) is the weakest. This implies that farmers who put all their wealth into farmland and bonds could improve financial performance by considering other assets such as stocks, gold and REITs (this implies owning less farmland and leasing more, hence a greater need for F-REITs). Portfolio 2 (bonds, stocks, REITs–most non-farmer investors) did not perform much better. Portfolio 3 (bonds, stocks, REITs, gold, oil) and portfolio 4 (bonds, stocks, REITs, F-REIT, gold, oil) performed best. The improvement in financial performance in portfolios 3 and 4 can be mainly attributed to the inclusion of oil, as F-REIT enters the portfolio at a weight of 1.7% only. However, in portfolio 5 (bonds, stocks, REIT and F-REIT) when oil and gold are not available, F-REIT enters at a higher weighting (15.4%) to provide some of the diversification benefit lost by excluding gold and oil. Therefore, it appears that in low risk portfolios, oil is the best diversifier with F-REIT coming in a close second. Those investors who prefer dividends will likely choose F-REIT over oil or gold for a low risk portfolio. However, it is important to note that the low risk efficient portfolios are dominated by bonds.

Table 4 shows medium risk efficient portfolios. Portfolio 1 does not earn a high enough yield to achieve the desired 8%, even if 100% of the portfolio is F-REIT, and portfolio 2 does not perform well with only bonds, stocks and REITs available. Portfolios 3 and 4 have

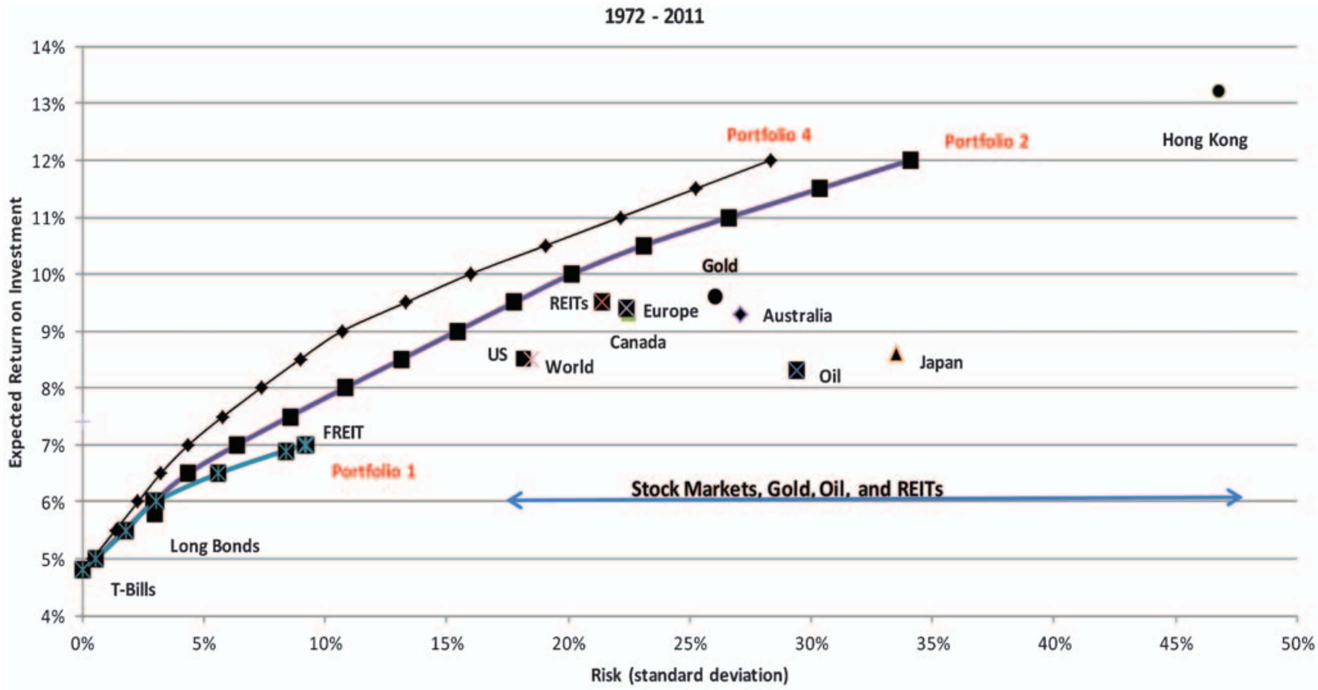

Figure 2: The capital market line for portfolios 1, 2 and 4 (1972–2011)

almost identical performance and when compared, it appears that if F-REIT is available, as in portfolio 4, it will replace bonds and oil but not to a large degree. Portfolio 5 shows that if oil and gold are not available, F-REIT enters the portfolio in a significant way, completely replacing bonds (compare portfolios 5 and 2). Therefore, it appears that in medium risk portfolios, F-REIT can add little value over an oil investment but significant value for investors averse to gold or oil. Again, those investors who prefer regular dividends may choose F-REIT over oil, but they lose some performance in the process.

In Table 5 (high risk efficient portfolios), F-REIT does not play an important role unless gold and oil are not available for investment. In portfolio 4 when F-REIT, gold and oil are in the choice set, F-REIT is not chosen at all. Indeed, portfolios 3 and 4 are identical efficient portfolios because adding F-REIT to the choice set added no improvement, mainly because F-REIT does not offer a high enough yield. Notice that gold has

Table 3: Investment performance of low risk portfolios (1972-2011)

Portfolio #:	1	2	3	4	5
Investment Yield	6%	6%	6%	6%	6%
Risk (std deviation)	3.07%	2.95%	2.31%	2.31%	2.47%
Coef of Variation	**.51**	**.49**	**.39**	**.39**	**.41**
Portfolio Weights:					
T-bills and Bonds	80.2%	90.2%	81.8%	81.0%	76.2%
F-REIT	19.8%	0.0%	0.0%	1.7%	15.4%
Gold	0.0%	0.0%	0.0%	0.0%	0.0%
Oil	0.0%	0.0%	8.7%	8.1%	0.0%
REITs	0.0%	3.0%	3.6%	3.6%	2.9%
Stocks	0.0%	6.8%	5.9%	5.6%	5.5%

Table 4: Investment performance of medium risk portfolios (1972-2011)

Portfolio #:	1	2	3	4	5
Investment Yield	7.0%	8%	8%	8%	8%
Risk (std deviation)	9.19%	10.82%	7.37%	7.36%	8.16%
Coef of Variation	**n/a**	**1.35**	**.92**	**.92**	**1.02**
Portfolio Weights:					
T-bills and Bonds	0.0%	44.7%	26.8%	23.6%	0.0%
F-REIT	100.0%	0.0%	0.0%	6.5%	60.7%
Gold	0.0%	0.0%	0.0%	0.0%	0.0%
Oil	0.0%	0.0%	31.7%	29.0%	0.0%
REITs	0.0%	25.8%	17.1%	17.2%	18.6%
Stocks	0.0%	29.5%	24.4%	23.7%	20.7%

Table 5: Investment performance of high risk portfolios (1972-2011)

Portfolio #:	1	2	3	4	5
Investment Yield	n/a	10%	10%	10%	10%
Risk (std deviation)	n/a	20.15%	15.98%	15.98%	19.68%
Coef of Variation	**n/a**	**2.01**	**1.60**	**1.60**	**1.97**
Portfolio Weights:					
T-bills and Bonds	n/a	0.0%	0.0%	0.0%	0.0%
F-REIT	n/a	0.0%	0.0%	0.0%	14.5%
Gold	n/a	0.0%	36.5%	36.5%	0.0%
Oil	n/a	0.0%	0.0%	0.0%	0.0%
REITs	n/a	51.5%	31.3%	31.3%	46.1%
Stocks	n/a	51.5%	31.3%	31.3%	46.1%
Borrowing	n/a	0.0%	-1.2%	-1.2%	0.0%

replaced oil as the efficient diversifier for this level of required investment yield, mainly due to gold's higher yield. Once again, if gold and oil are not available, as in portfolio 5, F-REIT is chosen but overall performance of portfolio 5 in only slightly better than portfolio 2, where only bonds, stocks and REITs are included.

F-REIT has significant investment advantages, including low risk, low to negative correlation in yields with other assets, excellent inflation hedge, and offers a dividend yield. However, when both gold and oil are included in the choice set of assets, oil seems to outperform F-REIT and gold in the low and medium risk portfolios and gold outperforms F-REIT and oil in the high risk portfolios. While F-REIT is valuable in the low and medium risk portfolios, it does not appear to dominate. These results are consistent with many of the other studies completed such as Barry (1980), Kaplan (1985), Moss *et al*. (1987), Lins *et al*. (1992), Ruebens and Webb (1995), Bigge and Langemeier (2004), Libbin *et al*. (2004a and 2004b) and Noland (2011). However, there are some inconsistencies with Waggle and Johnson (2009) who found farmland provided an advantage only at low levels of risk, and with Hardin and Cheng (2005) who found no significant advantage to adding farmland to a portfolio.

6. Conclusions

Can traditional investors improve financial performance by adding a farmland real estate investment trust, gold and oil to their investment portfolios? This study shows that for the period 1972–2011, financial performance was significantly improved with the addition of F-REIT, gold and oil to a portfolio of traditional investments of T-bills, bonds, stocks and REITs. A Canadian F-REIT is considered relatively low risk, enters the efficient portfolios at low to medium risk levels and adds the most financial improvement to medium risk portfolios. Gold and Oil are higher risk assets with no dividend yield but because of their low correlations with other assets, they are able to reduce portfolio risk and add significant financial improvement in all portfolios.

What are the implications for investors? For current farmland investors, including farmers, it implies that they should own bonds, stocks, oil, and REITs to complement their farmland investment holdings, and possibly gold if they want a higher risk portfolio (most farmers do not). Farmers might consider leasing instead of buying more farmland when they expand their farm operations. As the number and size of F-REITs expands, retiring farmers will have additional potential buyers for their farmland. Institutional investors and large pension funds can consider the diversification benefits of holding F-REITs as part of their portfolios. The main benefits for the agricultural market is that F-REITs inject new equity by purchasing land from retiring farmers and leasing to farmers who want to expand. The main benefit for the non-farmer investor and institutional investors is another asset choice with excellent diversification and inflation hedge benefits offering a dividend yield.

What are the implications for farm businesses? The demand for F-REITs by the farm business sector depends, at least partially, on the speed at which average farm size is expected to grow. If cropping and machinery technological changes continue to replace labour with machines and larger farm sizes are needed to achieve economies of scale associated with those technological investments, the internal equity generated by farmers may not be sufficient to finance those farm expansions. In this scenario, there will be even larger farms, fewer farm managers, and more external farm equity investment needed, implying a greater need for F-REITs. On the other hand, if technological changes come at a pace where farmers are able to generate sufficient internal equity financing needed to grow, the farmer demand for F-REITs may not materialize. Farmland may continue to be traded and leased predominantly between farmers, as it is currently. Of course there are other questions to consider associated with F-REITs. For example, what are the cultural and social implications for the farm community of having much of the land owned by investment trusts? Some Canadians believe that farmland should be owned by farmers only. Would Canadians be comfortable with a significant amount of farmland being owned by foreigners or would F-REIT's be restricted to Canadian investors? Would there still be a sufficient supply of farm management skills available to efficiently and sustainably manage the farmland? These and many other questions still need to be addressed.

In summary, F-REITs can offer value to a portfolio comparable to gold and oil, in terms of being a hedge against inflation, diversifier and stabilizer, and providing safety of principal. It is better than gold and oil in some respects, including lower overall risk, less risk of price fluctuation, shorter price cycle, and provides an annual dividend. However, in terms of efficient portfolio risk-return trade-off, F-REIT does not outperform gold or oil.

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Appendix A: Calculating Average Asset Returns, Risk, Correlations and Capital Market Lines

Average Returns, risk and correlations are calculated using 1972-2011 time series data for the following asset set: Canadian government treasury bills (90 day T-bills), long term Canadian government bonds (10 years to maturity), Canadian farmland real estate investment trust, gold, oil, US real estate investment trusts, and stock markets for Canada, Australia, United States, Japan, Europe, MSCI world portfolio, and Hong Kong. For each of these, the data used and calculation method is described.

Canadian government 90 day Treasury Bills: Statistics Canada provides average annual T-bill rates. A geometric average over the time series is calculated to provide the average annual compounded rate of return that could have been earned by continuously investing in 90 day T-bills. Data Source: http://www.statcan.gc.ca/start-debut-eng.html

Long Term Government of Canada Bonds: similar to T-bills, Statistics Canada provides average annual long term bond yields over the time series. A geometric average is calculated to provide the average return on investment that could have been earned. The standard deviation is calculated and represents the risk (same source as T-bills).

Canadian Farmland Real Estate Investment Trust: The general approach to calculating F-REIT returns is provided in the body of the paper but more detail is provided here. The data is provided by Statistics Canada as aggregate farmland financial information, by province, by year. The data needed to calculate average annual farmland ownership returns by province includes (Statistics Canada Cansim table numbers in bracket) Value per acre Farmland and Buildings (002-0003), Value of Farm Capital (002-0007), Farm Debt outstanding (002-0008), Farm Cash Receipts (002-0001), Farm Operating Expenses (002-0005), and Farm Income in Kind (002-0012). Total farm cash receipts by province are used to estimate the average income return per hectare for a land owner by applying a crop-share lease percentage.

From this, property taxes and building depreciation are deducted to arrive at the net lease or income return to the landowner, per year. This represents part of the overall farmland ownership return, which is referred to here as the income return (comes from the operating revenues of the farm). The other part of the return is the land value appreciation or depreciation each year–if farmland values increases there is a capital gain and if it decreases, there is a capital loss. This is measured each year and called the capital gain yield. Each year, for each province, the income return is added to the capital gain yield to arrive at the total yield for the year. The geometric average of total yields over the time series is the average annual return on farmland investment for that province. The standard deviation is the measure of risk for the farmland investment. The annual Canadian F-REIT return on investment is the non-weighted arithmetic average of the five provincial annual returns for that year (cross-sectional). The time-series geometric average and standard deviation are then calculated for the F-REIT over the 1972-2011 time period and the tax and management expense adjustments are made to arrive at a net F-REIT return on investment, which is then used in the EV analysis.

Gold: historic gold prices, in US dollars, were used to calculate an average annual compounded return for investing in gold. Source: http://www.nma.org/pdf/gold/his_gold_prices.pdf

Oil: historic oil prices were used to calculate the average annual compounded return for investing in oil. Source: http://www.fintrend.com/inflation/inflation_rate/Historical_Oil_Prices_Table.asp

United States Real Estate Investment Trusts: Annual average returns are provided by FTSE NAREIT US Real estate Index Services. Source: http://www.reit.com/DataAndResearch/IndexData/FNUS-Historical-Data.aspx

Stock Market Returns: all stock market returns are calculated from the Morgan Stanley world stock market indices site, which is update daily. All indexes are for countries or regions and are an average of the stock markets within that country or region. Indices are provided for both dividends and capital gains so geometric averages are calculated for both and added together to produce a total stock market return, per year, per country or region. The standard deviation for the time series is used as the risk measure. Source:
http://www.mscibarra.com/legal/index_data_additional_terms_of_use.html?/products/indices/international_equity_indices/gimi/stdindex/performance.html

Table A1: Summary of Average Returns and Risk (1972–2011)

Asset	Std Dev	E[R]
T-Bills	0.0%	4.8%
Long Bonds	3.0%	5.8%
FREIT	9.2%	7.0%
Gold	26.1%	9.6%
Oil	29.4%	8.3%
REITs	21.4%	9.5%
Canada	22.5%	9.2%
Australia	27.1%	9.3%
US	18.2%	8.5%
Japan	33.5%	8.6%
Europe	22.4%	9.4%
World	18.5%	8.5%
Hong Kong	46.8%	13.2%

At this point in the study, the data set shown in Table A1 has been produced:

The next step is to use the time series annual returns to calculate the Variance Co-Variance matrix and from that derive the Correlation matrix, as illustrated in the paper. The average returns for the time series, along with the variance co-variance matrix are required inputs for the EV model. When the EV analysis is applied to the data, a table of portfolio results is produced, as follows, which represents the Markowitz set of Efficient Portfolios, when the risk-free asset is included.

Applying this methodology to five different scenarios allows for a comparison of financial performance (risk and return) when various assets are included or not. This allows us to see whether any particular assets, such as F-REIT, Gold, or Oil make a difference in overall performance.

Appendix B: The Expected Value - Variance Model and the Capital Market Line

The E-V Model

The expected value-variance model (E-V model) has long been the fundamental approach in showing how the efficient set of portfolio investments is derived. The usual method of deriving the efficient set of investments is to minimize risk for various expected return constraints. The mapping of the minimum risk levels provides the feasible set, of which the dominant assets or portfolios represent the efficient frontier.

The efficient frontier is derived by minimizing investment risk (variance), subject to expected return and wealth constraints.

$$\text{Minimize } X' QX \tag{B.1}$$

subject to:

$Rp = C' X$

$W = e' X$

where:

X=vector of wealth invested in each asset, xi being the dollar amount invested in asset i

Q=variance-covariance matrix of asset returns, Cov(ri, rj)

Rp=portfolio return on investment

C=Nx1 vector of return on investment for N choice assets

W=the investor's total wealth

e=Nx1 vector of 1's.

Table A2: The Capital Market Line (Farmland Included in Choice Set)

Portfolio Return	Standard Deviation	T-Bills	Long Bonds	FREIT	Gold	Oil	REITs	Canada	Australia	US	Japan	Europe	World	Hong Kong	Borrowing
		Portfolio Weights for Choice Set of Assets													
12.00%	28.32%	0.0%	0.0%	0.0%	64.6%	0.0%	59.1%	0.0%	0.0%	0.0%	0.0%	31.9%	0.0%	23.5%	-79.2%
11.50%	25.24%	0.0%	0.0%	0.0%	57.6%	0.0%	52.7%	0.0%	0.0%	0.0%	0.0%	28.5%	0.0%	20.9%	-59.7%
11.00%	22.15%	0.0%	0.0%	0.0%	50.5%	0.0%	46.3%	0.0%	0.0%	0.0%	0.0%	25.0%	0.0%	18.4%	-40.2%
10.50%	19.07%	0.0%	0.0%	0.0%	43.5%	0.0%	39.8%	0.0%	0.0%	0.0%	0.0%	21.5%	0.0%	15.8%	-20.6%
10.00%	15.98%	0.0%	0.0%	0.0%	36.5%	0.0%	33.4%	0.0%	0.0%	0.0%	0.0%	18.0%	0.0%	13.3%	-1.1%
9.50%	13.32%	0.0%	0.0%	0.0%	18.3%	19.3%	31.7%	0.0%	0.0%	0.0%	0.0%	23.6%	0.0%	7.2%	0.0%
9.00%	10.72%	0.0%	0.0%	0.0%	0.0%	41.9%	27.0%	0.0%	0.0%	3.2%	0.0%	25.7%	0.0%	2.2%	0.0%
8.50%	8.97%	0.0%	6.6%	8.1%	0.0%	35.0%	21.2%	0.0%	0.0%	8.6%	1.1%	19.5%	0.0%	0.0%	0.0%
8.00%	7.36%	0.0%	23.6%	6.5%	0.0%	29.0%	17.2%	0.0%	0.0%	7.0%	0.6%	16.1%	0.0%	0.0%	0.0%
7.50%	5.81%	0.0%	40.8%	4.5%	0.0%	23.3%	13.0%	0.0%	0.0%	5.5%	0.2%	12.6%	0.0%	0.0%	0.0%
7.00%	4.39%	0.0%	57.5%	3.3%	0.0%	17.2%	9.0%	0.0%	0.0%	3.8%	0.0%	9.1%	0.0%	0.0%	0.0%
6.50%	3.25%	2.8%	70.5%	2.4%	0.0%	11.3%	5.1%	0.0%	0.0%	2.2%	0.0%	5.7%	0.0%	0.0%	0.0%
6.00%	2.31%	30.8%	50.2%	1.7%	0.0%	8.1%	3.6%	0.0%	0.0%	1.5%	0.0%	4.1%	0.0%	0.0%	0.0%
5.50%	1.37%	58.9%	29.8%	1.0%	0.0%	4.8%	2.2%	0.0%	0.0%	0.9%	0.0%	2.4%	0.0%	0.0%	0.0%
5.00%	0.43%	87.0%	9.4%	0.3%	0.0%	1.5%	0.7%	0.0%	0.0%	0.3%	0.0%	0.8%	0.0%	0.0%	0.0%
4.80%	0.00%	100.0-%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

The resulting Lagrangian equation is:

$$\text{Minimize } L = X'\,Q\,X + l1(Rp - C'X) + l2(W - e'X) \quad \text{(B.2)}$$

X, l1, l2
where:
l1=the incremental risk (variance) due to an increase in portfolio return, Rp.
l2=the change in risk given an increase in wealth.
The first order conditions are:

$$\frac{\partial L}{\partial Xi} = 2X'Q\text{-}ri\ l1\text{-}l2 = 0$$
$$\frac{\partial L}{\partial l1} = Rp\text{-}C'X = 0 \quad \text{(B.3)}$$
$$\frac{\partial L}{\partial l2} = W\text{-}e'X = 0$$

where: ri, rj=expected returns on assets i and j
The first order conditions provide the optimum values of X, l1, and l2:

$$X^* = Q\text{-}1[Ce]\begin{bmatrix} l1 \\ l2 \end{bmatrix} \quad \text{(B.4)}$$

Premultiplying (B.4) by [Ce]' and rearranging provides:

$$\begin{bmatrix} l1 \\ l2 \end{bmatrix} = A\text{-}1[Ce]'X^* \quad \text{(B.5)}$$

A is a 2x2 matrix called the 'fundamental matrix of information' since it contains all the information about the asset means, variances, and covariances. The A matrix consists of:

$$A = \begin{bmatrix} C'Q-1C & C'Q-1e \\ e'Q-1C & e'Q-1e \end{bmatrix} = \begin{bmatrix} a & b \\ b & c \end{bmatrix} \quad \text{(B.6)}$$

The scalar elements of A are called the 'efficient set constants'. By substituting (B.5) into (B.4) and rearranging, the optimal solution vector X* is derived at given levels of expected return and risk.

$$X^* = Q\text{-}1[Ce]A\text{-}1\begin{bmatrix} Rp \\ W \end{bmatrix} \quad \text{(B.7)}$$

The variance of returns for the optimal portfolio X* can be found by substituting (B.7) into the following equation for variance of the portfolio:

$$s_p^{2}* = X^*QX^* = \frac{1}{ac - b2}\left[R_p^{2}c - 2RpWb + W2a\right] \quad \text{(B.8)}$$

Equations (B.7) and (B.8) determine the E-V efficient portfolio and variance for a given level of expected return. By varying Rp over a reasonable range, the efficient frontier can be mapped in expected return-standard deviation space.

The Capital Market Line

The E-V model is based on a concave investment opportunity surface. However, the introduction of a risk-free asset changes the nature of the efficient set. The two-fund separation theorem suggests that investors can maximize their utility by choosing a portfolio which is some combination of the market portfolio (tangency portfolio) and the risk-free asset. All optimal portfolios would then fall on the Capital Market Line (CML), which represents the linear efficient set of portfolios for investors. The linear efficient set is a combination of N risky assets and one riskless asset:

$$\bar{X}^* = \bar{Q}\text{-}1[\bar{C}\,\bar{e}]A\text{-}1\begin{bmatrix} Rp \\ W \end{bmatrix} \quad \text{(B.9)}$$

where the hats (^) indicate that the risk-free asset has been included. The variance-covariance matrix , becomes:

$$\hat{Q} = \begin{bmatrix} Q & f \\ f' & e \end{bmatrix} \quad (B.10)$$

where: f=an Nx1 null vector
e=a very small number, which represents the variance of the risk-free asset. Setting e to some number other than zero allows $\hat{Q}$to be inverted.
$\hat{Q}$ = an (N + 1) x (N + 1) variance-covariance matrix, which includes the risk-free asset.
The CML then becomes a linear combination of the risk-free asset and the point of tangency with the investment opportunities surface.

Appendix C: Alternative Risk Measurement Approaches

Capital Asset Pricing Model (CAPM)

The most common alternative risk measurement approach has been the Capital Asset Pricing Model, developed by Sharpe (1964). The Capital Asset Pricing Model (CAPM) is derived from the E-V model and is predicated on investors maximizing utility by choosing portfolios from the linear efficient frontier. The CAPM, as developed by Sharpe, assumes:

1. Markets are perfect in that there are no taxes or transaction costs, there is perfect liquidity and marketability, and assets are priced efficiently.
2. Investors are risk averse and asset returns are normally distributed, which implies that utility is maximized by investing on the CML.
3. There is unlimited borrowing and lending at the risk-free rate of return.

The major characteristic of the CAPM is the assumption that the returns of various securities are related only through common relationships with some basic underlying factor. Sharpe suggested that the return for asset i is determined solely by the outside element plus a random set of factors:

$$Ri = Ai + BiI + Ci \quad (C.1)$$

where:
Ri=the return on asset i
Ai, Bi=parameters
Ci=a random variable where E(Ci)=0 and V(Ci)=Qi
I=the level of some index which may be a stock market index, GNP, some price index, or any other factor that is the most important influence on the return on assets.
Then, with estimates of Ai, Bi, and E(I), E(Ri) could be estimated:
E(Ri)=Ai + Bi E(I)
with variance:

$$V(Ri) = B_i^2 V(i) + Qi$$

The variance equation illustrates the two components of total risk; systematic and unsystematic risk. The term $B_i^2 V(I)$ represents that portion of total risk that is a function of the variance of the common outside element, namely the systematic risk. Since this part of the risk is due to an element common to all assets, it cannot be diversified away simply by combining different assets in a portfolio. The term Qi represents the variance of the random elements associated with asset i. Because these elements are random for each asset i, this part of the risk, called unsystematic risk, can be diversified away simply by holding many different assets together in a portfolio. In attempting to solve Markowitz's problem in a simpler fashion, Sharpe laid out the groundwork for the CAPM by deriving his CAPM model.
The CAPM equation states explicitly the expected return for an asset, based on the systematic risk of the asset, and implicitly the price of the asset.

$$E(Ri) = rf + [E(Rm)\text{-}rf]\frac{sim}{s_m^2} \quad (C.2)$$

where:
E(Ri)=the expected return on asset i
rf=the risk-free rate of return
E(Rm)=the expected return on the market portfolio
sim=the covariance between Ri and Rm
s_m^2 = the variance of Rm
Hence, in a liquid, divisible, and efficient market, the expected CAPM rate of return for farmland is:

$$E(RF) = rf + [E(Rm)\text{-}rf]\frac{sFm}{s_m^2} \quad (C.2)$$

where:
E(RF)=the expected return on farmland

$$BetaF = \frac{sFm}{s_m^2}$$

The CAPM is an equilibrium model which implies that all asset prices will adjust to offer investors the CAPM expected rates of return. In the case of farmland, if the beta is zero, then the CAPM required rate of return is equal to the risk-free rate. If the market for farmland is liquid, divisible, and efficient, the CAPM suggests that farmland prices will adjust so that the expected return to farmland ownership equals to the CAPM risk adjusted rate, E(RF). However, if there are impediments to investing in farmland, such as lumpy farmland assets or ownership restrictions, no such guarantee exists. The result is an observed rate of return which exceeds the E(RF). If the causes of persistent excess returns to farmland are non-divisibility, illiquidity, non-marketability, and thin markets, then the removal of these inefficiencies (possibly through F-REITs) could reduce excess returns and provide efficient farmland pricing.

The Arbitrage Pricing Theory Model

The Arbitrage Pricing Theory (APT) model developed by Ross (1974, 1976) is a competing model to the CAPM. The APT is an equilibrium model like the CAPM but does not require the assumptions of risk aversion and normally distributed returns. Ross suggested that an asset's risk premium is determined from the systematic risk associated with common market factors, where one factor could be the market portfolio, but not necessarily.
The general APT model is:

$$Ri = E(Ri) + Bi1[I1 - E(I1)] + ...Bin[In - E(In)] + ei \quad (C.3)$$

where:
Ri=the return on asset i
E(Ri)=the expected return on asset i
Ii=systematic sources of risk or common factors
ei=random error
As with the CAPM, the objective of the APT is to determine the risk adjusted required rate of return for each asset in the market. The required rate of return for an asset will be dependent upon its covariance with the common factors in the market. Assets with high betas display a high level of systematic risk, therefore requiring a high risk premium. Assets with low or zero betas display a low level of systematic risk and therefore, require a low or zero risk premium.

In order for the APT to fully describe required rates of return and asset pricing, there must be full and complete arbitraging between markets. If an asset in any single market is over or under priced, it is assumed that investors can quickly and with relatively small transaction costs, take advantage of the price discrepancy. The constant pursuit of arbitraging profits by investors causes asset prices to adjust to equilibrium values, where the expected returns are equal to the required returns for every asset.

In the absence of complete arbitraging between markets, prices may not adjust to APT equilibrium levels. Impediments to arbitraging such as non-divisibility, illiquidity, and non-marketability, could cause excess returns to persist. The market for farmland has impediments to arbitraging, such as lumpy farmland assets, poor marketability of farmland due to thin markets, and legislative ownership restrictions. Due to these impediments, there is no reason to believe that the APT could adequately explain rates of return or pricing in the farmland market. However, with the removal of the impediments to cross market arbitraging, the APT model could possibly provide a reasonable estimate of required rates of return for farmland.

Value at Risk (VAR)

VAR can be used to aggregate risk for a portfolio of different kinds of assets, such as stocks, bonds, real estate, farmland, gold and oil. VAR does not require normally distributed returns or any other assumptions about the probability distribution of gains and losses for the portfolio. While standard volatility measures such as variance of past returns measures both upside and downside volatility, VAR is only concerned with the probability of a large loss. VAR has three main components: a time period (can be a day, a month, a year), a confidence level (95% is very common), and a loss amount. For example, what is the largest expected loss over the next year for a mixed portfolio of stocks, bonds, farmland, and real estate, given a 95% confidence level? That % or dollar amount is the VAR. There is a 5% chance that the portfolio loss will be greater than the VAR estimate, which would be referred to as a VAR break.

There are three common methods of calculating VAR for an asset or portfolio: historical method, variance-covariance method, and the Monte Carlo simulation approach. The historical method plots all the return points in a frequency distribution chart for a past period of time–in this study it would be a frequency plot of annual returns for each portfolio being compared, for the period 1972–2011. The worst 5% of all returns for each portfolio (the left tail of the distribution) would indicate the 95% confidence limit. For example, if for a portfolio the left tail included annual losses of 10% to 35%, we would expect that, with a 95% confidence level, our annual loss next year would not exceed 10%.

The variance-covariance method assumes that portfolio returns are normally distributed so we only need to estimate the expected return and standard deviation for a portfolio to fully describe the distribution of returns. We also know that in a normal distribution a 95% confidence lower limit would be the expected return on the portfolio minus 1.96 x the standard deviation. For example, if the expected return on the portfolio is 8% with a standard deviation of 7.36%, the 95% lower limit would be -6.43% (loss). Thus, for this portfolio, there would be a 95% confidence level that the maximum loss next year would be 6.43%, with a 5% chance that the loss would be greater.

The third method of calculating VAR uses a Monte Carlo simulation model to generate a probability distribution of expected returns for each portfolio being compared. Probability distributions would be required for all portfolio assets, based on past return experience. The Monte Carlo model is used to generate outcomes of portfolio returns, based on randomly selected inputs from the individual asset probability distributions. The worst 5% of the Monte Carlo outcomes would provide the 95% VAR for the portfolio.

In summary, VAR would calculate the maximum loss expected on a portfolio for a given time period, for a specified degree of confidence. For this study, VAR is an alternative method of assessing risk that could be used to compare investment portfolios that include various mixes of stocks, bonds, real estate, farmland, gold and oil, to determine which mixes have the lowest value at risk.

CASE STUDY

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Estimating the economic impact of the adoption of novel non-crate sow farrowing systems in the UK

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ABSTRACT

The majority of indoor sows in the UK (around 95 per cent) farrow in conventional farrowing crates. There is pressure from a number of quarters – EU and national regulators, supermarket buyers and consumers – to improve the welfare of sows by adopting "free" farrowing systems. A DEFRA-funded project (under the acronym PigSAFE) conducted by Newcastle University and the Scottish Agricultural College (SAC) has developed and tested such a non-crate farrowing system. The trial monitored the costs and pig performance of over 450 sows which farrowed in either PigSAFE pens or conventional farrowing crates. The data generated in this work were used to construct spreadsheet-based budgeting models and linear programming (LP) models to assess the comparative economic performance of the two systems and determine the likely uptake of the new system. The results suggest that the cost of production under the new farrowing system would be about 1.6% higher than the conventional farrowing crate while pig performance was comparable in the two systems. A survey showed that UK producers were prepared to consider the new systems when renewing their farrowing accommodation, although the modelling exercise suggests that a price premium would still be required to ensure the viability of the new systems.

KEYWORDS: farrowing sow; animal welfare; pig; housing system; cost of production

1. Introduction

One of the major factors affecting the profitability of breeding sow units is the number of piglets weaned per litter. In the case of indoor units, this has lead to the widespread use of farrowing crates as a system of controlling the movement of the sow and thereby safeguarding her piglets, particularly from crushing. It could be argued that in the design of this system, emphasis has been on the welfare (or at least survival) of the piglets rather than on the welfare of the sow. Crates prevent the sow from exhibiting many of her natural behaviours, such as freedom of movement and nest building at farrowing time. The regulatory framework at both national (DEFRA, 2007) and EU (Council of Europe, 2011) levels is moving away from the use of confined systems for gestating (or dry) sows. Also, in the UK in particular, there has been increasing interest from buyers of pigmeat, particularly supermarkets, in the development of non-crate farrowing systems.

This paper describes the economic evaluation of a novel free-farrowing system developed under a DEFRA-funded project run jointly by Newcastle University and the Scottish Agricultural College (SAC). This project, under the acronym PigSAFE, firstly designed and then tested a pen-based farrowing system and compared the results with those in conventional, crate-based systems. The data generated were used to populate a spreadsheet-based budgeting tool which compares the cost of weaner production through a wide variety of dry-sow and farrowing sow systems. Linear Programming (LP) models were then used to estimate the likely uptake of the PigSAFE system by the UK pig industry and to consider the conditions under which the adoption of the new system by producers would be cost-neutral.

2. Background – UK farrowing systems

A survey of producers was undertaken to establish the current types of indoor farrowing systems used in the UK and to investigate the intentions of producers with regards to likely replacement strategies. A web-based questionnaire was mounted on the National Pig Association (NPA) website, 'Pig World', in January, 2011.

A total of 45 replies were received from producers representing around 10,000 farrowing places which accounts for around 40–50,000 breeding sows or about 20% of the UK indoor breeding herd. The results showed that 96% of sows were farrowed in farrowing crates, 2% in a modified crate design and 2% in other systems. Sixty seven per cent of producers surveyed expected to replace part of their existing system over the course of the next 10 years. When replacing existing

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farrowing systems, 64% of producers reported that they would replace with the same housing design, with 27% considering replacing with a different system whilst 9% were unsure about which system they would choose as a replacement.

Of those producers considering replacing with a new system, one-third suggested they might adopt a fully-slatted opening pen that allowed the sow to turn around (a system developed and promoted by a commercial UK pig production company under the brand name '360°Farrower'). Another one-third of producers were considering a non-crated, part-bedded pen design such as the PigSAFE system. Finally, one-quarter of all producers who answered the questionnaire were thinking of trialling some form of non-crate farrowing system as a pilot.

3. The PigSAFE project

In the first stage of the project, a wide-ranging review of the literature on free-farrowing systems was undertaken to examine the principal features which contribute to the welfare of both the sow and her piglets (Baxter *et al.*, 2011a), and to consider the design and management factors affecting the performance of those systems (Baxter *et al*, 2012). From these reviews and from an LP-based optimisation exercise (Ahmadi *et al*, 2011), a prototype pen-based farrowing system was designed. The PigSAFE pen has been developed to optimise welfare and economic performance, with the design intended to meet biological needs of sows and piglets, as well as requirements for stockperson safety and management ease. Following the review of more than 350 articles in the scientific, technical and industry literature, and extensive discussions with a wide range of scientists and stakeholders, a prototype pen was designed as shown in the Figure 1 below (Anon, 2010a and Anon, 2010b). The pen involves a basic nest area, with solid flooring to allow provision of nesting material and sloping walls against which the sow can slide more slowly to ground level for suckling, to lower the risk of piglets being trapped and killed. A heated creep area has easy access from the nest. A separate slatted dunging area is bounded by walls with barred panels to adjacent pens to discourage farrowing outside the nest. A feeding crate for the sow is included at one side of the pen, where the sow can be locked in to allow safe inspection or treatment of the piglets.

The resulting PigSAFE system then has embedded design features to promote piglet survival and ease of management. The pen layout encourages the sow to farrow in a particular location promoting the use of a readily accessible heated safe creep area by the piglets and incorporates sloping walls to facilitate their escape from crushing. It also provides a safe environment stockpersons as the sow can be confined in a feeding stall thus allowing personnel to undertake piglet tasks. The pen is easily cleaned between batches as the sides are fabricated from plastic panels which are easily cleaned and disinfected, and the slatted dunging area has automated manure removal.

This design, with some variations to test specific alternative design features, was piloted at Newcastle University's Cockle Park farm (Edwards *et al.*, 2012a) and SAC's Bush Estate (Baxter *et al.*, 2011b), using 150 litters at each site. Analysis of pig performance of this pilot stage was used to finalise a design for the new system which was then run for a further year at both sites under commercial conditions. The building space occupied by the pen is approximately 20% more than that occupied by a conventional farrowing crate.

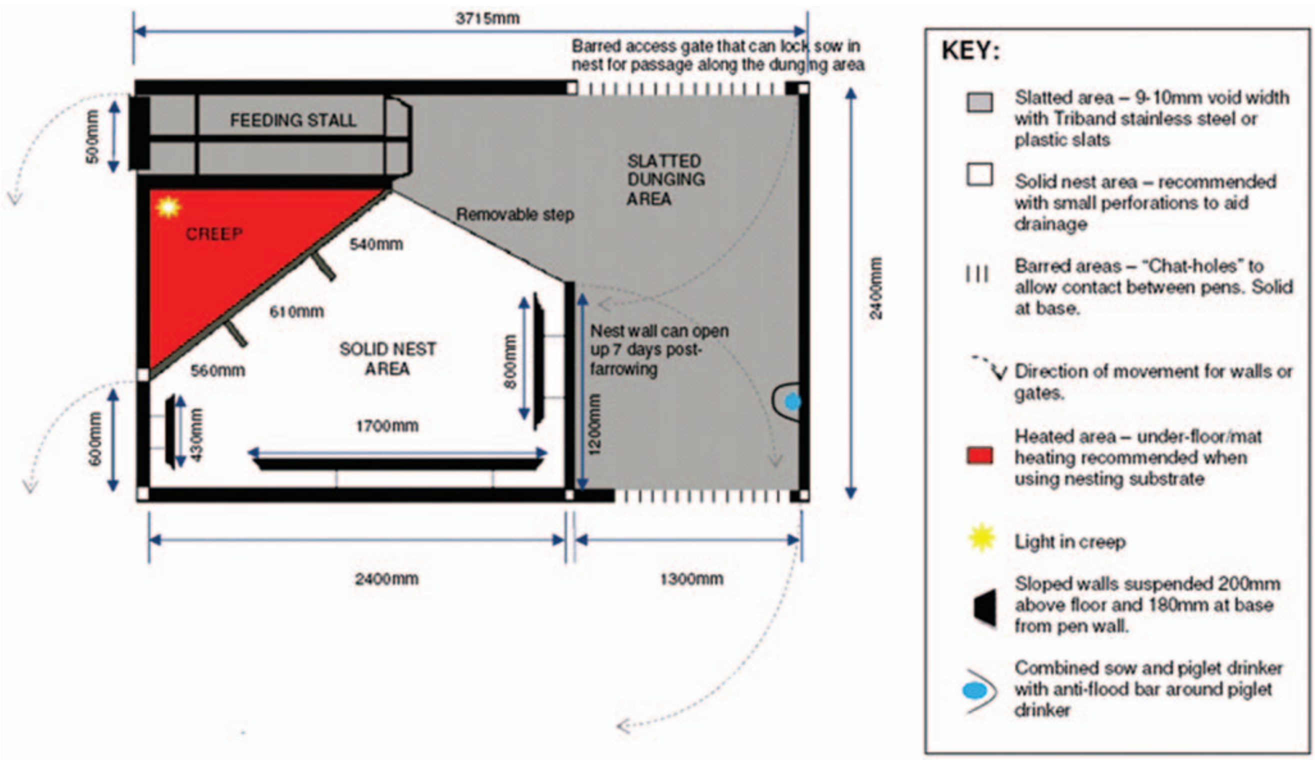

Figure 1: Prototype pen, PigSAFE

Table 1: Base model unit parameters

Parameter	Unit value
Breeding sows	540
Staff (FT equivalent)	4.5
Farrowing places	120
Weaner places	1,200
Finisher places	3,600

4. Method of economic analysis

A suite of linear programming (LP) models was developed to test the economic conditions under which pig producers might adopt new farrowing systems. The alternative farrowing systems considered were the PigSAFE system, the 360 Farrower described previously and a Danish free farrowing pen. The latter consists of a minimally bedded pen with a slatted dunging area but without walls dividing functional areas and having a smaller area than the PigSAFE system (Vivi Aarestrup Moustsen, Pers. Com., 2011). A common dry-sow system was assumed for cost purposes, by taking a weighted average of the two most prevalent UK systems, namely kennels with individual feeders and large straw yards with electronic sow feeding.

The base LP model was constructed to simulate the representative UK breeder/finisher unit of 540 sows according to national statistics (BPEX, 2010). Larger (1000-sow) and smaller (200-sow) units were also considered. Table 1 shows the physical parameters of the basic representative unit model. In each case the new farrowing systems were tested against the conventional part-slatted farrowing crate-based system and conditions under which producers were likely to adopt the new system tested. To evaluate the sensitivity of the results, costs, resource use and animal physical performance were varied and the models re-run.

5. Data

To populate the models, in addition to data generated from the farm trials of PigSAFE, data were collected from industry and further supplemented with that from the scientific literature.

Animal performance

Because of the lack of large scale reliable published data on the performance of pigs in non-crate systems, sow performance parameters (e.g. litters per sow per year, numbers born alive, pre-weaning mortality), initially were assumed to be equal for all systems and were taken from the average technical performance data for UK indoor herds (BPEX, 2010). Thus farrowing performance was assumed initially to be 2.25 litters per sow per year and 10 piglets weaned per litter.

In the trial, sow performance in the crates and in the commercial PigSAFE phase were not significantly different (Edwards *et al*, 2012b) and the number of piglets weaned per litter were the same under both systems. This is contrary to the results of many previous investigations into free-farrowing systems. Also, at the Edinburgh site weaning weights were about 0.3 kg higher in the PigSAFE system than in the crate system.

Cost data

Cost data used included the costs of building construction, level of resource use (labour, power etc.) in operating the various housing systems and the unit costs of these resources. Estimates of building construction and repair costs were provided by a number of UK commercial pig building companies, assuming new build construction costs and provision of a building frame in which the farrowing system will be located. The PIGSafe system proved the most expensive to construct at £4,388 per unit compared with £3,170 for the conventional farrowing crate system. The annual building costs per sow place were estimated based on the expected lifespan and repair costs of the various housing systems as shown in Table 2.

Standard unit prices were collated for feedstuffs, labour cost per hour and machinery. Average electrical power use for farrowing systems was calculated from data collected on UK farms by Farmex Ltd (Reading, UK). Stockperson labour hours for farrowing and weaner phases were calculated from industry labour studies for indoor pig systems (Webster and Harper, 2008), along with data from the Newcastle PigSAFE trial. Bedding use was estimated from trial results and information provided in literature (Vieuille *et al*., 2003; MAFF, 1993). Machinery use for general sow husbandry, slurry and solid manure disposal were adapted from standard farm management data (Nix, 2010 and SAC, 2010). The unit input prices used are shown in Table 3.

Building space requirement and labour use for each stage of pig production are shown in Table 4.

Production costs incurred for each stage of pig production, excluding resources included within the LP model matrices (principally buildings and labour),

Table 2: Building costs of farrowing sow systems

	Farrowing system			
Element	Crate	PigSAFE	360 Farrower	Danish
Capital cost (£/place)	3,170	4,388	3,670	3,804
Lifetime (Years)	20	20	20	20
Annualised capital cost (£ per £1,000 @8%)	102	102	102	102
Sow place cost (£/year)	323	448	374	388
Repair cost (£/sow place/yr)	45	61	51	53
Total cost (£/ sow place/yr)	368	509	425	441

[5] In mid-December 2012, £1 was approximately equivalent to $US 1.63 and €1.23

Table 3: Standard unit input prices

Resource	Description	Unit	Cost/unit (£)
Feed	Lactating sow diet	Kg	0.21
	Creep feed	Kg	0.74
Vet. and Med.	Farrowing sow	Per sow per year	41.78
Machinery	Tractor hour	Hour	14.55
	Slurry disposal	M^3	2.4
	Farm Yard Manure disposal	Tonne	3.2
Bedding	Straw	Tonne	60
Labour	Stockperson	Hour	13.08
Water	Mains water	M^3	1.3
Power	Electrical energy	KW/h	0.10

Table 4: Building space use and labour requirement

Phase	Pig space use (annual proportion of a place)	Labour (hours per animal)
Dry sows	0.78/year	4.7
Farrowing sows	0.1/farrowing	2.6
Weaners	0.1/year	0.32
Grower/finishers	0.3/year	0.08

Table 5: Production costs for each stage of pig production (£/animal)

Stage of pig production	System	Cost £/animal
Dry sow	Kennels/Straw yards	£357[1]
Farrowing sow	Crate	£95[2]
	PigSAFE	£95[2]
	360 Farrower	£95[2]
	Danish	£94[2]
Weaner	Fully-slatted	£17[3]
Grower/finisher	Fully-slatted	£54[3]

Notes:
1. Dry sow costs are annual total costs excluding labour and weighted 50/50 for the two systems.
2. Farrowing sow costs are per farrowing and exclude building and labour costs.
3. Weaner and finisher costs are per pig excluding labour.

Table 6: Variations applied to the PigSAFE base model

Parameter varied	System	Base model	Variation	Value
Building cost - new	PigSAFE	£509/place	−10%	£458/place
	Crates	£337/place		
No. piglets weaned	PigSAFE	10 pigs/litter	−5%	9.5 pigs/litter
			−10%	9.0 pigs/litter
Building renovation	PigSAFE	£509/place	renovation	£365/place
	Crates	£368/place	renovation	£249/place
Piglet weaning weight	PigSAFE	7 kglwt	+ 0.3kglwt	7.3 kglwt

were calculated in the spreadsheet budgeting models to be used as objective function values in the LP models (see Table 5).

6. Model Runs

Using the data described above, the base models were run allowing the optimisation process to select between the farrowing crate system and one of the new farrowing systems. In the first instance the farrowing systems were assumed to be new-build. The models were used in three ways. Firstly by applying a variable premium to sales from the free farrowing systems it was possible to simply calculate the differences in production costs between the systems as the premium required to promote a switch between systems. The models were then re-run for the PigSAFE system to determine the effects on these differences in costs of production of variations in some of the principal costs and of changes in the performance parameters. Table 6 shows the variations which were applied and, as can be seen, one of these was to include the renovation of existing farrowing facilities rather than simply allowing the new-build option. Finally, the models were used to test the economic conditions under which the optimum solution would select the free farrowing system.

Table 7: Effects of variations on production costs

Model run	PigSAFE cost (pence/kgcwt)	Difference compared to farrowing crate production costs (145.0 pence/kgcwt)	
		p/kgcwt	%
Base	147.3	2.3	1.6
Reduced numbers weaned	152.7	4.7 (−0.5 pig)	3.2
		7.7 (−1 pig)	5.3
Reduced building cost	146.5	1.5	1.0
Renovated buildings	145.3	1.8	1.2
Higher weaning weight	146.3	1.3	0.9

7. Results

The results were firstly expressed as differences in cost of production per kg carcass of pigmeat (p/kg cwt). The base model, using only conventional crates, showed a production cost of 145.0 p/kg cwt, and using the PigSAFE system this rose to 147.3 p/kg cwt, a difference of 2.3 p, or 1.6% (Table 7). The costs calculated for the other two alternative farrowing systems, namely the 360 Farrower and the Danish free farrowing system, showed lower cost increases as a result of their lower capital (building) costs. The 360 Farrower had the lowest additional cost above the farrowing crate at 1.1 p/kg cwt, with the Danish system 1.5 p/kg cwt above the crate system.

When considering changes in performance, if numbers of piglets weaned from the PigSAFE system were reduced by 5% (to 9.5 pigs per litter) the cost difference compared to farrowing crates rose markedly to 4.7 p/kg cwt, and when reduced by 10% (9.0 pigs per litter) the cost difference rose to 7.7 p/kg cwt or 5.3%.

When the new-build construction costs for the PigSAFE system were reduced by 10%, as could happen if this novel system became more popular and producers might benefit from economies of scale in fabrication of the system, the difference in production cost narrowed to 1.5 p/kg cwt. Similarly, if it were possible to alter existing buildings to allow PigSAFE to be installed by renovation rather than new-build, the difference in cost of production was also less at 1.8 p/kg cwt. When improved weaning weights were assumed for the PigSAFE system, the additional 0.3 kg of liveweight at weaning which was experienced in the trials resulted in a narrowing of the production cost difference by 1.0 p/kg cwt compared to the conventional system or 1.3 p/kg cwt compared to the basic PigSAFE system (see Table 7).

The effect of scale of the pig enterprise on the structure and level of production costs was examined. There is evidence to suggest that larger scale units can achieve lower labour costs, of the order of 15 to 20% per animal, and lower building costs through construction of larger units. The evidence for differences in physical performance is mixed, with some survey data showing better performance in smaller units. As far as the current study is concerned, the calculations do not suggest that scale would differentially affect the cost of production under the various farrowing systems and is therefore unlikely to effect the decision about whether adopt a particular farrowing system beyond those factors analysed in the base model.

8. Conditions for adoption of the PigSAFE system by the UK pig industry

The results presented above showed differences in the cost of pigmeat production between conventional farrowing crates and the PigSAFE system under various financial and physical conditions. The base models were re-run to test the conditions under which the adoption of PigSAFE would be cost neutral to the pig industry. The first of these conditions would simply be the receipt of a premium of 2.3 p/kg cwt to cover the higher cost of production. In the UK, pigmeat from certain production systems such as outdoor-reared or under the RSPCA Freedom Food scheme commands a premium, suggesting that there may be a proportion of the market which might be prepared to pay more for pigmeat from sows which are not confined at farrowing. Similarly, if the building costs of the PigSAFE system matched those of the conventional crate (a considerable reduction of 28%) whilst performance remained constant, adoption of this alternative farrowing system would clearly be cost neutral. In terms of pig performance, the re-runs of the models also showed that the adoption of the PigSAFE system would be cost neutral if it could deliver higher performance (0.5 more pigs weaned per litter for example). Similarly, a higher weaning weight, of about 0.75 kg/pig, would also eliminate the gap in production cost. Clearly, not all of these factors are achievable individually, but combinations of more realistic changes (e.g. a modest premium coupled with slightly higher weaning weight or an effect on the efficiency of sows rebreeding) might be more feasible and lead to voluntary adoption of non-crate systems such as PigSAFE by the UK pig industry.

9. Conclusions

This analysis of the economic impact of using alternative non-crate farrowing systems suggests that there are two principal factors which affect cost of production: capital costs of construction and animal performance.

Capital costs of construction ranged from £3,170/sow place for conventional crates, up to £4,388/sow place for the PigSAFE system. This difference resulted in a production cost differential of 2.3 p/kg cwt over the lifetime of the system. Such a cost penalty would be further compounded if it were linked with lower physical performance of the animals. For example, the loss of an additional 0.5 piglets weaned per litter lead to a rise in production costs of 4.7 p/kg cwt. Conversely, improved performance in the PigSAFE system could narrow the gap in cost of production, with an average higher weaning weight of 0.3 kg weaning saving 1.0 p/kg cwt. This illustrates the different scenarios under which commercial pig producers might be encouraged to adopt non-crate systems such as PigSAFE.

This study has focused on production costs and not profitability. The other factor in the profit calculation is price received for pigmeat produced under the various systems. Although not explicitly considered in this study, clearly carcass value would depend on the details of any contract and the grading of pigs produced, as well as any premium accorded to the different systems under which the animals are produced. Changes to housing legislation would be another important factor which could affect the level of uptake of alternative farrowing systems. Whilst there is nothing currently in the pipeline, it could be that future changes in EU animal welfare rules force the adoption of alternative systems, a possibility that has prompted the recent interest by producers in developments in free farrowing systems.

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BOOK REVIEW

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The Food and Financial Crises in Sub-Saharan Africa: Origins, Impacts and Policy Implications

Edited by D.R. Lee and M.B., Ndulo Cornell University, USA

Published December 2011 by CABI, Nosworthy Way, Wallingford, Oxfordshire, OX10 8DE, UK. (www.cabi.org). 304 pages. ISBN: 9781845938284. Price: (hardback): £85.00/$160.00/€110.00.

Although the causes of the global food crisis (2007–2008) and the subsequent financial crisis are complex, it is generally accepted that the roots of these crises cannot be found in Sub-Saharan Africa (SSA). Nonetheless, the series of crises struck Sub-Saharan Africa (SSA) hard during the late 2000s. This is explained by the increased interdependence between the SSA's economies and other economies and inaccurate response to the crises. An international conference was organised at the Cornell University (May 2009) on 'The food and financial crises and their impacts on achieving the Millennium Development Goals in Africa' to discuss the impact and consequences of the crises. This multi-authored book (which results in quality differences among the different chapters) builds upon the updated versions of the submitted conference papers.

The book collects a number of chapters focussing on a wide range of aspects of Africa's dual crises. In this manner, the book offers a comprehensive introduction to the causes and consequences of the crises. The different topics are approached in different ways. While some chapters describe selected cases to illustrate and analyse their research topic, other chapters use a more generic approach (e.g. sub-national analysis). A second distinction is based upon the timeframe of the analysis; some chapters mainly provide a reflective analysis of the late 2000s' situation, other parts of the book mainly look forward while describe (e.g.) future challenges and opportunities for SSA. Each chapter however results in a set of policy alternatives that could enable governments to better deal with crises' effects in the future.

As a starter, the first chapter thoroughly introduces the food and financial crises and their effects in SSA. Keeping in mind the good quality of this first chapter, it is a pity that both crises are unnecessarily re-introduced in the beginning of too many of the subsequent chapters. These repetitions make the reading of the entire book a bit wearisome (not an issue when only selected chapters are read). Second, the time and space assigned to these repetitions could have been used for additional and more useful contributions. The subsequent chapters go into detail on agricultural productivity, the situation of the poorest Africans, the role of policies, and food security in in SSA. Many subcategories of these topics are discussed. The political dimensions of food price increases, the role of the financial sector, FDIs, and infrastructure are just a few examples. Also climate change, and SSA's status as net-importer of food, are often referred to as important factors. In addition, the book also contains some case studies that elaborate on the situation of urban consumers in Kenya, Malawi, Mozambique, and Zambia; on nutritionally vulnerable households in South Africa; and on the impact of high food prices on poverty in Uganda.

Focussing on these specific cases allows useful and interesting insights in the specific situations of the poor. Generalising the conclusions based upon this limited set of cases is dangerous however. The overview in the book's last chapter even suggests highly heterogeneous country-level and local-level impacts. On top of this, the cases' conclusions must be threatened with caution since the data used for the case studies is often of questionable quality. In fact, the entire book is constrained by the limited availability of good-quality data in the region it is focusing on. The lack of trustworthy data and data gathering methods in SSA is even mentioned by some authors as one of the main constraints for good policy design and research in SSA.

Both crises and their aftereffects undeniably have impacted the African economic performance and the livelihoods of the Africans. Hence, the necessity and usefulness of the conference and the book remains unquestioned. It can be questioned whether some of the book's chapters have not been published too early. In 2008 the impact of the food crises was most visible. High food prices on the international markets were experienced all over the world. Questions on the poor's ability to cope with these high food prices obviously arose. In 2009 food prices (as one of the most visible indicators of the crises) again decreased but the global economic deadlock is even at present not entirely behind us. Whether all aspects and impacts of the financial and food crises can thus be fully analysed and identified can be doubted. The longitude of the economic downturn is great, the problems that policy makers have to deal with are still not resolved. New policy challenges arose in addition to the 2008-2009 situation. Recently, Abdolreza Abbassian (economist at the FAO) even warned of a repetition of the 2008 food crisis. He fears that this year's low grain yields (grain is logically often referred to in the book) could result in government-interference in grain trade flows. Hence, not all worries are behind us, and policy makers are still struggling with comparable issues. Indeed, the book presents updated versions of the presented papers, but its main focus is on the topics of the first years of the crises. In the meanwhile, additional lessons learned have been formulated and the structural aspects of the crises become more evident. Even at present, retrospective analysis might face difficulties. The value and quality of part of the contributions can only be assessed after the crises. The chapters focussing on future challenges and policy implications of course add to the on-going discussions.

In conclusion, this book provides good and useful insights in various aspects of the food and financial crises in SSA. In particular, readers looking for an introduction to specific aspects of the crises in SSA will appreciate the effort made. While reading the chapters, one must realize however that the economic downturns described in the book are not completely behind us. Some aspects of the crises might also be seen in a new perspective as the longitude and structural aspects of the crises have become more – but not entirely – clear.

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BOOK REVIEW

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Agricultural Policies for Poverty Reduction

Edited by Jonathan Brooks

Published 2012 by CABI, Nosworthy Way, Wallingford, Oxfordshire, OX10 8DE, UK. (www.cabi.org), with OECD Publishing. ISBN: 978-17-80-64105-8. Price £75.00/$145.00/€100.00. 191 pages, 52 tables and figures. Pdf version available from the OECD Bookshop (www.oecdbookshop.org), ISBN: 978-92-64-11290-2.

Given the strong consensus that has finally been achieved about the interconnectedness of commodity price trends and a broad range of welfare indices, both for nations and individuals, a book looking at the role of agricultural policies in poverty reduction could not have been more timely. Very few economic phenomena have affected all countries to the same extent that the recent increases in prices have done. It is therefore understandable that they would form the starting point of this robust but succinct analysis in which seven researchers and development practitioners have joined forces to elucidate this important subject. The focus on rural incomes continues to be justified on a number of grounds, including the fact that the first of the eight Millennium Development Goals specifically addresses the urgency for that. But it has not always been clear how the targets are to be achieved and by whom, and whether or not there is scope for flexible application of the strategies in response to local circumstances and conditions. This is what makes this book an essential, practice-oriented tool for policy makers who have to design and guide the implementation of interventions in settings where seemingly similar conditions and circumstances actually hide stark dissimilarities that are often ignored with disastrous results. The sooner it is realized at the policy making level that all sizes do not fit all, the earlier a solution can be found and more progress made towards achieving the global goal of poverty reduction.

The volume is introduced by an editorial piece in which the editor reviews the role of agricultural policies in raising rural incomes in a broad sense. It recognized and applauds the primacy of rural income improvements not only as a political goal but also an economic imperative in response to recent developments in world food markets. The alignment with the structural arguments in support of such strategies is also highlighted from a historical perspective. The double-barrelled effects of prices and their role in determining whether market participants are net sellers or buyers and how these responses are affected by the structure of incentives, including the subsidization of farmers by the industrialized Western Countries, receive a fair amount of attention in the book.

The main body of the book consists of five chapters that are well-linked by the thematic focus on prices, food security and poverty alleviation and organized to progress smoothly from theory to estimation techniques to policy implications and recommendations, with well-situated suggestions for future research. In Chapter 1, the theoretical basis for policy intervention to strengthen rural incomes is developed and situated within the framework of the on-going structural transformation of smallholder agriculture in the developing world. How this emphasis fits the current national and regional priorities on the African continent and the global theme of poverty reduction within the framework of the Millennium Development Goals, is discussed and linked to a vast array of earlier empirical work on agricultural development in developing countries, with crucial references made to the induced innovation models, the Green Revolution, and more recent works on the role of institutions.

Chapter 2 isolates the commodity prices in developing countries and takes a critical look at their distributional impacts, emphasizing measurement and methodological issues and drawing examples from past and current trends to make projections for the future. The implications of the food price developments for rural welfare are given explicit attention and there is the strong suggestion that things are likely to get worse before they get better over the future years.

Chapter 3 continues on the methodological exposition and describes a new simulation model, the Development Policy Evaluation Model (DEVPEM) whose four key components cover such issues as the multiple roles of the households in production and consumption, market participation and associated costs and obstacles, market linkages, and resource constraints especially in relation to the fixity of the land asset. The main finding of the chapter is the conclusion that targeting of agricultural policy is a condition for ensuring that policies are sufficiently pro-poor, thus making a rare strong case for market intervention through input subsidies. Suggestions for improving the model, including the incorporation of liquidity and risks, are made.

Chapter 4 turns to the "how" of welfare improvement and poverty alleviation, describing a range of stabilization policies for both the short-term and long-term and how these are influenced by the nature of the governance regime in place. Methodological considerations are also taken up in this chapter. Policy recommendations are also made around the actions to reduce price variability and instability and enhance more predictability of commodity prices. Future research agenda is also proposed to accommodate the dynamic nature of the commodity markets.

Chapter 5 singles out input subsidies for more scrutiny given its profile as "an operationally simple and politically attractive way of addressing multiple objectives". The circumstances when input subsidies cannot be avoided are identified as when a country experiences "extensive and severe market failures" and where markets are vastly separated that their influences are rather localized. Experiences with input subsidies in Malawi, India and Sri Lanka, are used to illustrate how this policy operates and highlight its benefits as well as "disadvantages and dangers". The chapter is quick to stress that there are more important economic and developmental outcomes to input subsidies when local demand is stimulated through the multiple pathways of raising incomes, expanding rural employment, lowering food costs and expanding food consumption. The need for making complementary investments in infrastructure as public goods is recognized as one sure way the benefits of input subsidies can be optimized. How the time-boundedness of input subsidies can be guaranteed so as to avoid dependence and draining the funds for public goods is described and the international development system guidelines on this process are recognized.

Without question, this volume has benefited from excellent insights and experience from seasoned experts covering diverse but immensely relevant contexts. It has also been well-written and the logical flow of the main themes allows for easy comprehension by audience as widely dispersed as beginning and advanced students, policy makers and practitioners and experts. It is clearly recommended as an indispensable component of course in agricultural development and public policy focusing on the developing world and countries in transition.

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BOOK REVIEW

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Sustainable Livestock Management for Poverty Alleviation and Food Security

Katrien van't Hooft, Terry S. Wollen and Dilip P. Bhandari

Published 2012 by CABI, Nosworthy Way, Wallingford, Oxfordshire, OX10 8DE, UK. (www.cabi.org), ISBN: 978-1-845938277. Price £75.00/$145.00/€100.00. 194 pages.

While many farming systems in developing countries include livestock production as an adjunct to crop production, meant to hold the fort during the period crops are in the field, livestock are fast assuming an important place in the economic and social lives of the people, especially smallholders. Many reasons have been adduced for this trend, not least of all the fact that the world population of those able to afford livestock products has been growing, and the recent price increases seem to have been less for livestock than for crop products, making livestock products even more affordable. There are good reasons to believe that livestock plays a crucial role in the lives of the poor who predominate in the developing world. Policy makers and donor organizations have therefore been promoting livestock production in recent years, with particularly the Food and Agriculture Organization of the United Nations and The World Bank being in the forefront.

This is why a book that specifically aims to develop capacity for expanding and sustaining livestock production systems within resource-poor settings is an important one. Its further appeal rests on the fact that it has been structured as a practical guide that targets the key players in the livestock economy such as the farmers themselves, the animal health practitioners, the extension services, the students of animal agriculture and those who teach them, making it an indispensable tool for training, operation, and advocacy alike. The book is an intelligible fusion of diverse perspectives of a rather vast constituency both local and international, and combining researchers, farmers, development administrators and publishers. Another important point that needs to be made is about the way the book originated, virtually from the grassroots, being, according to the acknowledgements at the beginning, the product of a workshop on Endogenous Livestock Development held in Yaoundé, Cameroon, that ignited interests among individuals and institutions that culminated in the publication of an earlier book released in four languages (with a DVD) in 2008, and now distilled into a practical learning guide and training manual.

That said, attention should turn to the book's structure which no doubt contributes to its instrumental value. There are all together 12 formal chapters which are somewhat glued together by a well-focused introduction and an appendix that artfully synthesizes the key recommendations already made in the three last chapters of the book. Of course, one might see the consigning of such crucial points to the appendix as somewhat unusual given the tendency to treat that part of book in much the same way as its human counterpart. However, this may not detract from its high importance if the reader has read the introduction before delving into the book proper.

Chapter 1 kicks off with a presentation of the major trends in the livestock sector which are linked to the significant demographic shifts that have occurred with respect to population and incomes in the last two decades. Three critical issues that the livestock sector confronts are highlighted as the increasing resource intensification, globalization of the food system and the social implications of the structural changes in the sector. Some discussion of the phenomenon of land grabbing that began in 2009 is presented and what it means for land availability for arable farming and opportunities, and possible threats, for wider sectoral developments are explored.

Chapter 2 catalogues the various approaches for livestock development, starting with identifying the stakeholders for intervention, the motivation for productivity enhancement, and the theoretical case for optimization and efficiency in farming. Existing gaps are identified along with possible reasons for them and how they can be plugged. New challenges posed by Climate Change are recognized with some discussion on how they justify changing tactics in production and investment. Practical applications of these approaches are illustrated with insights drawn from far and wide, including Nicaragua, South Africa, Mexico, and India with the Netherlands representing best practice to be adapted to developing country contexts.

Chapter 3 highlights the methodological and organizational questions relevant to the implementation of the Endogenous Livestock Development approach with copious illustrations based on the experience in Cameroon. Chapter 4 provides a basis for the differentiation of livestock production systems, with clear distinctions made among High-Input, Low-Input, Extensive Land Use and Intensive Land Use systems. It is in Chapter 5 that the link to poverty is more explicitly made, showing how livestock keeping affects the household and what strategies farming families adopt to mitigate risk and uncertainties. This chapter brings together all the old arguments and fits them within the new challenges faced by developing country agriculture. The relevance of these systems to the attainment of the MDGs is elucidated.

Chapter 6 focuses on one of the two types of livestock keeping, namely the smallholder low-input and diversified livestock keeping. The specific aspects addressed include the characterization of this type of livestock keeping, level and sources of labour use, and its costs and advantages. Similar aspects are covered in respect of the other type of livestock keeping, namely, the specialized Livestock keeping, which is presented in Chapter 7. What it would take to change from the smallholder low-input and diversified type to the more specialized type is discussed in Chapter 8, again with rich illustrations from diverse environments.

In Chapters 9 and 10, the book presents recommendations for optimizing the low input and diversified as well as the more specialized livestock keeping types. The need to adapt to local circumstances is highlighted. Recognizing that the principal production problem is high mortality of the livestock, the recommendations focus attention on ways of reducing animal mortality, especially through improved nutrition, improved pasture and rangeland management, addressing water deficiency to improve access to adequate water resources for the animals, effective disease control especially for the communicable (infectious) ones, control of parasites, breeding and selection, ensuring efficient protection of the animals from predators, accidents, theft and adverse weather through provision of adequate housing with guarantees, and establishing a range of other animal-friendly measures.

Chapter 11 turns to the crucial question of market access and begins by stressing the importance of marketing and how smallholders can market their animals profitably. In Chapter 12 which is the final chapter, six case studies are used to illustrate how all these strategies work in practice in four developing countries and one industrialized Western country.

As a learning guide, this book is well-researched and comprehensive and has used the effective formatting of commencing each chapter with an itemized list of learning goals while the texts are organized in short paragraphs that are strategically interspersed with boxes, sketches, figures and graphs, presented in contrasting but subtle colour coding. All these enhance its appeal and accessibility and make it an indispensable tool for livestock development programming at all levels.

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Managing risks or stifling innovation? Risk, hazard and uncertainty

SUE DIBB (EDITOR)[1]

ABSTRACT

In the UK 1 million people suffer food poisoning, with 20,000 ending up in hospital, at a total cost to the UK of £1.5bn a year. We are not currently putting appropriate time and resources towards addressing the most significant food risks. Science is not absolute. It never 'proves' safety, nor uniquely dictates particular decisions. Rather, it provides crucial indications of risks and uncertainties.

Risk assessment does not address difficulties assigning probabilities under states of uncertainty, for example with BSE or with endocrine disrupters. Risk managers need to take account of a wide range of factors when deciding on appropriate courses of action including political, social as well as ethical. The precautionary principle says; 'be careful' when we're unable to determine clear risk assessments under various kinds of incertitude. A risk-based approach can obscure how ethical issues fit into decision making, (like animal welfare, social implications environmental impacts, consumer choice).

Much risk controversy is really about the politics of technology. Currently we do not have effective spaces for discussing or deciding "which way to go?" The public are typically sophisticated at weighing up risks and benefits with uncertainty and don't expect 'zero risk'. What is needed is a democratic space for deliberating the implications of plural interests and values.

KEYWORDS: Food; uncertainty; incertitude; precautionary principle; risk management

1. Introduction

Managing food safety risks is a top priority for any food business. Damaging headlines, whether over food poisoning or contamination scares, are bad for business. The UK Food Standards Agency (FSA) and the European Food Safety Authority (EFSA) were set up to establish better approaches to assessing and managing food risks. They were also an attempt to separate the 'science' from the 'politics' of decision-making. While regulations on new technologies such as GM crops, cloning and nanotechnology are criticised by some for stifling innovation, there remains confusion over the real nature of regulatory controversies. Far from being simply 'pro' or 'anti' science or technology, many of the most serious and intractable issues concern the appropriate directions in which to steer innovation.

The following is a report of the March 2012 meeting of the UK Food Ethics Council Business Forum, which explored how we manage existing and emerging risks and where ethics fit in decision making. The speakers were Andrew Wadge, Chief Scientist at the Food Standards Agency and Andy Stirling, Research Director for SPRU (Science and Technology Policy Research) and the Management School at the University of Sussex. The meeting was chaired by Michelle Harrison, CEO of the social research company TNS-BMRB and a member of the Food Ethics Council.

2. Definitions

A *hazard* is something that can cause harm, such as food-borne pathogens or chemicals. A *risk* is the chance that any given hazard will have adverse consequences, to health or the environment, for example. *Uncertainty* surrounds many risks where knowledge of the risk itself or its probability (likelihood) is limited. The word '*incertitude'* can be used to emphasise the distinct and variable aspects of uncertainty – as shown in the table below (provided by Andy Stirling).

Risks are less problematic and manageable, because knowledge of their nature and likelihood is well understood, such as routine pathogens. *Uncertainty* exists where knowledge of hazards may be well understood but likelihoods are less well defined in the case of rare events or where human factors come into play. *Ambiguity* describes a situation where there are disagreements in defining or prioritising the hazards themselves – irrespective of their probabilities in, for instance, GM or antibiotics. *Ignorance* is a situation where all these problems apply – where we are unsure of the nature, scope and likelihood of problems and opportunities. In other words, it is where 'we don't know what we don't know'.

Risk governance refers generally to the collection of institutions, arenas, processes and practices through which risks are understood, managed and communicated. *Risk assessment* refers to more particular methods, which seek to understand the nature of risks

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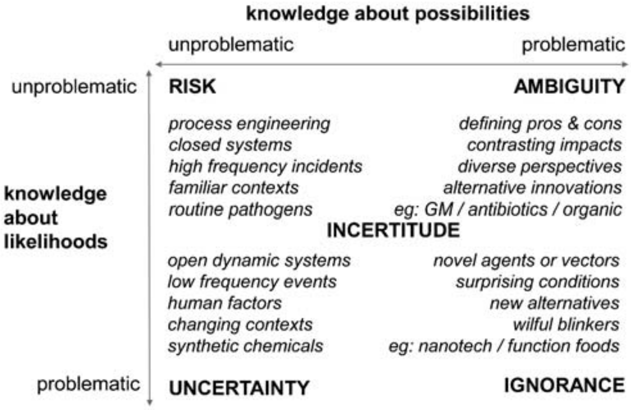

Figure 1: Beyond risk: contrasting aspects of 'incertitude'. Political pressures tend to push attention from 'plural conditional' (bottom right) to 'single definitive' (top left) methods. Source: Stirling (2010)

and their probabilities. *Risk management* refers to the procedures by which decisions and wider actions in response to risks are formed, implemented and evaluated. This takes into account factors other than what is known about the risk through risk assessment – for example broader social, economic, political and ethical impacts of intended risk management options.

3. Are we focusing on the most significant risks?

Figures for food poisoning in the UK are stark. One million people suffer food poisoning each year, with 20,000 ending up in hospital, at a total cost to the UK of £1.5 bn. For the Food Standards Agency protecting the public from food safety risks is its biggest priority.

Science can help us to understand and prioritise risks to public health from our food supply, but arguably we are not currently putting time and resources towards addressing the most significant risks. Have we got our priorities right when we consider the time and costs of regulating GM foods, when from a food safety perspective no-one has been harmed, compared with the nine million people in Europe made ill by campylobacter last year? Food poisoning, particularly campylobacter in chicken, is an avoidable risk. We can do something about it, yet our risk concerns often lay elsewhere.

For example, dioxins found in animal feed last year in Germany – for which there is no evidence of harm – got a higher profile than *E coli*, which made 4,000 people sick, of whom 50 died and 2000 were left with damaged kidneys. On their own, such numbers (as indicated by the prevailing science) suggest a misallocation of resources. Whether or not this is so, however, depends not only on the numbers alone, but also on the contrasting dimensions of each kind of risk and their associated implications and importance under different perspectives and priorities. Many factors come into play when risks are managed and communicated.

4. The role of science

Science has an important role to play in helping us assess risks. Yet the role of science can be overstated. Risk assessment often seems to imply precise determination of all relevant factors. This may be the case for well-understood risks such as campylobacter or *E coli*. But, depending on the nature of the risk, such precise forms of assessment are not always accurate. Under uncertainty, for example with BSE or with endocrine disrupters, it is not possible to be definite about the probabilities that are required in risk assessment. Equally reasonable analyses can yield remarkably different results, depending on the framing of assessment. As a result, it isn't always possible to identify a clear science-based answer. For example, unknowns around risks from Schmallenbergs disease justify scepticism over too much precision.

We therefore need to accept the limits of science; it is not infallible. It is necessary but not sufficient. It can never prove safety; instead often providing only an indication of risks and uncertainties. For example, it is not possible to 'prove' GM foods are safe. So the focus has been on attempting to show that they are as safe as their non-GM counterparts.

It is argued that the beauty of science is its openness. A key aim in scientific research is to open up analysis for others to challenge. Peer review is the 'gold standard' of science. In this way science is a starting point for achieving trust. Respect for science and openness has been at the heart of the way the Food Standards Agency works.

Despite the value of these aspirations, the challenge lies in whether they are always met in practice. And, though science as a whole may be open, individual scientists or organisations inevitably hold particular values and interests, which may influence their interpretations. These need not always be commercial or political interests. Scientific disciplines, for instance, can have interests in emphasising certainty in order to exercise influence. And science is also open to misuse in wider debates. Beyond inherent ambiguities, politicians, business, NGOs and the media can all be guilty of cherry picking science to support their own interests.

5. Managing risks

Risk management decisions are never the sole preserve of science. It is well recognised that risk managers need to take account of a wide range of issues when deciding on appropriate courses of action including political, social and ethical factors.

Deciding on the most appropriate course of action can be a difficult task. For example not everyone wants the benefits of milk pasteurisation. Some consumers want the choice to consume raw milk or raw oysters despite the risks. Considering how to take into account consumer autonomy for the minority while also protecting the majority is one example of the challenges of risk management.

It is important for trust and understanding of the outcomes that the same level of openness that applies to risk assessment also applies to risk management. But this is often not the case. Hidden pressures may arise from politicians, business or NGO interests, which are far less open to public scrutiny than risk assessment. Yet it is often 'science' – and specifically scientific uncertainty – that is cited as a reason for a particular course of action, even when it would be more honest to acknowledge political expediency as the real reason.

6. Using the precautionary principle

The precautionary principle was developed to help decision-making under conditions of uncertainty. Although different versions vary, the key ideas are expressed in the 1992 Rio Declaration. This states: *'Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.'*[2]

Despite this clarity, criticisms continue to persist that precaution is always about banning things. Such misrepresentation is often itself expedient. What the precautionary principle actually says is: 'be careful' – on the grounds that various kinds of incertitude mean we're often unable to definitively claim clear or unequivocal risk assessments.

Some are concerned about misapplication of the precautionary principle, arguing that there are always uncertainties. But this is consistent with proper application of precaution, in requiring open explanation and democratic accountability for reasons. It is no more right to hide behind scientific uncertainty than to pretend a definitive risk.

For example, the use of antimicrobial treatment agents to reduce campylobacter in chickens has not been permitted on the grounds of scientific uncertainty. Yet the advice from the European Food Safety Agency (EFSA) does not support this view. In EFSA's opinion such treatments are not harmful to health. The FSA believe that this argument is not due to 'scientific uncertainty', but to other political factors. Likewise, it has also been argued that the ban on Bisphenol A (an endocrine disrupting chemical used in plastic babies bottles) was a political rather than a scientific judgement.

7. Where do ethical issues fit?

Where decision-making is ostensibly based so exclusively around 'risk', it is not always easy to see where ethical issues fit in (such as the impacts on animal welfare, socio-economic and environmental impacts or consumer choice) These are not generally considered appropriate as part of risk assessment. For example the FSA has considered the safety of cloned meat and come to the opinion that it can be considered to be the same as non-cloned meat (substantial equivalence) and hence carries no additional risks. But many people are uneasy about the idea of consuming meat from cloned animals. The formal risk assessment process doesn't take account of such ethical concerns. However, such public concerns do influence the decision-making of regulators – and particularly of business. Yet if there isn't a way in which such considerations can formally be taken into account, then 'safety and science' becomes an artificial focus for concerns.

This can be illustrated by the regulation of new GM crops. Broader concerns including intellectual property (IP) and ownership, power relationships, potential impacts on non-GM producers, environmental impacts, and contamination and maintaining consumer choice, are not part of the formal risk assessment process.

Arguably, without a 'space' to engage on these broader ethical issues, it is understandable that the issue of GM has become so controversial. So much of risk controversy is really about the politics of technology. The lack of space in which to discuss which way to go through opening up the boundaries means our only tool is risk regulation. This can lead to everyone piling in, often inappropriately. We need a framework for considering wider issues than just food safety that brings into consideration ethical questions.

8. Is risk regulation stifling innovation?

There is a prominent concern that each country is involved in a 'race' to advance innovation. But this embodies a misunderstanding of the real nature of technology change. Innovation isn't a single inevitable track, but a series of continuously branching pathways. Once a particular path is embarked upon, it can become 'locked in' and 'crowd out' others. Examples include QWERTY keyboards and VHS videos. When we talk about issues like functional foods or nanoscience, we are discussing alternative directions for progress – where are we, as a society, trying to get to and how can we shape technologies to help us? When we restrict ourselves to discussing these issues merely in terms of 'risk', we can compound lock-in around the pathways favoured by the most powerful interests. It is important to see that technological innovation can take many forms. For example alternative responses to food insecurity include GM – but also other advanced biotechnologies like marker assisted breeding and participatory farmer innovation.

Innovation can also come from different sources. For example Making Local Food Work has demonstrated innovation in new ways of food production, retailing and distribution that also empower communities and individuals.

Innovation can be both an opportunity and a threat. How it is perceived will determine the response. For example, politicians mistakenly saw opening up space for considering the risks of BSE as a threat and tried to shut down the issue in an attempt to prevent panic.

Resistance to new technologies is not a modern phenomenon. For example, milk pasteurisation was strongly resisted when it was first introduced, with concerns that it would cover up 'dirty milk'. Yet despite its clear health benefits, the delay resulted in a further 65,000 preventable deaths from Bovine TB. The availability of raw milk continues to be a contentious issue today.

9. Understanding public responses to risk

Despite perceptions that the public can be 'irrational' in the face of risks, social science demonstrates that we are typically sophisticated at weighing up risks and benefits. We don't expect 'zero risk'. Far from being generally averse to new technologies, benefits and convenience can often outweigh potential risks to generate public

[2] The Earth Summit 1992: *Rio Declaration on Environment and Development* (Principle 15), Rio de Janeiro, 3–14 June 1992.

support, for example with mobile phones. GM crops have yet to provide a direct consumer benefit. Cost is also a key factor.

It is clear that being open with the public about uncertainties need not give rise to undue anxiety. For example the 2000 Stewart Inquiry into risk from mobile telephony concluded that if there were risks (as yet not fully understood) then children would be most susceptible and warned parents to moderate children's use of mobile phones. Far from engendering panic, public acceptance grew.

Under the traditional 'deficit model', it was presumed that the key problem lay in lack of education about risks among policymakers, media and the public. This has been discredited. It is now understood that the reverse is true. There are repeated correlations between the more people think or can be shown to understand (and their overall levels of education) and a tendency to increased scepticism. This is not the same as irrationality.

Trust is often cited as a crucial factor in public scepticism and acceptance. But this also relates to power. It is often addressed, for instance, as always being about trust in the powerful by the less powerful. But what is needed is often more trust by the powerful in the less powerful. Crucial here is the demonstration of trustworthiness. This includes tolerating critical debates and accepting that there are different ways to look at the science.

10. The way forward

How can we develop better risk governance? One option is for science advisors to provide plural and conditional advice. Typically, science advice delivers a single recommendation to decision makers. Providing options would place decision making more clearly where it rightly belongs – with Ministers rather than with scientists. Yet this is unpopular as it would expose Ministers to greater accountability and (potentially) blame. It is often more comfortable for Ministers to hide behind the science and so pass the buck back to their advisors. It has been argued that the FSA was set up in part to do exactly this, after the debacle of BSE.

Another example is that of drugs legislation. Under many interpretations, the science is clearly in favour of legalising many drugs. But this is not considered a politically acceptable option. Scientists should not be blamed for providing unwelcome advice. But the life of politicians is also rendered difficult by the intensity of reactions in fora like the *Daily Mail*.

Given the argument for a new 'space' in which to open up debate and consideration, the question then arises as to what this 'space' looks like in practice.

Undoubtedly more openness and transparency is desirable, particularly greater clarity of other social and political factors that appropriately come into play when managing risks or taking policy decisions.

We also need to recognise the limits of risk assessment. The FSA and EFSA need to be able to say 'we are only dealing with a small part of the bigger picture'. Arguably we've lost the ability to see the bigger picture and ask: What is the purpose of regulation? What is it that we want it to achieve? Currently we are largely responsive to new technologies rather than using regulation or other levers to proactively shape the future direction we decide to go in.

What's needed is democratic space to deliberate and acknowledge scope for plural values. We also need to be more mature about the implications of power. It is a reality – and not necessarily a bad thing. But it can sometimes lead to unhelpful premature closing down of debate and so needs balancing measures.

And we also need to consider how we can all become more comfortable when facing uncertainties. Politicians, in particular, are often uncomfortable with saying 'we don't know all the risks'. Here, the most rational approach in the face of incertitude lies in greater humility about the role that science can play. Scepticism is not anti-scientific; rather it is a vital part of scientific progress and discovery.

Does anyone do technology assessment better? In Germany more questions are often asked, and science is not so readily treated as the source of transcendent wisdom and authority. Yet no-one would argue that Germany has not been technologically successful. Perhaps then, there is something we can learn from our European neighbour about how we handle risk, hazard and uncertainty.

About the authors

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Ethical questions around climate change, obesity and new technologies are becoming core concerns for food

businesses. The Business Forum of the Food Ethics Council is a seminar series intended to help senior executives learn about these issues. Membership is by invitation only and numbers are strictly limited. The Business Forum meets six times a year for in-depth discussion over an early dinner at a London restaurant. To read reports of previous meetings, visit www.foodethicscouncil.org/businessforum.

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Effectiveness of occupational health service programmes in farmers' safety and security risk management

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ABSTRACT

Occupational health service programmes aim to reduce injury and illness risks. Yet, recent studies indicate that members of the voluntary Farmers' Occupational Health Service programme (FOHS) in Finland have filed more occupational injury and disease claims than non-members. To investigate this unexpected finding further, we conducted a safety risk management survey among farmers (n=591). We used multivariable regression to evaluate the differences in injury incident reporting between FOHS members and non-members while controlling for demographic, risk perception, and management practice variables. We found that FOHS members were significantly younger, had larger farms, and had more livestock than non-members. Similar to recent studies, FOHS members reported 1.5 times more injury incidents compared to non-members. However, when controlling for farm size, dependence on one person, physical strain at work, and injuries to family members, there was no significant difference in injury incidence between FOHS members and non-members. In some models, FOHS had a protective but non-significant effect. While no consistent protective effect was found on injuries, FOHS members reported greater awareness of risks and greater effort in controlling risks. Regular self-monitoring of safety had a protective effect on injury incidents. A crucial challenge in FOHS and similar risk management programmes is how to ensure farmers and managers commit to the practical implementation of the programme.

KEYWORDS: Farm; risk; management; safety; injury; survey

1. Introduction

Occupational health and safety risks are significant in agriculture. About one in fifteen farmers experiences a farm injury each year (Mela, 2013), and about one in ten thousand becomes a victim of an occupational fatality (Eurostat, 2012). Typical sources of injury among farmers include machinery, livestock, hand tools, working surfaces, and human error (Rautiainen et al., 2009; Kaustell et al., 2007; Donham and Thelin, 2006; Thurston and Blundell, 2005; Rautiainen et al., 2004). Suutarinen (2004) found that working capacity, ergonomics, and business management practices are associated with occupational health and safety risks and accidents on farms.

In addition to occupational health and safety risks, farmers manage a broad range of risks from financial and production risks to fire, assets, machinery, environmental and other farm security risks. (Leppälä et al., 2012; Leppälä et al., 2011; Kay et al., 2008; Hardaker, 2006; Hardaker et al., 2004; Wagner, 1999). The security risks may seriously threat the firm activities (EK, 2012, Leppälä et al., 2012). In search of the ideal safety management culture, Reason (1997) suggests using comprehensive safety information systems, which can be used to collect, collate and regularly check the system's safety risk signs. Such safety information systems may include human, technical, organizational and environmental information.

An understanding of theories of risk can provide a mechanism for improving safety risk management. Risk can be defined as 'the effect of uncertainty on objectives'. It includes the probability of occurrence and severity of consequences (ISO 31000; IEC 60300). Formal risk management phases include risk assessment (identification and analysis), control, monitoring, and developing of risk management. Different risks involve different potential losses and costs, and a positive risk could also be seen as business opportunity, like potential profit as a consequence. The best risk management strategy is calculated by the sum of negative and positive risks (ISO 31000; COSO, 2004; Uusitalo et al., 2003).

Farmers in Finland can join the voluntary farmers' occupational health service (FOHS) programme, which aims to manage risks concerning safety, health, and security on the farm. FOHS offers preventive health screenings, farm visits with walk-through safety assessments, information on identified health and safety concerns, and insurance incentives (Kinnunen et al.,

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2009). Similar services are available in Norway. The Certified Safe Farm programme in the USA is also similar, and it has been tested in limited studies. Other western countries have similar programme elements but no comprehensive occupational health service programmes, specifically designed for farmers (Rautiainen, 2011; Lehtola et al., 2008; Rautiainen et al., 2004). FOHS is well established in Finland nationally; it was developed and implemented in the 1970's and 1980's and had 30,148 members in 2011 (Mela, 2012). Major national investments have been made into this programme. It has been a common belief that FOHS has a positive impact on farmers' health behaviour and occupational safety and health risks (Kinnunen et al., 2009). However, recent studies have shown that FOHS members have more workers' compensation claims in comparison to non-members (Karttunen and Rautiainen, 2013; Rautiainen et al., 2009). To investigate this unexpected finding further, we conducted a survey to evaluate differences in injury incident reporting between FOHS members and non-members while controlling for demographic, risk perception, and management practice variables. Our research posed two questions:

- Is FOHS membership associated with greater risk management activity on farms in general?
- Does FOHS membership provide a reduction in injury incidents when controlling for important background variables?

2. Materials and methods

To address question 1, differences in risk management variables among FOHS members and non-members were identified. To address question 2, the association of injury incidence and FOHS membership was evaluated while controlling for potential confounding variables, particularly those where a difference between FOHS members and non-members existed.

Data collection

The questionnaire data variables are listed in Appendix 1 under groups and subgroups addressing the respondent, farm, farm management, and safety management characteristics. Variables were derived and adapted from VTT Technical Centre of Finland's PK-RH–risk management tools for small and medium size enterprises (SME's) (Uusitalo et al., 2003), Confederation of Finnish Industry's YTNK - safety and security programme (EK, 2012; Kerko, 2001) and Insurance Company Tapiola's risk identification guide applied to farms (Tapiola 2002). Risk perceptions and incidents were addressed in 24 areas including personal, property, financial, environmental, and crime risks. The significance of each risk was measured on a 4-point Likert scale. Incidents leading to a loss or close call (Yes/No) in each of the 24 risk areas were included. Further, variables were included to identify risk monitoring and risk control measures on the farm (Appendix 1). The questionnaire is in Finnish and it is published in MTT's project report 126/2008 (Leppälä et al., 2008).

Statistical methods

Most survey questions had categorical responses. Likert scale answers were dichotomized into yes/no or high/low responses. SAS Enterprise Guide 4.3 was used for frequency and logistic regression analyses. The analyses focused on first identifying the differences between FOHS members and non-members, and then looking at differences in injury/close call incidence between FOHS members and non-members while controlling for potential confounding variables. The analyses progressed in stages as presented in figure 1. First, data were prepared for analyses and table analyses were used to identify variables that were associated with each of the two outcomes. At this stage, we used a low threshold for significance (chi square test, $p<0.2$ level). Next, the associations of FOHS membership and significant variables from Phase 1 were tested in univariate logistic regression analyses. Then multivariable models were fitted using the stepwise (forward) procedure one subgroup (same as in Appendix 1) at a time. Statistically significant variables (at $p<0.05$ level) from subgroup analyses were entered into the final stepwise procedure, which identified the variables that predicted being a FOHS member. Next, a similar process was repeated using injury incident as the dependent variable. The flow of the analyses phases is described in figure 1.

3. Results

The data were collected by a farm safety and security survey, which was mailed out to 1499 Finnish farmers in November 2005. During winter 2005 - 2006 we received 591 responses (39% response rate). One reminder letter was mailed out to increase responses. The questionnaire sheet was piloted before posting by one grain and one animal production farmer. The questionnaire included 75 questions and took about 45–60 minutes to fill in. Five responses were rejected due to returning an empty questionnaire. In 21 questionnaires there was no answer to the FOHS membership question and these responses were excluded.

The survey participants were sampled randomly from the farm client register of the insurance company Tapiola[4]. At the time of the survey Tapiola's market share of farm (property) insurances in Finland was 44% (Tapiola 2006). Considering the growth trend in farm size, the survey sample was limited to farms with over 20 hectares of arable land to be more representative of active farms in the future. There were 14,000 farms in this size category at the time of the survey (2005), which was 52% of Tapiola's farm clients (Tapiola, 2005). The most frequent production type in the survey was grain/crop farms (44%). Compared to national data, dairy cattle farms were over-represented in our survey (37% vs. 24% nationally). About 56% of the Finnish farms had over 20 hectares of arable land in 2005 (TIKE, 2010). Farm production in Finland compared to the sampling frame and the survey respondents is presented in table 1.

[4] http://www.lahitapiola.fi/www/Maa_ja_metsataloudet/

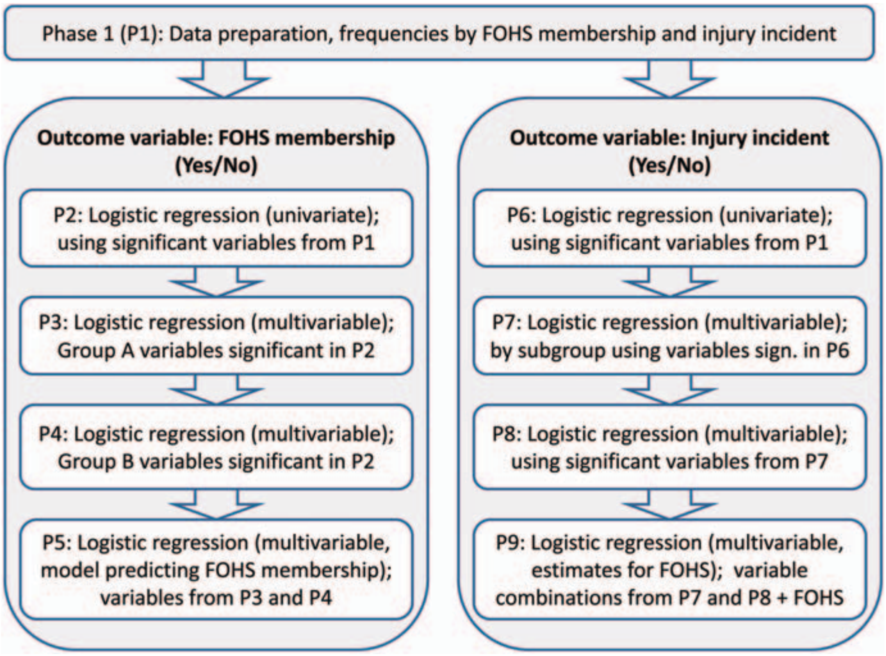

Figure 1: Description of the analysis process

Frequencies

The data included 338 (60%) FOHS members and 227 (40%) non-members (total n=565). Injury incidents or close calls were reported by 157 (28%) respondents. Those variables that had significant associations with the two outcomes of interest (chi square test, $p<0.2$ level) were entered into regression modelling phases. Distributions of these variables by FOHS membership and injury incident are presented in Appendix 1.

Variables associated with FOHS membership

In Phase 2 univariate (unadjusted) odds ratio estimates were calculated for the association of FOHS membership and each variable that was associated with FOHS in initial table analyses. These estimates are presented in Appendix 1 (statistically non-significant variables are indicated as blank). The analysis showed that FOHS members reported more frequently personal protective equipment (PPE) use and monitoring of safety and security issues than did non-members. FOHS members had larger farms and they estimated their profitability as higher than non-members. FOHS members provided more safety orientation for their workers, and they also perceived to have less risks related to the field machinery condition. However, about only 17% of FOHS members reported having safety and security assessment done, which is an essential part of FOSH. Further, the safety and security training (including first aid) was more common (10% vs. 30%) among non-members, while this training is recommended for FOHS members.

Multivariable odds ratio estimates were then calculated in Phase 3 for Group A variables using the stepwise (forward) procedure (Table 2). Several demographic, farm, and management variables from Group A were strongly associated with being a FOHS member including: animal production, forest hectares ⩾80, having dairy cows, full-time farming, having plans and goals documented, and having safety plans and budgets set yearly. Computer use for farm management and annual planning and budgeting of safety were also clearly more common among FOHS members.

In phase 4 we included these variables as confounders and evaluated Group B variables one variable at a time, controlling for these confounders. Adjusted odds ratio estimates from these analyses are presented in Table 2. In these analyses, FOHS members reported more profitability risk and regional risk incidents than did non-members, but the wide confidence limits should be noted due to low 'yes' responses in these variables.

In Phase 5, all significant variables from the adjusted models by subgroup (table 3) were entered into a

Table 1: Number of farms by type of production in the survey and Finland in 2005

Farm production	Survey respondents	%	Base population for sampling*	%	Farms in Finland	%
Grain/crop	254	44	7.700	55	43.000	62
Dairy cattle	216	37	5.000	36	16.400	24
Beef cattle	51	9			4.400	6
Swine	32	5			3.200	5
Others	29	5	1.300	9	2.000	3
Farms total	586	100	14.000	100	69.000	100

* Farm clients of Tapiola insurance company, categorised into grain/crop, dairy/cattle and other animal farms.

Table 2: Association of FOHS membership and explanatory variables (n: members=338, non-members=227)

	Multivariable estimates			**Final model estimates**		
Group A	*95% Confidence Limits*			*95% Confidence Limits*		
Respondent	*OR*	*LL*	*UL*	*OR*	*LL*	*UL*
Occupation: full time farmer (vs. part time)	2.1	1.22	3.63	4.55	2.14	9.67
Farm						
Farm size: forest hectares < 80 (vs. ⩾ 80)	0.59	0.37	0.93			
Main production: animals (vs. crops)	2.24	1.24	4.04			
Dairy cows (vs. no dairy cows)	2.45	1.3	4.63	4.78	2.5	9.12
Farm management						
Production plans and goals documentated (vs. not)	3.45	1.77	6.74			
Computer used for farm management (vs. not used)	2.32	1.36	3.96			
Safety management						
Safety plans and budgets set yearly (vs. not)	1.91	1.1	3.34	2.28	1.09	4.77
Self-assessment of farm safety: high (vs. low)	1.55	1.02	2.37			
Security training (fire, first aid) (vs. no training)	0.36	0.18	0.71			
Group B						
Risk perception; perceived risks: high (vs. low)						
Risk of field machinery damage	0.60	0.38	0.95			
Risk perception; actual incident or close call during past 3 years: yes (vs. no)						
Injury incident risk on farm	1.65	1.05	2.61	2.28	1.21	4.31
Mental wellness risk	2.80	1.41	5.57	4.87	1.68	14.19
Profitability risk	2.66	1.09	6.48			
Measures to monitor and control risks on farm: yes (vs. no)						
Using lockings in farm facilities	0.45	0.26	0.77	0.40	0.19	0.82
Farm safety and security assessment done	2.63	1.18	5.84			
Regular monitoring of work process flow	1.57	1.04	2.38			

logistic regression stepwise (forward) procedure. In the final model being a FOHS member was associated with having dairy cows, being full-time farmer, having safety plan and budget set yearly, having experienced mental wellness incidents, experiencing farm injury incidents and having less locking (doors etc.) on the farm. Overall, FOHS members and non-members differed in many respects. The odds ratio estimates were notably different for many variables in crude and adjusted models indicating that a complex set of characteristics is involved predicting whether farmers join the voluntary FOHS programme. In general FOHS members reported risk incidents more frequently than non-members (Table 2).

Variables associated with injury incidents

Variables that were associated with the injury incident (chi square test $p<0.2$ level) in Phase 1 were entered into regression modelling phases. The frequencies of significant variables are presented in Appendix 1. The Phase 6 analysis identified numerous risk factors for injury incidents. First, farmers that had an injury incident rated perceived risks higher than farmers without injury incident. Second, farmers that had an injury incident reported more other risk incidents including physical strain, mental wellness, liquidity, production machinery damage, fire, crime, building damage, natural disaster and water or energy supply risk incidents. Safety management variables including safety budgeting and planning yearly, security training and self-assessment of farm safety showed no significant relation with injury incident, but regular monitoring of safety and environmental risks had a protective association with injury incidents.

In phase 7, multivariable analyses were performed one subgroup at a time. All significant variables are presented in Appendix 1, and adjusted models are presented in Table 3. In the adjusted model, farms with larger field size (⩾40 hectares) were approximately four times more likely to have injury incidents than smaller farms. Farmers with injury incidents perceived injury incident risks, dependence on one person and dependence on few suppliers as significant risks on their farm. Farmers reporting physical strain incidents were almost 3 times more likely to have injury incidents. Dependence on one person, increased investment planning, quality management, and computer use for farm management were also risk factors for injury incidents.

In Phase 8, significant variables from Phase 7 were entered into a stepwise (forward) procedure (Table 3). Risk factors for injury incidents in the final model included dependence on few suppliers, water or energy supply incident, dependence on one person, family member's risk incident and physical strain incident. Regular monitoring of farm safety and security was the only protective factor (OR: 0.41; 95% CI: 0.23–0.73). FOHS membership was evaluated in the final adjusted model. It was not associated with injury incidents when adjusted for the variables in the final model (OR: 1.29; 95% CI: 0.78 - 2.10). No significant multicollinearity was observed in the final models.

FOHS membership and injury incidents on the farm

Phase 6 analysis showed that FOHS members had 1.5 times greater likelihood of injury incidents than did non-members. While controlling for Group A variables in

Table 3: Risk factors for injury

	Multivariable estimates			Final model estimates		
Group A	*95% Confidence Limits*			*95% Confidence Limits*		
Respondent	*OR*	*LL*	*UL*	*OR*	*LL*	*UL*
FOHS membership (vs. not membership)	1.49	1.00	2.22	1.29	0.78	2.10
Farm						
Farm size: field hectares < 40 (vs. ⩾ 40)	0.26	0.09	0.80			
Beef cattle (vs. no beef cattle)	0.24	0.06	0.90			
Farm Management						
Quality management training (vs. no training)	1.46	1.00	2.12			
Computer used for farm management (vs. not used)	1.76	1.01	3.06			
Group B						
Risk perception; perceived risks: high (vs. low)						
Injury risk	1.61	1.07	2.42			
Dependence on one person	1.68	1.04	2.71			
Dependence on few suppliers	1.90	1.01	3.55	2.55	1.30	5.01
Risk perception; actual incident or close call during past 3 years: yes (vs. no)						
Physical strain risk	2.75	1.63	4.62	2.64	1.50	4.63
Risk on farm family members	5.31	2.49	11.30	6.13	2.78	13.52
Dependence on one person	2.52	1.28	4.98	2.71	1.30	5.66
Water or energy supply risk	2.31	1.35	3.94	2.24	1.27	3.95
Measures to monitor and control risks on farm: yes (vs. no)						
Regular monitoring of safety and security	0.43	0.25	0.74	0.41	0.23	0.73

Note: Injury incident n = 157 and not injury incident n = 410

Phase 9, the odds of injury reduced to 0.90, but the association was not statistically significant. Several other models were tested and the odds ratio estimates varied from 0.7 to 1.7, depending on the combination of control variables in the multivariable models. Overall, with our sample size and available background variables, FOHS membership does not have a robust protective effect, nor is it associated with an increase in reporting of injury incidents.

4. Discussion

Minimising health and safety risks is important in agriculture due to the high risk of injury and illness in this industry (Eurostat, 2012). In Finland, the farmers' occupational health service programme (FOHS) aims to reduce the risks of injury and illness among farmers. This programme is voluntary and has about 40% participation rate (Kinnunen et al., 2009). Contrary to the programme's objectives, recent studies have shown that FOHS members have more compensated injury claims compared to non-members (Rautiainen et al., 2009, Karttunen and Rautiainen, 2013). However, it is likely that member and non-member populations differ in many respects due to self-selection into the voluntary programme. Only a limited number of background variables have been available to control for these differences in previous studies. In this study we examined the differences in member and non-member populations using a unique dataset with variables not available in previous reported studies.

Our first question was to identify differences in risk management activity between farmer's occupational health service (FOHS) members and non-members. The results indicate that FOHS members were more likely to be full-time farmers and livestock farmers. They had bigger farms and better profitability. FOHS members reported more documentation and goal setting, quality management training and computer use in farm management. They were also more active in safety planning and use of personal protective equipment (PPE). Generally, FOHS members reported greater awareness of risks and greater effort in controlling risks. However, compared to non-members they had less emphasis on fire risks, economic risks, investment planning and handling of mental wellness risk.

It is common that injury incidents have many causes, and a number of unsafe acts can be indirectly related to accidents (Reason, 1997). Many demographic and farm production characteristics have been identified as risk factors for injury (Rautiainen et al., 2009). In this study, we identified several injury risk factors including animal (vs. crop) production, larger farm size (field and herd size), dependence on one person on the farm, physical work strain, perceived fire risk, and infrastructural problems on the farm. Regular monitoring of safety and security risks was likely to reduce the risk of injury.

Our second question explored whether FOHS membership is a protective factor for injury incidents when controlling for important background variables. Our data indicated that FOHS members reported more injury incidents compared to non-members. Despite the fact that FOHS members receive information and assistance on health and safety issues, they reported 1.5 times more injury incidents compared to non-members. However, members also had more personal and farm characteristics that expose them to injury. When controlling for these confounding variables FOHS was no longer a significant variable explaining injury incidents on farms. Variables like field size, physical strain and dependence on one person on farm were stronger explanatory variables for injury incidents than FOHS membership. This indicates that differences between FOHS members and non-members, rather than FOHS itself, explain the higher incidence of injuries among FOHS members. Depending on the combination of variables used in the models, the effect of FOHS varied widely, from 0.7 to 1.7. In most models there was no significant difference in injury reporting between FOHS members and non-members. None of the models showed that FOHS had a statistically significant protective effect while few models showed a significant risk factor effect.

The results indicate that FOHS members participate more frequently in quality management training and are more active in risk management in general. However, members did not report high participation in farm safety assessments and safety and security training, which could be essential parts of FOHS. They also perceived their farm safer than non-members, but still they have more injuries and other risk incidents. Main part of the farmers in general (both FOHS members and non-members) are not doing safety and security self-monitoring very regularly or systematically, which was reported as a protective factor for injury incidents. This might be an area where the delivery of FOHS should be improved.

Occupational health and safety management contributes to production and quality. As the farm unit size and complexity in management increase, there is a growing need for improved knowledge management systems, which need to incorporate safety issues. The development of a holistic management system is a challenge for farm managers. FOHS membership provides tools and services for identifying and managing safety and security risks, which may contribute to a holistic management approach on farms. FOHS may contribute to risk management more broadly than just health and safety; the results indicated that members reported greater awareness of risks and greater effort in controlling risks. Yet, a crucial challenge in FOHS and similar programmes is how to ensure farmers and managers commit to the practical implementation of the programmes.

Limitations

The wide variation in odds ratio estimates indicates that strong biases may exist in injury incident reporting. Major sources of bias include self-selection into the voluntary FOHS programme. Those with new and existing health conditions may be more likely to join FOHS. Awareness of injury risks and risk management may be heightened among FOHS members due to education, and therefore members may report risks and incidents more readily. Participation vs. non-participation in a voluntary survey may result in biases. Self-reporting in surveys may involve recall and other biases.

5. Conclusion

While FOHS members were more aware of safety risks, they were 1.5 times more likely to self-report injury incidents. When controlling for confounding factors, there was no significant difference between members and non-members. Overall, the results from this survey support the need for improvements in the FOHS programme. As one option, holistic or broader risk management approaches could be utilized to addresses occupational health and safety risks along with management of production, asset, product quality, and environmental risks, among others. FOHS membership appears to increase awareness of safety and security risks in general. However, awareness is not sufficient without a good safety culture and safety management in practice. A crucial challenge in FOHS and similar risk management programmes is how to ensure farmers and managers commit to the practical implementation of the programmes.

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Appendix 1: Univariate association of FOHS membership and injury incidents: basic variables.

Group A	FOHS membership			Injury incident		
Respondent	% Yes	% No	OR	%Yes	%No	OR
Respondent sex: female (vs. male)	**15.7***	**9.7***	**1.74***	15.9	12.5	
Respondent age: < 50 (vs. ⩾ 50)	55.8	56.9		**60.9**	**54.3**	**1.31**
Education: agriculture school (vs. no agr. school)	***52.4****	***42.5****	**1.49***	**54.1**	**46.2**	**1.37**
Occupation: full time farmer (vs. part time)	**88.2***	**62.1***	**4.55***	79.1	77.0	
Farm						
Farm size: field hectares < 40 (vs. ⩾ 40)	**48.5***	**58.04***	**0.68***	**43.59***	**55.83***	**0.61***
Farm size: forest hectares < 80 (vs. ⩾ 80)	**63.4***	**74.2***	**0.6***	**63.2**	**69.6**	**0.75**
Animal herd size: Dairy cattle < 30 (vs. ⩾ 30)	**35.3**	**48.9**	**0.57**	**30.8**	**40.9**	**0.64**
Main production: animals (vs. crops)	**67.4***	**33.9***	**4.02***	57.3	52.7	
Dairy cows (vs. no dairy cows)	**51.2***	**17.6***	**4.9***	41.4	36.4	
Full-time farm workforce: 1 person (vs. >1)	**39.7***	**62.6***	**0.39***	49.6	46.6	
Part time farm workforce: 1 person (vs. >1)	**70.0***	**53.9***	**2.0***	**75.7**	**59.0**	**2.17**
Location: Southern Finland (vs. Middle, North)	**29.8***	**45.6***	**0.51***	34.9	36.6	
Beef cattle (vs. no beef cattle)	**22.2**	**17.5**	**2.02**	**19.8**	**20.5**	**1.91**
Farm management						
Quality management training (vs. no training)	**53.3***	**30.8***	**2.56***	**52.23***	**41.08***	**1.57***
Strategy documented (vs. not)	14.01	15.07		16.7	13.6	
Profitability: good (vs. weak profitability)	**56.8***	**38.7***	**2.01***	49.4	49.8	
Production plans and goals documentated (vs. not)	**41.3***	**19.9***	**2.82***	33.1	32.3	
Computer used for farm management (vs. not used)	**87.2***	**75.3***	**2.23***	**88.46***	**79.9***	**1.93***
Safety management						
Security training (fire, first aid) (vs. no training)	**10.3***	**30.0***	**0.27***	9.55	11.49	
Safety plans and budgets set yearly (vs. not)	**27.5***	**13.9***	**2.33***	25.2	20.6	
Self-assessment of farm safety: high (vs. low)	**69.6***	**60.8***	**1.48***	63.7	66.8	
Rescue plan made for farm (vs. not)	6.3	4.0		5.9	5.1	
FOHS membership (vs. not)	100	0		**66.88***	**57.11***	**1.52***

Note: Percentages indicate the proportion of FOHS members or injury incident (Yes) and non members or non injury incident (No) having this characteristic
Note: FOHS members n = 338 and non-members n = 227
Note: Injury incident n = 157 and not injury incident n = 410
Note: statistical value (P<0,2) have percents and OR bolded
Note: significant variables with statistical value p < 0,05 have *

Appendix 2: Univariate association of FOHS membership and injury incidents: explanatory variables of risk perceptions

Group B **Perceived risk on farm: yes (vs. no)**	FOHS membership			Injury incident		
	% Yes	% No	OR	%Yes	%No	OR
Injury incident risk on farm	41.4	42.7		**52.9***	**37.78***	**1.85***
Physical strain risk on farm	**52.0**	**45.5**	**1.3**	52.9	48.1	
Mental wellness risk	**46.5***	**36.5***	**1.51***	45.9	41.3	
Risk to farm visitors	3.2	4.8		6.08	2.94	
Risk to farm family members	14.2	15.3		14.7	14.9	
Risk of losing production data	**16.6**	**11.6**	**1.52**	**19.35***	**12.66***	**1.66***
Profitability risk	46.3	50.9		53.2	47.6	
Liquidity risk on farm	**32.9**	**26.4**	**1.37**	32.2	29.5	
Building damage risk	**24.2**	**29.7**	**0.75**	28	25.9	
Risk of field machinery damage	**22.9***	**32.7***	**0.61***	**31.21**	**25.19**	**1.35**
Risk of production machinery damage	22.1	26.1		26.6	22.5	
Rescue situation risk	**29.5**	**23.7**	**1.34**	**32.48**	**25.0**	**1.44**
Crime or vandalism risk	**20.8**	**27.1**	**0.71**	**31.58***	**20.0***	**1.85***
Fire risk on farm	29.3	30.8		**34.39**	**28.46**	**1.32**
Local/regional crises risk	43.1	41.0		46.2	40.3	
Risk to product safety	5.1	4.3		**6.41**	**3.85**	**1.71**
Environmental risk on farm	8.7	6.2		6.7	8.1	
Dependence on one person	69.7	72.6		**80.89***	**67.77***	**2.01***
Farm employee safety risk	**29.2**	**23.3**	**1.35**	**31.37**	**25.26**	**1.35**
Electrical risk	**16.6**	**22.8**	**0.67**	**23.57**	**17.26**	**1.48**
Natural disaster risk	32.6	28.4		28.7	30.9	
Product sale risk	**13.8***	**23.4***	**0.53***	20.9	16.3	
Water or energy supply risk	26.0	25.2		26.8	25	
Dependence on few suppliers	9.6	9.9		**16.03***	**7.51***	**2.35***

Note: Percentages indicate the proportion of FOHS members or injury incident (Yes) and non members or non injury incident (No) having this characteristic
Note: FOHS members n = 338 and non-members n = 227
Note: Injury incident n = 157 and not injury incident n = 410
Note: statistical value (P<0,2) have percents and OR bolded
Note: significant variables with statistical value p < 0,05 have *

Appendix 3: Univariate association of FOHS membership and injury incidents: actual risk incidents

Group B **Perceived risk actual incident on farm: yes (vs. no)**	FOHS membership			Injury incident		
	% Yes	% No	OR	%Yes	%No	OR
Injury incident risk on farm actual incident	**31.1***	**22.9***	**1.52***	100	0	
Physical strain risk actual incident	**19.2**	**13.7**	**1.5**	**35.03***	**10.27***	**4.71***
Mental wellness risk actual incident	**15.7***	**7.5***	**2.3***	**27.39***	**6.6***	**5.34***
Risk to farm visitors actual incident	3.0	1.8		**8.28**	**0.24**	**36.8***
Risk to farm family members actual incident	7.1	9.2		**22.29***	**2.93***	**9.49***
Risk of losing production data actual incident	2.2	3.6		**7.64**	**1.22**	**6.69***
Profitability risk actual incident	**8.3**	**3.5**	**2.47***	**12.1***	**4.4***	**2.99***
Liquidity risk on farm actual incident	**10.4***	**5.7***	**1.9***	**17.2***	**5.13***	**3.84***
Building damage risk actual incident	11.5	9.3		**17.2***	**8.07***	**2.37***
Risk of field machinery damage actual incident	20.1	24.2		**35.03***	**16.63***	**2.7***
Risk of production machinery damage actual incident	**17.2***	**7.5***	**2.56***	**24.84***	**8.8***	**3.42***
Rescue situation risk actual incident	**6.8**	**2.2**	**3.24***	**12.74***	**1.96***	**7.42***
Crime or vandalism risk actual incident	**6.5**	**3.5**	**1.91**	**12.1***	**2.69***	**4.98***
Fire risk on farm actual incident	***9.8***	***3.5***	**2.96***	**15.92***	**3.91***	**4.65***
Local/regional crises risk actual incident	**7.7**	**1.3**	**6.22***	**12.74**	**2.2**	**6.49***
Risk to product safety actual incident	**3.6**	**0**	**1.7**	**5.73**	**0.73**	**8.23***
Environmental risk on farm actual incident	**3.9**	**0.9**	**4.5***	**7.01**	**0.98**	**7.63***
Dependence on one person actual incident	**12.1***	**6.6***	**1.95***	**22.93***	**5.13***	**5.5***
Farm employee safety risk actual incident	**4.4**	**0.9**	**5.22***	**7.01**	**1.47**	**5.06***
Electrical risk actual incident	***6.8***	***3.1***	**2.29***	**10.83**	**3.18**	**3.7***
Natural disaster risk actual incident	8.4	8.3		**14.01***	**6.11***	**2.5***
Product sale risk actual incident	4.7	2.2	**2.21**	**9.55**	**1.47**	**7.1***
Water or energy supply risk actual incident	**18.9***	**9.7***	**2.18***	**28.66***	**10.27***	**3.51***
Dependence on few suppliers actual incident	**3.0**	**0.4**	**6.86**	**6.37**	**0.24**	**27.76***

Note: Percentages indicate the proportion of FOHS members or injury incident (Yes) and non members or non injury incident (No) having this characteristic
Note: FOHS members n = 338 and non-members n = 227
Note: Injury incident n = 157 and not injury incident n = 410
Note: statistical value (P<0,2) have percents and OR bolded
Note: significant variables with statistical value p < 0,05 have *

Appendix 4: Univariate association of FOHS membership and injury incidents: risk controlling variables

Group B	FOHS membership			Injury incident		
	% Yes	% No	OR	%Yes	%No	OR
Contracting (written, checked)	**76.8**	**70.7**	**1.37**	75.5	73.9	
Investment planning	38.6	35.2		**42.21**	**35.26**	**1.34**
Asset registering	**12.4**	**7.7**	**1.7**	8.2	11.5	
Using lockings in farm facilities	**17.0***	**26.2***	**0.58***	22.7	19.9	
Updating insurances	81.9	83.3		83	82.3	
Using operators manuals	82.5	80.8		82.9	81.4	
Fire prevention updated	69.2	72.3		68.7	71.1	
Using data back up and computer virus protection	**75.1***	**66.5***	**1.52***	**76.47**	**69.77**	**1.41**
Rescue plan for farm	7.8	7.4		**4.9**	**8.74**	**0.54**
Farm safety and security assessment done	**16.7***	**4.4***	**4.4***	12.2	11.5	
Using of necessary personal protection equiments on farm	**81.4***	**73.5***	**1.58***	78.6	78.1	
Safety guiding of farm visitors	**51.7***	**34.1***	**2.1***	43.0	45.5	
Safety orientation and training for farm workers	**53.2***	**33.8***	**2.2***	48.7	44.3	
Using bookkeeping services	66.7	65.1		68.5	65.1	
Injury incidents and close calls documented	10.4	7.4		11.6	8.3	
Using of safety signs in farm machinery and equipments	17.8	15.9		15.9	17.5	
Relief worker arrangements on the farm	24.2	20.7		25.2	21.9	

Note: Percentages indicate the proportion of FOHS members or injury incident (Yes) and non members or non injury incident (No) having this characteristic
Note: FOHS members n = 338 and non-members n = 227
Note: Injury incident n = 157 and not injury incident n = 410
Note: statistical value (P<0,2) have percents and OR bolded
Note: significant variables with statistical value p < 0,05 have *

Appendix 5: Univariate association of FOHS membership and injury incidents: regular monitoring in farm management

Group B	FOHS membership			Injury incident		
	% Yes	% No	OR	%Yes	%No	OR
Regular monitoring of production costs	**66.3**	**58.3**	**1.39**	65.8	62.2	
Regular monitoring of production machinery and equipment condition	**76.2**	**70.7**	**1.33**	72.7	74.3	
Regular monitoring of changes in work environment	33.2	28.7		34.5	30.2	
Regular monitoring of production quality	**85.1***	**68.9***	**2.59***	82.2	77.3	
Regular monitoring of safety and security	**28.0***	**19.9***	**1.57***	**15.56***	**28.08***	**0.51***
Regular monitoring of environmental quality	**39.9***	**30.7***	**1.5***	**30.92***	**38.5***	**0.72***
Regular monitoring of legislation	37.4	38.3		36.4	38.4	
Regular monitoring of plans and objectives	**39.9**	**32.4**	**1.39**	36.8	36.9	
Regular monitoring of market prices	62.4	64.7		66.2	62.3	
Regular monitoring of work process flow	**61.4***	**51.4***	**1.51***	59.9	56.3	
Regular monitoring of work load	**38.4***	**24.3***	**1.94***	32.7	32.9	
Regular monitoring of sales and revenues	**70.7**	**63.2**	**1.4**	71.7	66.2	

Note: Percentages indicate the proportion of FOHS members or injury incident (Yes) and non members or non injury incident (No) having this characteristic
Note: FOHS members n = 338 and non-members n = 227
Note: Injury incident n = 157 and not injury incident n = 410
Note: statistical value (P<0,2) have percents and OR bolded
Note: significant variables with statistical value p < 0,05 have *

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Consumer preferences for beef with specific reference to fat colour: The case of Cape Town, South Africa

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ABSTRACT

Various consumer perceptions exist about white and yellow beef fat. These perceptions subsequently affect the price of beef with yellow or white fat. Although only 25% of South African beef is grass-fed (yellow fat), lower prices offered for yellow fat result in farmers potentially receiving about R157.5 million less income per year. This study determined consumer preferences for beef fat colour in the Cape Town area of the Western Cape, South Africa. The largest percentage (43.74%) of consumers preferred white fat, followed by consumers (42.68%) to who fat colour did not matter and those who preferred yellow fat (13.59%). Analysis of the different consumer groups found that consumers who preferred yellow fat were buyers with higher education levels. These consumers were more concerned about the physical visual properties of the meat than about the branding, classification and packaging neatness. Consumers who preferred white fat had lower education levels, were more concerned about the packaging neatness and grade, and did not care much about the physical visual properties of the meat. Rather than discriminating against the price of yellow fat beef, a niche market could be created to accommodate this product.

KEYWORDS: Beef fat colour; consumer preference; yellow fat; white fat

1. Introduction and background

Various consumer perceptions exist about white and yellow beef fat. A perception that consumers disliked yellow fat, especially those in European markets, may have followed the research of Morgan et al. (1969). Yellow fat in beef carcasses was also less acceptable for domestic (Australian) and export markets than whiter fat (Walker et al., 1990). Some consumers in Japan equate yellow fat with disease (Young and Kauffman, 1978). Forrest (1981) stated that consumers in North America (United States of America [USA] and Canada) became accustomed to the white fat of feedlot finished cattle, an established practice since the 1970's.

More recent studies in international markets sketch a different picture. Lusk et al. (2008) find that the market share implied from incentive compatible, non-hypothetical conjoint ranking is higher for beef with yellow fat (pasture fed market share =52.43%) than for beef with white fat (conventional market share =47.57%) in the south-eastern parts of the USA. The consumer thus developed a higher preference for pasture fed beef with yellow fat. Umberger et al. (2002) find that 23% of the participants in their study prefer yellow fat beef (grass-fed) and is willing to pay a premium for it. Consumers in France, Germany and the United Kingdom also place a higher value on beef from cattle that are not grain-fed, and thus prefer yellow fat from grass-fed animals (Lusk et al., 2003).

In the USA two studies explicitly investigated consumer preferences for type of fat in beef. Lusk et al. (2008) conducted non-hypothetical purchasing experiments with consumers in grocery stores to determine the value they placed on grass-fed beef, while McCluskey et al. (2005) administered a consumer survey in several grocery stores to determine relative preferences for beef price, fat and calories, and level of omega 3 fatty acids. Participants in the beef industry are continually interested in improving the competitive position of beef relative to other protein sources, and therefore it is important to know consumer preferences regarding the fat colour of beef so that marketing can be handled accordingly.

According to Strydom and Hugo (2008) no information about consumer preferences for beef fat colour exists in South Africa. South African consumers tend to select beef for purchase on the basis of quality, price and convenience of location (Vermeulen and Biénabe, 2010).

Due to the perception that the South African consumer dislikes yellow-coloured fat, the abattoirs in South Africa discriminate against the carcass price of cattle with yellow fat. According to Strydom and Hugo (2008), a discount of 30 to 40 cent per kg is incurred on yellow fat in the Northern Cape, while a penalty of R2 per kg is incurred in the Western Cape for yellow fat carcasses (Dürr, 2008). One of the leading abattoirs in the Northern Cape use no fixed discount on carcasses with yellow fat, but they discount the price with about

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50 cent per kg if an A-grade carcass has yellow fat (Lockem, 2009). The discount on carcasses with yellow fat stays on a fixed Rand[2] value, and not a percentage of the carcass price, although the differentiation of the carcass price occurs on a weekly basis. The same principle is used for different carcass grading according to age and the amount of fat. The difference in Rand between the price of an A2 and B2 carcass basically stays the same (with small differences of a few cent either way) regardless of the price of an A2 carcass for any given week.

The economic impact of lower prices offered for beef with yellow fat has a major influence on the income of the beef farming sector in South Africa. In South Africa about 630 000 tons of beef is produced annually (GIRA, 2007) and approximately 75% of the total beef production come from feedlots (Grant et al., 2004; Esterhuizen, 2008). This means that 25%, or 157 500 tonnes of grass-fed beef with yellow fat enters the market every year. The grass-fed beef that enters the market do not only consist of A-grade carcasses as in the case of the feedlot animals. If the price discrepancy between yellow and white fat on beef is R1 on average, the farmers in South Africa potentially receive about R157.5 million less income each year.

The aim of this paper is to investigate consumer preferences for beef fat colour. Firstly the origin and nutritional quality of white and yellow fat is described. Secondly, consumer preferences affecting purchasing decisions with regard to white or yellow fat are determined. Thirdly, a regression analysis is used to identify the characteristics of consumers who prefer a specific beef fat colour.

The origin and nutritional quality of white and yellow fat

Feedlots gained prominence after World War II, when the post-war oversupply of grain was fed to cattle. This trend continued for more than 50 years resulting in beef with whiter fat from the grain fed diet (McCluskey et al., 2005). In South Africa, cattle are grainfed in order to ensure beef that is tender and lean (South African Feedlot Association, 2012).

Palmer and Eckles (1914) found that cattle grazing succulent forages tended to have yellower-coloured fat. The fat-soluble carotenoid pigments absorbed from the diet is normally the cause of yellow fat and is commonly attributed to pasture feeding (Hill, 1968, as cited by Strydom and Hugo, 2008). Young and Kauffman (1978) state that although leaf colour is usually dominated by chlorophyll, lush green pasture contains up to 500µg carotenoids/g dry weight, whereas dry pasture or cut hay contain less than 50µg/g. Grains usually contain less than 5µg/g. Although the specie of the animal and the age of the animal (older animals tend to have a yellower fat colour) may also play a role in the fat colour, the effect of these factors is not as prominent as the effect of feeding practices (Strydom and Hugo, 2008).

Animals fed on pastures (grass) thus usually tend to have a creamier (yellow) fat colour than animals that are grain fed, due to high carotenoid values in green pastures. McCluskey et al. (2005) classify grass-fed beef as either organic or natural beef, depending on the production practices. Hormones and antibiotics are usually not administered to grass-fed animals. Studies on the fatty acid composition of grass-fed steers found that an increasing amount of grass intake decreased intramuscular saturated fatty acids. A higher grass intake also increased the omega 3 fatty acid concentration and decreased the omega 6 to omega 3 ratio (French et al., 2000; Scollan et al., 2006). McCluskey et al. (2005) indicate that the overall fat content of grass-fed beef is similar to that of skinless chicken, and that the higher levels of essential fats (omega 3 fatty acids) are beneficial in preventing or treating heart disease, stroke and possibly auto-immune problems such as lupus, eczema and rheumatoid arthritis.

Grass-fed beef (beef with yellow fat) is a product with several health benefits that may appeal to health-conscious consumers. As consumer preferences evolve, it is important for the beef industry to understand those preferences for speciality products such as grass-fed beef.

2. Methodology

The survey was undertaken in March 2009 in the Cape Town area of South Africa. This area was specifically identified because of the large amount of cattle that are grass- or pasture-fed in this area. The Cape Town region is a winter rainfall area suitable for fattening cattle on pastures during winter. The study was conducted over a period of 6 days (Monday to Saturday) in and around different supermarkets in the Cape Town region during normal shopping hours (08:30 to 18:00). This ensured that a range of clients (working and non-working) could be included in the survey. The random walking method was used so that the random character of the sampling was ensured. Face-to-face interviews were conducted and people older than 15 years of age had an equal chance to be included in the survey. In total, 471 consumers were interviewed about their perceptions and preferences regarding beef. The questionnaire[3] used in the interviews consisted of a combination of closed answers, Likert type scales and options where the consumer ranked his/her choices in level of importance.

Consumers rated 11 criteria that influenced their beef purchasing decisions using a score of 1 to 5, indicating unimportant to very important. The 11 criteria were subsequently arranged from most important to least important. Consumers were also asked to rate the aspects of beef that most negatively influenced their choice using a score of 1 to 6, indicating aspects that most influenced their choice to the aspect that least influenced their choice. The aspects were subsequently arranged from biggest influence to smallest influence.

Data were processed using SPSS Statistics 17.0 for Windows and Microsoft Excel to calculate the inferential statistics. The different factor rankings of the groups are represented in radar charts. Simetar 2008 for Microsoft Office was used to perform logit regression models on the different preference groups. Two logit regression models were run using consumers who prefer

[2] In mid-March 2013 the approximate value of 1 South African Rand (R) was $US 0.11, £0.07, and €0.083.

[3] Details on the questionnaire are available from the corresponding author.

white fat as the dependant variable (Prefer white fat =1; Not prefer white fat =0) in the one regression, and consumers who prefer yellow fat as the dependant variable (Prefer yellow fat =1; Not prefer yellow fat =0) in the other regression.

3. Results and Discussion

Table 1 gives a descriptive summary of the survey statistics as recorded from the random questionnaire sampling. Most of the consumers were between 15 and 45 years of age, while the gender was equally distributed between male and female. The consumers were distributed among all the income groups with a mean income level of R3201-R6400. Blacks (29.3%), Coloureds (39.7%) and Whites (28.9%) made up most of the population with only a very small percentage of Indians (0.8%) and Asians (1.3%).

Table 2 gives the consumers' income and monthly expenditure on groceries. Most consumers earned R1601-R3200 (20.4%) or R3201-R6400 (18.0%). The questionnaire survey showed that 8 consumers out of ten (83.23%) consumed beef. Vermeulen and Biénabe (2010) found that 76% of middle to high-income South African consumers purchased beef steak. Without indicating the difference between yellow and white fat, the consumers were asked what fat colour they prefer. The response was that 43.74% of the consumers preferred white fat, 13.59% preferred yellow fat, while 42.68% indicated that the fat colour of beef did not matter to them. In the survey of Vermeulen and Biénabe (2010), 7% (n=420) of consumers considered fat content the most important factor when purchasing beef steak; fat colour was not taken into consideration in the survey.

Consumer preferences for meat in general

The criteria influencing consumers' decisions when purchasing meat is given in Table 3 and visually represented in Figure 1 in terms of the mean score for each criterion. From Figure 1 it is clear that the

Table 1: Summary statistics of demographic variables

Variable	Coding	Description	Distribution of survey responses (N=471)[1]		Population statistics for the Western Cape province[2,3] (n=4 524 335)
Age	1	15-25 years	27.6%		15-19 years: 9.9% 20-24 years: 9.5%
	2	26-35 years	27.0%		25-29 years: 9.4% 30-34 years: 8.71%
	3	36-45 years	21.4%	Mean=2.6 SD=1.4	35-39 years: 8.0% 40-44 years: 6.8%
	4	46-55 years	14.2%		45-49 years: 5.3% 50-54 years: 4.2%
	5	56-65 years	5.7%		55-59 years: 3.1% 60-64 years: 2.6%
	6	66-75 years	3.2%		65-69 years: 1.9% 70-74 years: 1.4%
	7	>75 years	0.8%		75-79 years: 0.9% 80-84 years: 0.5% 85+ years: 0.4%
Gender	1	Male	48.2%		2 192 321
	0	Female	51.8%		2 332 014
Education	1	Primary School or lower	7.6%		28.8%[4]
	2	Secondary School	59.6%	Mean=2.4	59.9%[5]
	3	University or College	23.5%	SD=0.8	11.2%[6]
	4	Post-Graduation Course	9.3%		-
Marital Status	1	Married	42.5%		49.2%[7]
	0	Single	57.5%		51.8%[8]
Number of persons in household	1	1 person	11.9%		-
	2	2 persons	18.7%		-
	3	3 persons	17.0%		-
	4	4 persons	23.8%	Mean=3.7	-
	5	5 persons	12.5%	SD=1.9	-
	6	6 persons	6.4%		-
	7	7 persons	4.7%		-
	8	>7 persons	5.1%		-
Race	1	White	28.9%		19.4%
	2	Black	29.3%		3.4%
	3	Asian	1.3%		4.0%[9]
	4	Coloured	39.7%		61.1%
	5	Indian	0.8%		-[9]

[1]Mean and standard deviation (SD) of coding, [2]Statistics South Africa (2005), [3]Education pertains to person aged 20 years and older, [4]Includes: No schooling, Some primary, Complete primary, [5]Includes: Some secondary, Grade 12, [6]Higher, [7]Includes: civil, religious and traditional marriages, [8]Includes: never married, widowed, divorced, separated or other, [9]National census combines Indian and Asian. Thus 4.0% includes both groups

Table 2: Summary of consumers' income and expenditure on groceries

Variable	Coding	Description	Distribution of survey responses (N=471)[1]		National Statistics for the Western Cape[2]
Monthly Income	1	R0-800	8.5%		No income: 2.0% R1-400: 6.5% R401-800: 17.7%
	2	R801-1600	13.8%		R801-1600: 25.1%
	3	R1601-3200	20.4%		R1601-3200: 20.1%
	4	R3201-6400	18.0%	Mean=4.0	R3201-6400: 15.2%
	5	R6401-12800	15.9%	SD=1.8	R6401-12800: 8.3%
	6	R12801-25600	12.5%		R12801-25600: 3.4%
	7	R25601-51200	8.9%		R25601-51200:1.1%
	8	>R51200	1.9%		R51201-102400: 0.4% R102401-204800: 0.2% R204801 or more: 0.1%
Persons contributing to income	1	1 person	35.0%		-
	2	2 persons	43.5%		-
	3	3 persons	12.1%		-
	4	4 persons	6.2%	Mean=2.0	-
	5	5 persons	1.3%	SD=1.1	-
	6	6 persons	0.8%		-
	7	7 persons	1.1%		-
	8	>7 persons	0.0%		-
Monthly Expenditure on Groceries	1	R0-1000	29.7%		-
	2	R1001-2000	27.2%		-
	3	R2001-3000	21.2%		-
	4	R3001-4000	11.5%	Mean=2.5	-
	5	R4001-5000	7.1%	SD=1.4	-
	6	R5001-6000	2.5%		-
	7	R6001-7000	0.4%		-
	8	>R7000	0.4%		-

[1]Mean and standard deviation (SD) of coding, [2]Statistics South Africa (2005)

sequence of criteria importance almost followed an exact pattern for the consumers who preferred white fat and those to whom fat colour did not matter, while the criteria importance pattern for the consumers, who preferred yellow fat, differed.

For the consumers who preferred white fat and for those to whom fat colour did not matter, the sell by date of meat was the most important criterion when buying meat, and branding the least important. According to the rest of the criteria, the consumers who preferred white fat and those to whom fat colour did not matter had an almost identical ranking, except for the neatness of the cuts that was more important to consumers preferring white fat than the presence of blood in the packaging. For the consumers to whom fat colour did not matter these two criteria were just the opposite. Consumers who preferred white fat and for those to whom fat colour did not matter placed a higher value on the price, neatness of packaging, neatness of cuts and the presence of blood in the packaging than on the physical properties such as the meat colour, fat and fat distribution, texture, classification and the thickness of the cuts. The price of the product was the second most important criterion for these two groups.

The group of consumers that preferred yellow fat had a different ranking of the criteria although the sell by date of meat was also the most important criterion when buying meat, and branding the least important. This group was more concerned about the meat's physical properties than the packaging and appearance. The second most important criterion was the texture of the meat, followed by the neatness of the cuts, meat colour, neatness of the packaging, and fat and fat distribution.

Fat and fat distribution was in sixth place for the consumer group who preferred yellow fat, and seventh for the other two groups. Additionally, the importance of price was placed seventh by the group preferring yellow fat and second by the other two groups. Blood in the packaging was also much less important to the group who preferred yellow fat, while the thickness of cuts and the classification was more important.

Consumer preferences for beef

The ranking for beef aspect preferences is given in Table 4 and graphically demonstrated in a radar chart (Figure 2). Figure 2 is drawn using the ranking of each aspect in Table 4, which received the highest score (highlighted in Table 4). The important aspects for consumers who preferred yellow fat and consumers to whom fat colour did not matter followed the same pattern, although the value placed on each aspect differed. The important aspects for consumers who preferred white fat followed a different pattern than the other two groups.

Price had the biggest negative influence on the consumers' decision when purchasing beef in all three groups. Bone content had the least influence on the purchasing decision of all the consumers.

The consumers that preferred white fat placed grade as the aspect with the second highest influence, followed

Table 3: Importance of choice criteria influencing consumers' decisions when purchasing meat

Order[1]	Criteria	Consumers who prefer white fat			Consumers who prefer yellow fat			Consumers to whom fat colour does not matter		
		N	Mean	Standard deviation	N	Mean	Standard deviation	N	Mean	Standard deviation
1	Sell by date	206	4.60	0.96	64	4.69	0.71	194	4.60	0.91
2	Price	206	4.42	1.04	64	4.34	0.82	194	4.37	0.98
3	Neatness of packaging	206	4.36	0.94	64	4.33	1.04	194	4.26	0.99
4	Neatness of cuts	206	4.36	0.97	64	4.27	0.91	194	4.20	1.04
5	Blood in packaging	206	4.36	1.02	64	4.22	1.12	194	4.16	1.02
6	Meat colour	206	4.30	0.99	64	4.19	1.01	194	4.14	1.12
7	Fat and Fat distribution	206	4.17	1.15	64	4.17	1.06	194	4.04	1.17
8	Texture	206	4.00	1.09	64	4.06	1.08	194	3.92	1.05
9	Classification	206	3.84	1.24	64	4.06	1.08	194	3.75	1.20
10	Thickness of cuts	206	3.78	1.13	64	4.05	1.12	194	3.73	1.03
11	Branding	206	3.68	1.29	64	3.36	1.24	194	3.72	1.11

[1]The 11 criteria arranged from most important to least important

by fat content, fat colour and meat colour. This group of consumers focussed more on the information on the package than on the physical properties of the meat. It was interesting how important the grade was to this consumer group and it seemed if they relied almost completely on the grade to describe the quality of the beef.

The consumers who preferred yellow fat and those to whom fat colour did not matter placed a higher value on the physical properties of the meat and for both groups the grade of the meat was in second place. The group that preferred yellow fat placed a higher value on the meat colour than on the fat content, while for the group to whom fat colour did not matter it was the opposite. The very high rating of meat colour in these groups, against the low rating of grade, illustrated that these consumers relied more on the physical properties of the beef to determine the quality.

All three groups placed fat colour in the third place and according to the percentage of votes it is more likely to become less important than more important. Fat colour can thus not be seen as an important determinant when considering beef because of the consumers' low rating.

Regression statistics for beef fat colour preferences

Two logit regressions were done with preference for yellow fat as dependant variable in the one regression and preference for white fat in the other. The logit regression statistics in Table 5 represent the variables that were significant to a 10% (α=0.10) level of significance for yellow fat and white fat preferences.

For the consumers who preferred yellow fat, an increase in groceries expenditure, favourite meat expenditure and education would lead to an increase in the preference for yellow fat. An increase in the number of persons in the household, expenditure on meat, importance of the sell by date and the number of meals away from home would lead to a decrease in the preference for yellow fat. The consumers who preferred yellow fat were better educated, spent more money on groceries and meat, were particular about the freshness of the product and prepared most of their meals at home.

The regression on preference for white fat showed that an increase in education and the importance of meat colour would lead to a decrease in the preference for white fat. An increase in age, income and the amount spent on favourite meat would lead to increasing preference for white fat. The consumers that preferred white fat were thus not as educated and did not care about the physical properties of the meat, as can be seen from the low level of importance of meat colour indicated in Figure 2. These consumers tended to be from the older generation and had lower education levels.

4. Conclusion and recommendations

The study showed that a smaller percentage of consumers preferred yellow fat (13.59%) than white fat (43.74%). A lack of knowledge on the origin and properties of yellow fat, and that consumers became

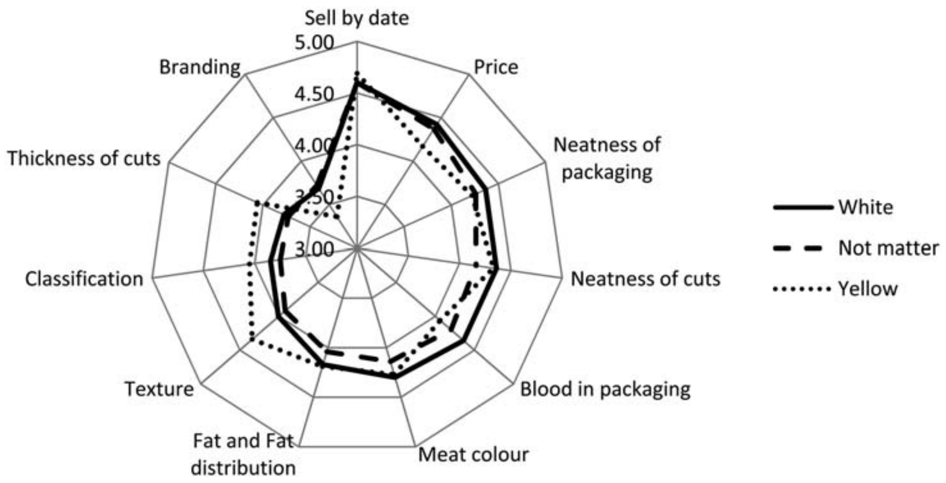

Figure 1: Importance of criteria influencing consumers' decisions when purchasing meat

Table 4: Aspects of beef that influenced consumers most negatively

Aspect		Consumers who prefer white fat (N=174)					
		Price	Grade	Fat content	Fat colour	Meat colour	Bone content
6 Biggest	Head	68	23	33	12	29	14
Influence	%	39.1	13.2	19.0	6.9	16.7	8.0
5	Head	19	40	37	27	36	15
	%	10.9	23.0	21.3	15.5	20.7	8.6
4	Head	15	23	38	36	35	27
	%	8.6	13.2	21.8	20.7	20.1	15.5
3	Head	18	27	28	41	25	33
	%	10.3	15.5	16.1	23.6	14.4	19.0
2	Head	22	31	21	31	37	30
	%	12.6	17.8	12.1	17.8	21.3	17.2
1 Smallest	Head	32	29	17	27	12	54
Influence	%	18.4	16.7	9.8	15.5	6.9	31.0

Aspect		Consumers who prefer yellow fat (N=51)					
		Price	Grade	Fat content	Fat colour	Meat colour	Bone content
6 Biggest	Head	13	13	7	1	10	7
Influence	%	25.5	25.5	13.7	2.0	19.6	13.7
5	Head	11	8	14	6	7	4
	%	21.6	15.7	27.5	11.8	13.7	7.8
4	Head	6	10	11	8	8	8
	%	11.8	19.6	21.6	15.7	15.7	15.7
3	Head	4	7	8	15	9	9
	%	7.8	13.7	15.7	29.4	17.6	17.6
2	Head	7	10	6	8	13	8
	%	13.7	19.6	11.8	15.7	25.5	15.7
1 Smallest	Head	10	3	5	13	4	15
Influence	%	19.6	5.9	9.8	25.5	7.8	29.4

Aspect		Consumers to whom fat colour does not matter (N=143)					
		Price	Grade	Fat content	Fat colour	Meat colour	Bone content
6 Biggest	Head	59	26	26	5	20	8
Influence	%	41.3	18.2	18.2	3.5	14.0	5.6
5	Head	21	34	26	13	25	24
	%	14.7	23.8	18.2	9.1	17.5	16.8
4	Head	15	27	40	24	21	17
	%	10.5	18.9	28.0	16.8	14.7	11.9
3	Head	11	19	28	41	22	23
	%	7.7	13.3	19.6	28.7	15.4	16.1
2	Head	21	17	19	27	25	33
	%	14.7	11.9	13.3	18.9	17.5	23.1
1 Smallest	Head	16	20	4	32	30	38
Influence	%	11.2	14.0	2.8	22.4	21.0	26.6

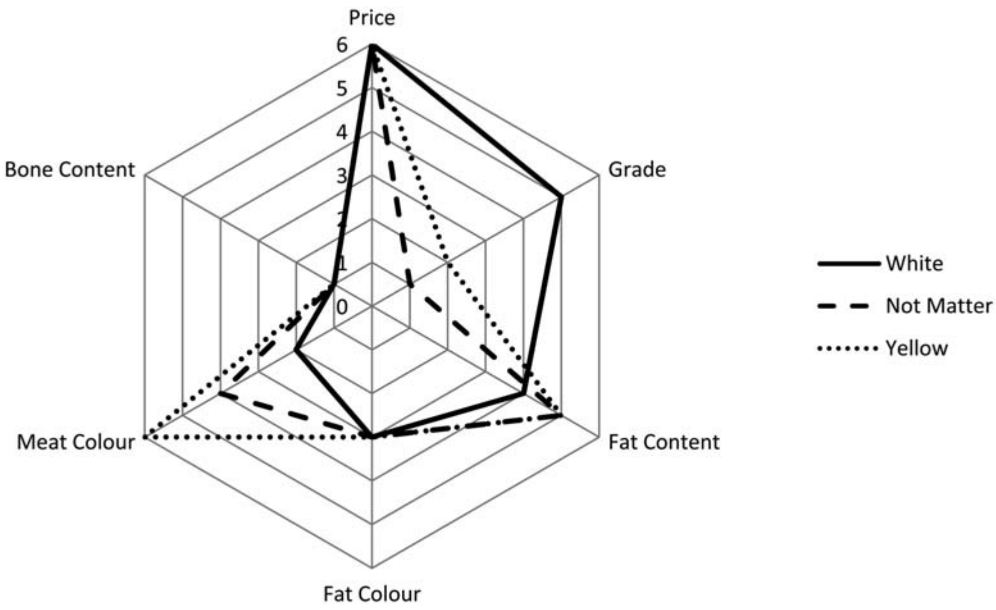

Figure 2: Aspects of beef influencing consumers the most negatively

accustomed to the white fat of feedlot-finished cattle, may have been the reasons for consumer preference of white.

For a fairly large portion of consumers in this study, fat colour did not matter (42.68%). These consumers would buy beef with white or yellow fat without considering the origin of the animal. The successful marketing of yellow-fat beef might influence this group of consumers to buy yellow-fat beef.

Grass-fed beef (all grades) make up only 25% of the South African beef supply, and is thus not enough to feed the nation, but a niche market should be developed for this product. The study showed that the consumers who preferred yellow fat had a higher level of education. These consumers were thus more likely to know the origin, properties and benefits of yellow fat and use this knowledge in their purchases. The introduction of organic produce is creating niche markets with premium prices for these products. If the relationship between organically produced beef and beef with yellow fat are marketed, beef with yellow fat may become part of a niche market. The successful marketing of yellow-fat beef as an organic product may lead to a situation where a premium is paid for yellow-fat beef.

This study only represents the preferences of consumers in the Cape Town area, and conclusions cannot be drawn for South Africa as a whole. A similar study for the rest of South Africa is recommended to determine the consumers' preferences in other regions. A thorough study of the whole country will determine if a niche market for organically produced beef, with yellow fat, will be successful and may help producers receive higher prices than what they currently experience.

About the authors

Frikkie Maré is a post-graduate student and junior lecturer in the Department of Agricultural Economics at the University of the Free State. He is involved in both postgraduate and undergraduate courses that include marketing, production economics, agricultural financing and microeconomics. Fields of research includes livestock economics, more specifically cattle and feedlots, as well as agricultural risk management.

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Table 5: Logit regression statistics for consumers who preferred yellow or white fat

	Consumers preferring yellow fat				Consumers preferring white fat			
Variable	**Beta**	**S.E.**	**t-test**	**Prob(t)**	**Beta**	**S.E.**	**t-test**	**Prob(t)**
Persons in Household	-0.2112	0.0887	-2.3803	0.0177				
Groceries Expenditure	0.2934	0.1159	2.5304	0.0117				
Education	0.4999	0.1879	2.6606	0.0081	-0.2292	0.1419	-1.6155	0.1069
Meat Expenditure	-0.2484	0.1368	-1.8158	0.0701				0.0704
Favourite Meat Expenditure	0.2530	0.1449	1.7464	0.0815	0.1499	0.0826	1.8141	
Sell by Date	-0.4000	0.1145	-3.4937	0.0005				
Meals Away from Home	-0.2162	0.0875	-2.4696	0.0139				
Age					0.1765	0.0712	2.4774	0.0136
Income					0.1199	0.0660	1.8168	0.0700
Meat Colour					-0.2041	0.0823	-2.4795	0.0135

Free State. He is currently a full time farmer but is still involve in various research projects especially in the red meat industry.

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REFEREED ARTICLE

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An analysis of the factors associated with technical and scale efficiency of Irish dairy farms

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ABSTRACT

The objectives of this study were to estimate the levels of technical and scale efficiency for a sample of pasture based Irish dairy producers, to identify the factors that contributed to reaching the optimum scale and to examine the relationship between technical and scale efficiency with farm size, intensification and specialisation. Efficiency scores were calculated using Data Envelopment Analysis (DEA). Technical efficiency was on average 0.757 under constant returns to scale (CRS), 0.799 under variable returns to scale (VRS) and scale efficiency was estimated at 0.951. Twelve per cent of the sample was operating at optimum scale (CRS). Fifty six percent of the sample was operating below optimum scale and 32% of the sample was operating above optimum scale. Overall optimum scale was associated with production systems operating with larger land area, with reduced proportion of rented land, increased amounts of hired labour, a higher quantity of quota and achieving a longer grazing season. It was also shown that increased farm size, intensification and dairy specialisation were associated with increases in technical and scale efficiency at farm level.

KEYWORDS: Scale efficiency; data envelopment analysis; dairy systems; Ireland

1. Introduction

The Common Agricultural Policy (CAP) reform process, in particular the phasing out of milk quota by 2015 will create significant opportunities for Irish and EU dairy farmers to expand their production for the first time unhindered since 1984. The clear potential for expansion of the Irish dairy industry has been recognised (Lips and Rieder 2005; O'Donnell et al., 2008; Department of Agriculture Food and Marine (DAFM), 2011). The Irish dairy industry is targeting a 50% increase in dairy output by 2020 (Food Harvest 2020, DAFM, 2011). If this increase in milk output is to be realised profitably it will need to be facilitated by an increase in scale and technical efficiency at farm level.

More generally, it has been estimated that an expanding world population will need 70 to 100% more food by 2015 (O'Brien, 2011) and this will require producers to substantially increase output from available resources. Moreover, the demand for greater productive efficiency must be balanced with the need to conserve the environment. Within Ireland, key environmental issues include reduction targets for Greenhouse Gas emissions and potential pollution from excessive nitrates and phosphates.

A continual price-cost squeeze and risk factors such as milk and feed price volatility also necessitate that producers focus on becoming more technically and economically efficient. The key to reducing overall costs of production is to maximise efficiency in the use of inputs. This can be done by adopting the best practice management techniques utilised by the most efficient producers. As studies by Tauer (1993), Rougoor et al., (1998), and Hansson and Öhlmér, (2008) have concluded, substantial differences between efficient and inefficient producers were attributed to poor management.

Boyle (2002) and Donnellan et al., (2011) suggested that the competitiveness of the Irish dairy industry will be improved by increasing scale through expansion. Similarly, Shalloo et al., (2004) simulated that dairy farmers must increase scale during the period 2004–2013 to remain profitable. However, new management challenges will arise following the abolition of milk quota as land and labour become more prominent constraints at farm level (O'Donnell et al., 2011; Hennessy, 2005; Shalloo, O'Donnell and Horan, (2007). Successful expansion will require greater focus on technical and scale efficiency at farm level.

The objectives of this study were to estimate the levels of technical and scale efficiency for a sample of pasture based Irish dairy producers, to identify the factors that contributed to reaching the optimum scale and to examine

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the relationship between technical and scale efficiency with farm size, intensification and specialisation.

2. Materials and methods

Concept of efficiency

The efficiency concept in this paper is defined according to the relative efficiency definition of Farrell (1957). Technical efficiency was defined by Farrell (1957) as maximizing output from the lowest set of inputs. Scale efficiency was defined by Coelli et al., (2005), as an indication of the amount that productivity could increase by moving to a point of technically optimal scale, as a business may be technically efficient but not scale efficient. Much of the efficiency measurement work on dairy farms has used Data Envelopment Analysis (DEA) including technical and scale efficiency studies (Jaforullah and Whiteman, 1999); Hansson, 2008; Latruffe et al., 2005).

Methodology

The principal efficiency measurement techniques comprise of the parametric Stochastic Frontier Analysis (SFA) developed by Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977), and the non-parametric DEA developed by Charnes, Cooper and Rhodes (1978). The main advantage of DEA over SFA is the fact that DEA does not require the specification of a functional form for the formation of the production frontier. Barnes (2006) noted that the potential mis-specification of a functional form with SFA approach may also lead to biased results. It must be acknowledged however that DEA is unlike SFA, as it is non-parametric, does not contain an error term and therefore attributes all error to inefficiency which may lead to the possibility of biased DEA results. DEA has been widely used in previous technical efficiency studies of dairy farms. For example Jaforullah and Whiteman (1999) used DEA to measure technical and scale efficiency on a sample of New Zealand dairy farms. Barnes (2006) and D'Haese et al., (2009) also used DEA to measure the technical efficiency of a sample of Scottish and Reunion Island dairy farms, respectively. Latruffe et al., (2005) used DEA to measure the effect of specialization on technical and scale efficiency for livestock and crop farms in Poland. A number of studies have compared results of both methods including Balcombe, Fraser and Kim (2006), Johansson, (2005) and Jaforullah and Premachandra (2003). The studies revealed that there are sometimes moderate variations in the efficiency results produced by the different methods. However, Balcombe, Fraser and Kim (2006) noted that neither method could be regarded as entirely superior to the other.

The DEA methodology works by estimating a best practice frontier which is created by enveloping the inputs and outputs of the most efficient decision making units (DMU). Those DMU lying on the frontier are classified as efficient relative to the sample, with a score of 1, while those below the frontier are regarded as inefficient, with a score of less than 1. All efficiency scores lie in the DEA range of between 0 and 1. The level of inefficiency for a DMU is the distance from that data point to the frontier. DEA essentially measures the overuse of inputs for a given level of output (input orientated) or potential increase in output for a given level of inputs (output orientated). According to Coelli et al., (2005) both output and input orientated models recognize the same set of efficient and inefficient DMU. Also, as the DEA methodology does not experience statistical problems like simultaneous equation bias, the choice of orientation is not as critical as opposed to econometric methods.

Both input and output orientated models have been used in previous studies similar to the work presented (Hansson, 2008; Hansson and Öhlmér, 2006; Barnes, 2006). It was noted by Coelli et al., (2005) that orientation should be selected based on which quantities the manager has most control over. In this paper efficiency scores were calculated using output orientated models. This approach was chosen because the quota constraint that has restricted EU dairy producers is soon to be removed and therefore the expected future focus of producers will be to maximise output using the least amount of inputs. DEA models were calculated under the assumption of constant returns to scale (CRS) and variable returns to scale (VRS). The assumption of CRS requires that every increase in input will result in a proportional output increase and this measure of technical efficiency is also known as a measure of overall technical efficiency as it will include both controllable and non-controllable sources of inefficiency (Färe, Grosskopf and Lovell, 1985). In contrast the assumption of VRS, as used by Banker, Charnes and Cooper (1984), incorporates scale inefficiencies and assumes output will not proportionally increase with an increase in inputs and consequently the estimated production frontier envelopes the data points tighter than under the assumption of CRS. This measure is also known as a measure of pure technical efficiency and does not attribute inefficiencies to differences in scale (Färe, Grosskopf and Lovell 1985). As the VRS assumption prescribes that not all producers are operating at optimum scale and the assumption of CRS assumes that producers are scale efficient, this implies that if there is a difference in efficiency scores under both assumptions then scale inefficiencies are present.

Scale efficiency

Scale efficiency is defined by Coelli et al., (1998, 2005) as an indication of the amount that productivity could increase by moving to a point of technically optimal scale. This is because a business may be technically efficient but not scale efficient. If, for example, a farm is experiencing increasing returns to scale (IRS), this indicates that the farm is sub-optimum in terms of its scale and if a change in inputs is less than the change in output then productivity should increase by increasing the size of operation. Decreasing returns to scale (DRS) illustrates that the farm is supra-optimum, highlighting that the productivity of these producers may potentially increase by reducing the scale of operation. If the farm cannot increase productivity by altering its scale and every increase in inputs results in a proportional increase in output then that farm is experiencing CRS or is operating at the optimum scale. Therefore productivity cannot be improved by changing scale.

An example of scale efficiency is shown in Figure 1 which illustrates the effect of scale on productivity and returns to scale following the example of Coelli et al., (2005). This example is a single input, single output mix under the assumption of VRS where the farms A, B and C are all technically efficient because they are all on the production frontier. As productivity relates to the ratio between input and outputs then this is equal to the slope of a ray from the origin through each data point. Looking at farm A, it is experiencing IRS because it could increase productivity by moving towards point B. Farm C exhibits DRS and could increase its productivity by reducing its scale of operation towards farm B. Farm B is at its optimum scale (CRS) or scale efficient as changing scale of operation would not lead to gains in productivity.

Dataset

Data from the National Farm Survey (NFS) in Ireland for 2008 were utilised in this analysis. The NFS is an annual survey of approximately 1,200 farms weighted by size and system to represent a population of 104,800 farms in Ireland. This study uses a sample of 266 farms classified by Connolly et al., (2008) as specialist dairy farms, generating the majority of their farm gross output from the dairy enterprise.

First stage analysis

DEA technical and scale efficiency scores were generated in the first stage analysis using DEAP software, version 2.1 developed by Coelli (1996).

Inputs and outputs used in data envelopment analysis models

All inputs and outputs relating to the dairy enterprise only were used in the analysis. Allocation of costs was minimal as many costs were already allocated within the NFS. For more information on the NFS see (Connolly et al., 2008). Overhead costs that were not allocated to the dairy enterprise were allocated based on proportion of gross output originating from the dairy enterprise which was done using the dairy cost allocation methods, explained in Table 1. Allocation methods like the one described in Table 1 have been widely used in previous studies by Smyth, Butler and Hennessy (2009), Donnellan et al., (2011), Thorne (2004) and Fingleton (1995). As all inputs and outputs were specific to the dairy enterprise only, the analysis concentrates on measuring dairy enterprise efficiency, independent of non-dairy subsidiary activities that might be present on the sample farms. Descriptive statistics for all inputs and outputs used in the DEA models are shown in Table 2[5].

Inputs. The model inputs comprised physical quantities of land, milk quota, labour, concentrate, fertiliser and financial value of other direct and overhead costs. Land area included both owned and rented land used by the dairy enterprise. Quota was the amount of milk quota (both owned and rented) in litres for the year 2008. Physical quantities of purchased fertiliser, purchased concentrate and total labour units used by the dairy enterprise were included. Labour was expressed in full time equivalents (FTE) based on total farm labour units and quantified in accordance with NFS specifications including paid (hired labour) and unpaid (family labour). Other direct and overhead costs included depreciation, veterinarian and animal health costs, electricity, repairs, miscellaneous costs attributed to the dairy enterprise.

Output. Output in the analysis consisted of the financial value of milk sold and other dairy farm output including livestock sales from the dairy enterprise.

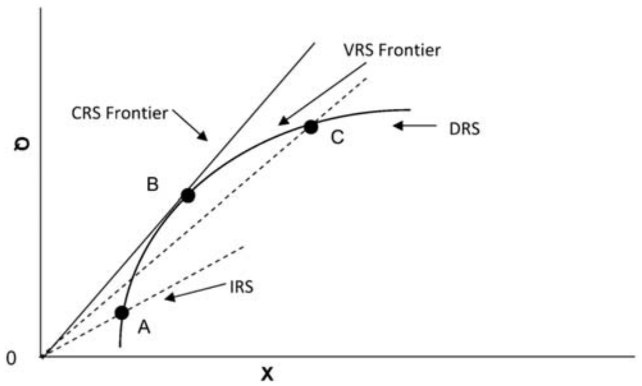

Figure 1: Scale efficiency and returns to scale

Second stage analysis

To determine the optimum scale and the factors contributing to optimum scale, producers at CRS, DRS and IRS were compared. In a further analysis the technical and scale efficiency levels were analysed according to farm size, intensification and dairy specialisation. This was undertaken to determine whether efficiency levels increase with increasing levels of farm size, intensification and dairy specialisation.

Identification of optimum scale and factors associated with optimum scale

In this analysis the scale behaviour (whether producers were operating at CRS, DRS or IRS) for all producers was identified. To determine the factors associated with optimum scale, a number of productive and management variables were compared between CRS, IRS and DRS producers. As DEA scores are censored between 0 and 1 with a positive probability a Tobit regression is possible (Hoff, 2007). However as the focus was on the average of the different groups, this analysis follows Barnes et al., (2011) and was completed using an analysis of variance (ANOVA) in SAS (SAS Institute, 2006). The factors considered included land area, average cow numbers, quantities of concentrate per cow, fertiliser per hectare, quantity of quota, levels of output produced, stocking rate, grazing season length, milk production per cow and per hectare.

Efficiency at different levels of scale, intensification and specialisation

To investigate whether technical and scale efficiency scores increased with larger farm size, intensification and specialisation, efficiency scores were compared between producers in groups ranging from smaller to

[5] In mid-March 2013 €1 was approximately equivalent to £0.87 and $US 1.3.

Table 1: Allocation keys used to define variables associated with the dairy enterprise

Variable	Allocation Key
Land	Owned and rented (physical and financial)
Cow	Average number of dairy cows (physical and financial)
Labour	Labour units (physical and financial)
Concentrate	Dairy concentrate (physical and financial)
Fertiliser	Dairy fertiliser (physical and financial)
Other direct and overhead costs	Dairy direct costs (minus costs for concentrate and fertiliser) + Total Overhead costs(minus cost of labour) x Dairy % of Gross Output
Milk Solids	Total milk solids produced and sold (physical and financial)
Other Output	Value of livestock sales from the dairy enterprise

Note: Dairy enterprise use of the resource/input is directly allocated in National Farm Survey

larger levels of scale, intensification and specialisation. Groupings were established based on groupings used in previous Irish studies by O'Brien et al., (2007), O'Brien et al., (2006), Connolly et al., (2008) and Creighton et al., (2011).

Farm size measures included land area, cow numbers and volume of milk produced. Land area was divided into 4 groups following Connolly et al., (2008) of <20ha, 20-30ha, 30-50ha and >50 to reflect a range from low to high scales of production. Cow numbers was divided into three groups of <50 cows, 50-80 cows and >80 cows which were also groupings used by O'Brien et al., (2007). Volume of milk produced was categorised among four groups of 135,000-250,000litres, 250,000-320,000 litres, 320,000-500,000 litres and >500,000 litres following quartiles used by O'Brien et al., (2006).

Measures of intensification were stocking rate and quota per hectare. Stocking rate was divided into three groups similar to groupings used by Creighton et al., (2011), the producers were divided into groups of <1.50 livestock units (LU)/ha, 1.50-2.00LU/ha and >2.00LU/ha. Three milk quota per hectare categories were also used to compare intensification and this varied from <5,000 l/ha, 5,000-10,000l/ha and >10,000l/ha to give a low, medium and high level of intensification.

To investigate whether efficiency increased with dairy specialisation comparisons were undertaken for producers grouped according to proportion (<66%, 66%-75% or >75%) of gross output generated by the dairy enterprise.

An analysis of variance ANOVA in SAS (SAS Institute, 2006) was again carried out to identify if there were significant differences in technical and scale efficiency among producers at the different size, intensification and specialisation categories described above.

3. Results

First stage analysis - efficiency results

Technical and scale efficiency scores for 266 specialist Irish dairy farms calculated in the first stage are shown in Table 3. Overall technical efficiency (CRS) was on average 0.757 for the farmers in the sample ranging from a minimum of 0.332 to a maximum of 1.000 with a standard deviation of 0.148. On average pure technical efficiency (VRS) across the 266 farms was 0.799 ranging from a minimum of 0.451 to a maximum of 1.000 with a standard deviation of 0.154. On average, producers were 20% inefficient (1-0.799) and could become fully efficient by increasing output by 20% with existing input levels. On average scale efficiency across the 266 farms was 0.951 ranging from a minimum of 0.337 to a maximum of 1.000 with a standard deviation of 0.083. A scatter graph of the overall technical efficiency, pure technical efficiency and scale efficiency for the sample of farms is shown in Figure 2.

Returns to scale

Figure 3 contains the proportion of dairy producers that were operating at CRS, DRS or IRS. Twelve percent of the producers in this study had scale behaviour where they were operating at CRS or could be defined as

Table 2: Descriptive statistics of input and output variables used in the efficiency models

Variables	Units	Mean	s.d.	Minimum	Maximum
Inputs					
Land	Ha	35.63	18.43	7.25	119
Labour	FTE	1.15	0.52	0	3.87
Cow		63	36	7	230
Quota	Litres	332,968	257,298	27,306	2,647,727
Fertiliser	Kg	5,565	3,789	328	19,337
Concentrate	Kg	65,307	61,351	900	423,100
Other Costs	€	51,985	41,616	2,034	285,114
Milk Solids (MS)	Kg	20,078	12,361	1,138	81,957
Other dairy output	€	10,993	10,592	0	84,107
Outputs					
MS Price/Kg	€/kgMS	4.60	0.22	3.96	5.27
Stocking Rate	LU/ha	2.01	0.86	0.38	7.30
Solids/cow	Kg/cow	321	94	17	545
Solids/ha	Kg/ha	646	331	33	2,546

Table 3: DEA Efficiency scores

	TEcrs[1]	TEvrs[2]	SE[3]
Average	0.7574	0.7992	0.9495
Minimum	0.3320	0.4510	0.3370
Maximum	1.0000	1.0000	1.0000
Median	0.7485	0.7980	0.9760
St Dev	0.1476	0.1428	0.0836

[1]TE: overall technical efficiency score
[2]TE: pure technical efficiency score
[3]SE: scale efficiency score

operating at the optimum scale. Producers operating at the optimum scale were farming 41 hectares and milking 80 cows. Thirty two percent or 86 producers were found to be experiencing DRS, on average they were farming 51 hectares and 86 cows, (Table 4). Fifty six percent of the sample was experiencing IRS operating with 26 hectares and milking 47 cows.

Second stage analysis

Comparison of optimum, sub optimum and supra optimum scale

Producers operating at supra-optimum levels of scale had a greater percentage of land rented ($P<0.1$) compared to optimum and sub optimum scale producers. Supra optimum scale producers were operating at significantly higher stocking rates ($P<.001$) compared to producers at sub-optimum scale. In terms of labour, producers operating at sub-optimum scale had greater proportion of family labour and lower proportion of hired labour compared to producers at optimum and supra optimum scale ($P<0.01$). There were also significant differences in terms of quota with producers at sub optimum scale having significantly lower levels of quota compared to producers at optimum and supra-optimum scale ($P<0.001$). There was no significant effect of concentrate feeding between the three groups. The supra optimum and optimum producers had higher number of grazing days ($P<0.05$).

Efficiency at different levels of scale, intensification and dairy specialisation

Table 5 contains the results of a comparison of the overall technical efficiency, pure technical efficiency and scale efficiency results at different levels of farm size, intensification and dairy specialisation.

As land area increased to >50ha, technical increased ($P<0.001$), however scale efficiency showed higher levels at land areas of <50ha and <20ha ($P<0.001$).

Similarly as cow numbers increased to >80 cows, technical and scale efficiency increased ($P<0.001$). Technical and scale efficiency also increased as volume of milk produced increased to >500,000l ($P<0.001$).

Technical efficiency increased with an increase in stocking rate of >2 LU/ha and was highest with milk quota per hectare of >10,000 l/ha ($P<0.001$) but there were no significant association with scale efficiency.

As the level of dairy specialisation increased from <66% to >75%, technical efficiency increased ($P<0.01$). Scale efficiency was significantly higher for the specialisation category between 66 and 75% ($P<0.01$).

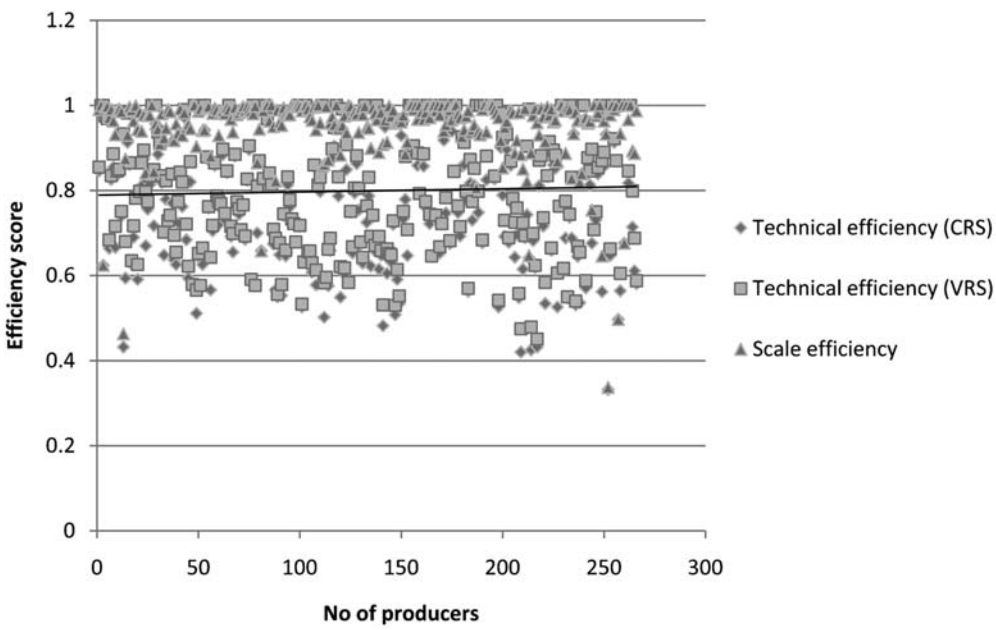

Figure 2: Technical and scale efficiency results

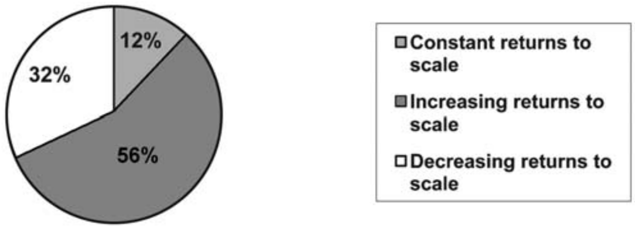

Figure 3: Percentage of sample operating at CRS[1], IRS[2] and DRS[3]

4. Discussion

Technical efficiency results

The results generated in this study show that producers were not fully technically or scale efficient in 2008. Therefore a clear potential to increase technical and scale efficiency exists on Irish dairy farms. Firstly looking at technical efficiency results the mean technical efficiency scores of 0.757 (CRS) and 0.799 (VRS) reveal that producers were generating between 76% and 80% of their potential output at current input levels. Therefore producers could generate on average 24% (CRS) and 20% (VRS) extra output using the current level of inputs. This suggests that there could be substantial increases in output without significant increases in inputs through improved management. The results are also positive as they suggest that the dairy industry has the potential to reach the production targets as set out in the Food Harvest 2020 report (DAFM, 2011) through increasing levels of technical and scale efficiency. The technical and scale efficiency results generated in this paper are in line with results from similar studies in the literature. In a New Zealand study of dairy farm technical efficiency, Jaforullah and Whiteman (1999) found average overall and pure technical efficiency to be 83% and 89% respectively, however the producers in that study were not limited by quota like the producers in this study. Hansson (2008) found on average technical efficiency scores of 0.877 for pure technical efficiency in a study of Swedish dairy producers.

Scale efficiency results

As there were differences in technical efficiency scores under CRS and VRS assumptions, this highlights that scale inefficiencies were present. Scale efficiency was on average 0.951 for this sample of producers. The scale efficiency results were high on average highlighting that this sample of Irish dairy producers were operating near full scale efficiency. The mean value of 0.951 for scale efficiency highlights that producers could generate 5% extra productivity by becoming more scale efficient. Analysis conducted by Jaforullah and Whiteman (1999) found on average scale efficiency to be 94% for New Zealand dairy farmers and in a separate Swedish study by Hansson (2008) scale efficiency was found to be 95%. Therefore the results from this study indicated similar findings to previous studies despite geographical differences, differences in production systems and again the constraint of a quota system in Ireland which is not present in New Zealand.

Returns to scale

The analysis found that 12% of producers were operating at constant returns to scale. The optimum scale was estimated at 80 cows and 41ha for this group of producers. This shows significant potential to

Table 4: Optimal, sub optimum and supra optimum scales of production

Variable	CRS [1] (n=31)	DRS [2] (n=86)	IRS [3](n=149)	Significance [4]
Land (ha)	41.36 [a]	50.64 [b]	25.78 [c]	***
Cow	80 [a]	86 [a]	47 [b]	***
Land Rented %	0.05 [a]	0.09 [b]	0.07 [b]	*
Stocking Rate	1.94 [a]	2.21 [b]	1.91 [a]	*
Labour Units (FTE)	1.82 [a]	2.04 [b]	1.45 [c]	**
Dairy (FTE)	1.29 [a]	1.40 [b]	0.97 [c]	***
Family Labour %	0.73 [a]	0.82 [b]	0.94 [c]	***
Hired Labour %	0.24 [a]	0.18 [b]	0.06 [c]	***
Con [5] per cow	872	938	1,080	NS
Fert [6] per Ha	163	146	158	NS
Quota litres	385,102 [a]	462,565	247,321 [c]	***
Quota per Ha	9,792	8,976	9,612	NS
Milk Solids per Ha	607	711	616	NS
Milk Solids per Cow	311	326	320	NS
Grazing Days	231 [a]	230 [a]	222 [b]	*
TEvrs [7]	0.935 [a]	0.803 [b]	0.767 [b]	***
TEcrs [8]	0.935 [a]	0.775 [b]	0.710 [b]	***
SE[9]	1.0000 [a]	0.967 [b]	0.929 [c]	***

a, b, c and d labels within column represent significant differences at *** <0.001, **0.001-0.01, *0.01-0.05, +0.05-0.1
[1]CRS (constant returns to scale - Optimum Scale)
[2]IRS (increasing returns to scale- Sub optimum scale)
[3]DRS (decreasing returns to scale- Supra optimum scale)
[4]Significance -PROC GLM SAS (2006), *** <0.001, **0.001-0.01, *0.01-0.05, +0.05-0.1, NS>0.1
[5]Concentrate per cow
[6]Fertiliser per hectare
[7]TEvrs: pure technical efficiency score
[8]TEcrs: overall technical efficiency score
[9]SE: scale efficiency score

Table 5: Comparison of efficiency scores at different measures of farm size, intensification andô specialisation

Variable	TEcrs[1]	TEvrs[2]	Scale[3]
Farm Size			
Land (ha)			
<20	0.681 [a]	0.805 [a]	0.985 [a]
<30	0.745 [b]	0.772 [b]	0.965 [b]
<50	0.781 [b]	0.795 [c]	0.982 [a]
>50	0.810 [b]	0.841 [c]	0.962 [b]
Significance[4]	<.0001	<.0001	<.0001
Cow			
<50	0.685 [a]	0.757 [a]	0.913 [a]
50–80	0.782 [b]	0.802 [b]	0.975 [b]
>80	0.844[c]	0.867[c]	0.972 [b]
Significance[4]	<.0001	<.0001	<.0001
Milk (l)			
135,000–250,000	0.691 [a]	0.755 [a]	0.921 [a]
250,000–320,000	0.773 [b]	0.796 [b]	0.972 [b]
320,000–500,000	0.799[c]	0.822 [c]	0.974 [b]
>500,000	0.881 [d]	0.901 [d]	0.975 [b]
Significance[4]	<.0001	<.0001	<.0001
Intensification			
Stocking Rate			
<1.50 LU/ha	0.681 [a]	0.729 [a]	0.943
1.50–2.00 LU/ha	0.764 [b]	0.803 [b]	0.953
>2.00LU/ha	0.811 [c]	0.851 [c]	0.953
Significance[4]	<.0001	<.0001	NS
Quota per hectare			
<5,000 l/ha	0.720 [a]	0.775 [a]	0.933
5000-10,000 l/ha	0.716 [a]	0.762 [a]	0.944
>10,000 l/ha	0.825 [b]	0.857 [b]	0.961
Significance[4]	<.0001	<.0001	NS
Dairy Specialisation			
<66%	0.699 [a]	0.747 [a]	0.941 [a]
66-75%	0.802 [b]	0.829 [b]	0.968 [b]
>75%	0.801 [b]	0.851 [c]	0.943 [a]
Significance[4]	<.0001	<.0001	<.0001

a, b, c and d labels within column represent significant differences at *** <0.001, **0.001-0.01, *0.01-0.05, +0.05-0.1
[1]TEcrs: overall technical efficiency score
[2]TEvrs: pure technical efficiency score
[3]SE: scale efficiency score
[4]Significance -PROC GLMSAS (2006), *** <0.001, **0.001-0.01, *0.01-0.1

enhance productivity by increasing cow numbers from the current national average herd size of 57 cows and 48 hectares (Connolly et al., 2010). The results from this analysis agree with findings of previous studies by Boyle (2002) and Donnellan et al., (2011) which have highlighted the effect of scale on the efficiency of the Irish dairy industry. Both Boyle (2002) and Donnellan et al., (2011) noted that the low level of scale of agricultural activity in Ireland leads to the deterioration of the competitive position of Irish farms when taking into account imputed costs for the owner's resources. The results of this paper showed that 56% of producers were exhibiting IRS and therefore might increase productivity through expansion above their current mean scale of 47 cows and 26ha. The analysis found that 32% of producers were operating at DRS, with an average herd size of 86 cows and 51ha; highlighting that a third of the sample of producers were deemed to be operating above an efficient scale and so could increase their level of productivity by reducing the size of operation. However, the modest difference in mean scales between the group found to be operating at optimal scale and those experiencing decreasing returns to scale suggests that the results should be interpreted with some caution. Other factors correlated with scale may be confounding the results. For example, it is likely that DRS may reflect specific 'scarcity' of one resource (e.g. labour or quota) relative the levels of other resources available. As producers in this sample that were milking 86 cows and farming 51ha were deemed to be exhibiting decreasing returns to scale and optimum scale is only slightly smaller this suggests that constraints to the industry such as quota are potentially causing producers to be operating at decreasing returns to scale. This result may also be due to sample bias and therefore all producers milking 86 cows farming 51 ha may not be operating under DRS. A solution to this problem would be to undertake a DEA slack based model where one can calculate by how much an input or output is being overused. Alternatively DEA results could be calculated based on different size classes. Further reasons why producers were not operating at optimum scale are discussed below.

In comparison with other studies optimum scale identified in this paper was relatively small. For example in a New Zealand study by Jaforullah and Whiteman

(1999) optimum scale was estimated to be 260 cows farming 83 hectares. According to Donnellan et al., (2011) the rate of increase in average herd size is much greater in New Zealand and the USA compared to Ireland. However, Lips and Rieder (2005) argue that Ireland is one of three EU countries that are expected to increase milk production in line with increases in milk quota.

Key factors affecting optimum scale of production

In order to elucidate the factors that were affecting the ability of producers to operate at optimum scale, a number of key variables were analysed. In a further analysis it was investigated whether technical and scale efficiency increased with increased farm size, intensification and dairy specialisation measures.

Farm size measures

Optimum scale production was associated with larger land area as producers at optimum and supra-optimum scale had significantly higher quantities of land compared to producers at sub-optimum scale. This indicates the benefits of economies of scale with larger scale production and that land availability will be central to increasing scale. It was also found that producers at optimum level of scale had a lower percentage of land rented. This may highlight better utilisation of land. A potential reason for inefficiency is farm fragmentation due to lack of land availability adjacent to the milking parlour. Percentage of land rented is likely to be correlated with higher degrees of farm fragmentation and resulting inefficiencies. In contrast optimum scale producers may be more likely to have consolidated holdings offering greater access to land adjacent to the milking parlour. Land quality which was found by Kelly et al., (2012) to be associated with technical efficiency may also be a factor associated with differences in level of land rented, with the influence of soil type and location dictating the quantity of land rented. According to O'Donnell et al., (2008) the largest constraint for Irish dairy farmers post quota will be land availability. It was also noted by Dillon et al., (2006) that land area around the milking platform is known to be a key constraint to expansion at farm level in Ireland. This finding also has policy implications, as land is a limiting factor in Irish agriculture, therefore if Food Harvest 2020 is to be achieved policy makers must focus on initiatives which will increase land mobility.

Increased levels of technical and to a lesser degree scale efficiency were also associated with higher overall milk production, land area and cow numbers suggesting increasing output post quotas will result in increases in efficiency levels. The positive effect of increasing cow numbers, land area and volume of milk produced on efficiency levels therefore highlights the benefits of economies of scale that could be realised in the Irish dairy industry through the relaxation of milk quotas. Yet successful expansion will only be realised if dairy farmers can increase their profitability through increasing efficiency with expansion. The results here mirror results by Kelly et al., (2012) who found increased levels of technical efficiency with greater milk solids produced. Similarly, Hansson (2008) found increased land area resulted in increased technical and economic efficiency for Swedish dairy farmers. However it must be remembered that increasing land area may not be easily achievable for all farmers due to issues such as cost of land, land fragmentation and land availability.

Labour

Optimum and supra-optimum scale producers had a higher number of overall labour units with a greater proportion hired, highlighting that labour options will have to be assessed to expand. Similarly, O'Donovan (2008) found that increasing scale resulted in an increased demand for hired labour. As producers at sub optimum levels of scale, with a potential to expand, had lower amounts of hired labour this may suggest that labour challenges are inhibiting expansion on some Irish dairy farms. Therefore labour will be important to expansion and for sub-optimum scale producers to increase scale and productivity will require the assessment of the labour options available to them. As sub optimum scale producers had higher levels of family labour this may suggest that social issues such as keeping the farm in the family may influence scale inefficiency. Although not analysed in this study, quality of labour may be another factor contributing to increased technical and scale efficiency. It would be anticipated that hired labour potentially possesses a higher labour quality standard as hired staff may have more training compared to family labour. This was also noted by O'Donovan (2008) who concluded that a focus must be placed on quality of labour with the view to creating a more specialised agricultural labour force. The association of labour with increased technical and scale efficiency found in this study also mirror the findings of O'Donnell et al., (2008) who stated that labour challenges will influence future decisions regarding expansion at farm level in Ireland.

Quota

A higher quantity of milk quota was associated with optimum scale production. By comparing the quantity of quota among producers, the results therefore suggest that quota availability is a factor contributing to why 56% of producers were at sub optimum scale. According to Burrell (2004) the constraint of quota thwarts the expansion over time of efficient producers and keeps inefficient producers in production. However milk quota is expected to be removed in the EU by 2015 which will allow expansion at farm level and producers to reap the benefits of increasing scale of production.

When focusing on intensification measures, increased quota per hectare was associated with increased technical efficiency. This may highlight that lower levels of efficiency may be due to the constraint of a quota system currently in place as producers with lower levels of efficiency may have little access to additional quota. Quota availability is another potential reason why some producers have lower levels of intensification. The high cost of purchasing quota and risk factors associated with managing annual farm production to avoid super levy threats are further potential reasons for the impeding effect of milk quotas on efficiency.

According to Lips and Rieder (2005) Ireland is able to increase production in line with increases in quota until quota is eventually removed. Based on the findings presented here, and as was noted by Donnellan et al., (2011) the technical efficiency at farm level and therefore the competitiveness of the Irish dairy sector should increase as scale is increased in a no quota environment.

Stocking rate

Stocking rate was significantly higher for producers at supra optimum scale compared to producers operating at optimum and sub-optimum levels of scale. However, it was also found that higher stocking rates were associated with greater technical efficiency, indicating that to expand in a post-quota scenario, many producers have scope to increase levels of intensification. However producers at higher stocking rates operating at supra optimum scale may have been maintaining a higher stocking rate due to increased proportions of purchased feed in the diet of the cow. As McCarthy et al., (2011) points out stocking rate can be more appropriately defined according to the feed and energy offered per cow. It must also be remembered that higher levels of intensification may lead to greater environmental risks such as increased levels of greenhouse gas emissions. The findings reported in this study are similar to a previous meta-analysis carried out by McCarthy et al., (2011) who reported an association between increased milk production per hectare and increased stocking rates. Gaspar et al., (2009) also found increased levels of technical and scale efficiency with producers with higher stocking rates in a study of Spanish livestock farms.

Dairy specialisation

Higher levels of dairy specialisation were associated with increased technical and to a lesser extent scale efficiency. This highlights potential for a rise in technical efficiency as milk quotas are removed and dairy farmers become more specialised. Previous studies have also found increased levels of technical efficiency with increased specialisation. According to Shalloo et al., (2004), dairy specialisation can be facilitated through expansion and predicted that Irish producers who remained static between 2004 and 2013 would have a 30% reduction in real income while those producers who expanded could maintain or increase their real income. Latruffe et al., (2005) also investigated specialisation and found Polish producers with increased specialisation in livestock to be more efficient compared to crop based farms. However it must also be noted the potential risks associated with specialisation such as output price risk which may affect the producer more in a heavily specialised enterprise compared to a mixed farming system. For example a drop in milk price is likely to have a much bigger impact on specialist dairy producers compared to producers that were operating a dairy alongside other enterprises as this would allow the spread of risk among the different enterprises. Risk management strategies must become a bigger feature of specialist milk producers, with the ultimate focus on cost reductions at farm level thus insulating against output price volatility.

Other productive and management factors

Grazing season length was significantly longer for producers operating at optimum and supra-optimum scales of production compared to producers operating at sub-optimal scale highlighting the association between optimum scale and management practices such as maximising the grazing season length. Lowering costs, by increasing the quantity of grazed grass in the diet of the dairy herd, will be positively associated with increasing scale through expansion in Ireland post quotas. The results in this study reflect those of Shalloo et al., (2004), who found that the grazing season length was associated with differences in production per hectare and Kelly et al., (2012) who found increased technical efficiency associated with increased grazing days. Production per cow and per hectare and concentrate per cow were also compared between optimum, sub-optimum and supra-optimum levels of scale and no statistically significant association was found.

5. Conclusion

The objectives of this study were to estimate the levels of technical and scale efficiency for a sample of pasture based Irish dairy producers, to identify the factors that contributed to reaching the optimum scale and to examine the relationship between technical and scale efficiency with farm size, intensification and specialisation. Technical efficiency was found to be on average 0.757 under constant returns to scale (CRS), 0.799 under variable returns to scale (VRS) and scale efficiency estimated at 0.951. The optimum scale on Irish dairy farms was found to be 80 cows and 41 hectares of land with 12% of the sample operating at their optimum scale (CRS). Fifty six percent of the sample was operating below optimum scale and 32% of the sample was operating above optimum scale. This study found that to achieve optimum scale will require a focus on factors such as land availability, levels of quota, labour options and management issues such as achieving a longer grazing season. It was also shown that increasing farm size, intensification and dairy specialisation will increase technical and to a lesser extent scale efficiency at farm level. The implications of these results are to confirm that a potential exists to enhance productivity through increasing average scale of production on Irish dairy farms as the industry moves to a situation with no quota constraints. As only one year of data were used in this study an extended dataset over a longer time period would be beneficial to future analysis.

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An analysis of the competitiveness of the South African citrus industry using the Constant Market Share and Porter's diamond model approaches

PORTIA NDOU[1] and AJURUCHUKWU OBI[2]

ABSTRACT

This study evaluated the export market share of the South African citrus industry amidst the ever-changing forces in the business environment such as food safety standards, economic, technological and political factors. The Constant Market Share (CMS) model used time series export quantities from Citrus Growers Association (CGA), the Department of Agriculture Forestry and Fisheries (DAFF) and Food and Agriculture Organisation database (FAOSTAT). The Constant Market Share showed a positive performance for oranges and lemons, which was linked to the industry's inherent competitiveness in the selected markets. Soft citrus quantities were almost stable to decreasing for most markets save for the Middle East, Americas and South East Asia. Limes and lemons as well as grapefruit and pomelos showed an upward trend in the Middle East and Central European markets respectively. Market availability, market size and strong support from the CGA- earn the industry advantage to compete in the export market. However, challenges from both the market and production side such as, high transport costs to markets, stringent food safety standards and high foreign market support regimes were on the increase. While South Africa is a key player in the export market, its competitiveness depends on diverse forces in the global business environment. These negatively affect the price competitiveness of the industry in the oversupplied export markets. It is often more difficult to penetrate the more lucrative markets to which standards are generally more stringent. The implications for market share of the South African citrus exports and hence the industry's competitiveness needs to be examined. In spite of all this, striving to meet the food safety and private standards, maintaining the market share in high value markets as well as government support are inevitable.

KEYWORDS: Constant Market Share; South African citrus industry; Competitiveness; Performance

1. Introduction

The South African citrus industry has enjoyed export of its fruit from the 1900s. Initially exports were most exclusively to Britain. The whole of the agricultural sector was highly protected and regulated, till the post-apartheid deregulation of agriculture in 1996 and the deregulation of the fruit industry in 1997 (Mather and Greenberg, 2003). The exporters had adapted to the single channel marketing system which majored in pooling products on cultivar and quantity bases (Mather and Greenberg, 2003). The single channel marketing system rewarded volume than quality, resulting in all growers receiving the same unit price (Gibbon, 2003). This long standing export performance of the South African citrus industry has not been without both opportunities and challenges. South Africa's diverse climatic conditions (tropical, sub-tropical and Mediterranean) (Philp, 2006) gives the nation an advantage of producing a vast range of citrus cultivars that may meet different consumer preferences in different markets. The diverse climatic conditions ensure that the industry will not suffer a total crop failure. Most citrus pests and diseases are climatic conditions specific. For instance, the Citrus Black Spot (CBS), false codling moth and the greening disease are prevalent in the northern warm districts. An infestation of one locale may not affect production in other areas. This is an advantage as supply to the market can be guaranteed at all times despite variations in quality. South African soils are also mostly slightly acid (pH around 6) sandy loams, characterised by less difficulties in managing soil nutrition (Philp, 2006).

The deregulation of the industry exposed the citrus producers to real market forces without government intervention. The high incidence of food-borne diseases associated with international trade and the potentially rapid spread of hazardous materials have seen the global agro-food industry tightening the food safety standards (Anders and Caswell, 2006). Stringent regulations that

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govern trade and tight private food safety and health standards to safeguard the consumers of traded food items, particularly in the developed countries, have been put in place. A growing appreciation of the link between diet and health has also contributed to different eating patterns and has influenced food purchases within and from the less developed countries. Consumers are demanding much more than quantity- they also want quality, consistency and value (Drabenstott, 1995). The changing and diverse consumer demands, new technologies (bio- and information technologies) and new product characteristics also led to major structural changes in the production and distribution of agro-food products not only in South Africa but in many parts of the world. Thus, exposure to world markets through the process of globalisation brings with it challenges, opportunities and opens up possibilities to new products and clientele. One of the greatest challenges for the South African citrus industry was adapting to quality demands by the importers in addition to adapting to the many changes that the nation has undergone in the past few years with respect to policy issues.

Increased access to information by today's consumers coupled with the process of labelling gives the consumer knowledge about the availability of certain products in markets, their origin and the production processes involved. This has attracted improvements in quality and rapid evolving of down-stream supply chains. The increased distances between suppliers and consumers associated with international trade have made quality assurance standards directly linked with supply chain management. Product characteristics increasingly demanded by consumers include safety, nutritional status and authenticity (Mehotra, 2006). The later relates to the need for easy traceability of the product. Thus, paying explicit attention to production processes that promote a safe and sustainable environment cannot be avoided. In general, attributes such as blemishes, absence of residues, hygiene and presentation, seediness of fruit, shape of fruit, consistency, maturity, disease and environment protection plus purity and freshness of the citrus juice are some of the highly esteemed requirements citrus fruits and products have to comply with (UNCTAD, 2010). Maturity is based on minimum juice content, minimum total soluble content (TSS), i.e. minimum sugar content and colouring. Oranges meant for juice production are tested for total soluble solids (brix)/acid ratio, which give flavour to the juice. Generally, the citrus fruit must be intact, free of bruising and / or extensive healed over-cuts, sound; produce affected by rotting or deterioration such as to make it unfit for consumption is excluded, clean, practically free of any visible foreign matter, practically free from pests, practically free from damage caused by pests, free of signs of internal shrivelling, free of damage caused by low temperature or frost, free of all abnormal external moisture and free of any foreign smell and/ or taste (FAO, 2008).

Despite the advantages of a counter-seasonality production system to its major northern hemisphere rivals especially Europe (South Africa Info, 2008), which is the country's main export market, South African citrus exporters face challenges of high transport costs, especially inland to ports (primarily Durban). In spite of the claims that South Africa enjoys world-class infrastructure such as deep water ports, shorter shipping times to Europe compared to southern hemisphere rivals, good road networks and a sophisticated financial sector that facilitates exports (South Africa Info, 2008), exporters also incur additional costs at harbours where congestions and operational inefficiencies are common (Van Dyk and Maspero, 2004). This is a major challenge especially when exports are destined for the European countries, where the South African citrus industry's northern hemisphere rivals have relatively lower transport costs as a result of geography. Moreover, delays anywhere within the supply chain can be detrimental to fruit quality, resulting in failure to meet market requirements. Apart from facing intense competition from the southern hemisphere rivals, longer northern hemisphere production seasons have posed a challenge (Mather, 2003). The international fruit export is often characterised by oversupply. In 2000, the industry as a whole lost about SAR1 billion[2] in export earnings (Mather, 2003). The losses were attributed to poor fruit quality, the existence of too many inexperienced export agents and oversupply in the international market. Oversupply automatically translates into non-price competition such as fruit quality and traceability which have dominated today's global market. It also leads to lower prices, a condition unfavourable for producers with high production costs.

However, South Africa ranks thirteenth in world citrus production, with China, Brazil, India and the USA taking the first four leading positions respectively. Although the Southern African citrus industry produces only 1.5% of the world production (Philp, 2006), South Africa ranks third in citrus export after Spain and Turkey (CGA, 2012). South Africa exports a diverse range of citrus products; oranges, soft citrus, grapefruits, lemons and limes, and citrus juices. Seventy (70%) percent of the total citrus production is exported, 8% processed and 22% is locally consumed as fresh fruit (CGA, 2012).

Despite its importance, South African citrus exports depend on diverse forces in the global business environment beyond the control of the industry. Among these, the food safety and health standards have been shown to be highly influential, determining export volumes to different markets. The competition for the more lucrative markets is therefore expected to be tight. Their influence determines the trend in the traded fruit quantities and market shares. This paper sought to investigate the export performance of the South African citrus industry in the post apartheid era particularly in the light of the changes in the food safety and quality standards as well as the many policy and business environmental changes surrounding the South African citrus export industry. Specifically, the study sought to determine the market share of the industry over the years using the Constant Market Share model. The study provides an analysis into the strength of the industry's competitive position in the global market and an understanding of the importance of external factors that may influence that position. The study is of great benefit as it explores how the industry fares against its

[2] At the time of writing this article (September 2012), SAR1 was approximately equivalent to $US 0.12, £0.075, and €0.094

rivals. Although the objectives of an industry may remain the same, its strategies, policies, organisation and operating practices may undergo a massive amount of adjustments when marketing is done beyond national borders. Thus, this analysis unveils the conditions that can aid in formulating strategies focused upon high competitiveness amidst the ever-changing business environment.

2. Analytical framework and model

The study on which this paper is based analysed the export market share of the South African citrus industry between 2004 and 2011 in the major high value international fruit markets, namely, the Americas, UK, Europe, the Middle East, Asia as well as Africa. To measure the performance of the South African citrus industry, it was necessary to evaluate the changes in the quantities traded to the top lucrative international markets and the most prominent emerging ones like the Middle East. Due to the rapidly changing regulatory environment with respect to trade restrictions and private food safety requirements, there are fluctuations in quantities exported, and exporters are frequently forced to look elsewhere to sell their produce. For this purpose, citrus export quantities from South Africa and import volumes in selected markets were examined.

Secondary data comprised trade statistics and international destinations of fruits. Time series data of sufficient length were available from Food and Agriculture Organisation's database (FAOSTAT), the Department of Agriculture Forestry and Fisheries (DAFF) and the local farmer organisation, the Citrus Growers Association (CGA) Statistics book.

The Constant Market Share (CMS) model was employed. The Constant Market Share (CMS) model was developed by Tyszynski in 1951 and later developed by Milana in 1988. The model measures a country's share of world exports in a particular commodity or other export items. It is based on the assumption that an industry should maintain its export share in a given market (i.e. remain unchanged over time). If a country's share of total products exports is growing in relation to competitors, for example, this may reflect increasing competitiveness of that country's product sector (Siggel, 2006). The Constant Market Share involves the measure of a country's comparative export performance as a ratio of its exports to those of a standard, i.e.

$$S = \frac{x}{X} \quad (1)$$

Where S, is the ratio of exports of a 'focus country' (x) to the exports of one or more countries that serve as a standard of comparison (X). The proportional change in exports (S) is decomposed into 3 terms: a scale effect (Q), a competitive effect (s) and a second-order effect (sQ):

$$q = Q + s + sQ \quad (2)$$

Where q, Q and s are the proportional changes of x, X and S respectively, over a discrete period of time.

Equation [2] is often used as an aggregate version of Equation [3] where in the later, the exports are differentiated in terms of product type (i=1, . . . , I) and regional destination (j=1, . . . ,J), the export growth for the focus country, say Russia, in market ij can be written as follows:

$$q_{ij} = Q_{ij} + S_{ij} + S_{ij} Q_{ij} \quad (3)$$

Where $q_{ij}=\Delta x_{ij}/x0_{ij}$ is the growth in exports of Russia for the $(i, j)^{th}$ commodity; $Q_{ij}=\Delta X_{ij}/X0_{ij}$ is the growth in exports of the set of countries against which the focus country's export performance is compared, herein called the reference group or standard; and $s_{ij}=\Delta S_{ij}/S0_{ij}$ is the growth in the export ratio for the $(ij)^{th}$ commodity.

The CMS model allows for the evaluation of international exchanges involving one or more countries exporting in one or more destinations. It is based on the disaggregation of variations occurring either in their exports or in their market shares. In this case the exporter consists of one country, South Africa, and 6 destination regions. The key consideration for the use of this model is that the growth rate of imports coming from the rest of the world is different from the growth rate of imports coming from a single country.

The CMS has as its basis, the assumption that an industry should maintain its export share in a given market (i.e. remain unchanged over time). Considering the global village within which today's agribusiness operates, the business environmental factors impact each country differently. The impact of these forces on similar industries may result in different and independent reactions, impacting also on the fruit volumes exported to the same market outlet. In addition, there are differences in home base environmental factors affecting the imports of a single market coming from different countries. The heart of the diagnostic interpretation of the CMS norm is based on the presumption that changes in market share reflect purely competitive conditions. Interpretation is thus a description of past trading pattern. Inevitably, inferences regarding the forces underlying the country's export performance may be the end result, thereby, resulting in an interpretation that is diagnostic. The CMS was found to be most appropriate for the analysis of the performance of the South African citrus industry since several markets for the industry were under review.

The CMS model is specified as follows (Barbaros, Akgungor, Aydogus, 2007):

$$\Delta q = \sum_i \sum_j S^o_{ij} \Delta q_{ij} + \sum_i \sum_j Q^o_j \Delta S_{ij} + \sum_i \sum_j \Delta S_{ij} \Delta Q_{ij}$$

[1] [2] [3]

Where:

q = target country's citrus exports (value)

S_{ij}= An exporter country's export market share of product i (where there are more than one selected products) in country j (more than one selected countries)

Q_{ij} = Total imports of market j

Δ = annual change

0=base year

The CMS analysis assumes three factors to explain why a country's exports grow faster than the world exports. The three terms are indicated on the right hand side of the equation, namely, (1) the structural or market effect, (2) the competitive effect and (3) the

Table 1: Components of the CMS Model

Item	Interpretation
Structural Effect	The change in exports due to the change in the importing country product imports.
Competitive Effect	The change in exports due to the change in the exporting country's competitiveness.
Second-order Effect	The change in exports due to the interaction of the change in an exporting country's competitiveness and the change in the importing country's product imports.

Adapted from Chen and Duan, 2001

second-order effect, respectively. These terms are defined in Table 1 below.

The structural effect is the change in exports due to the change in the importing country's imports. In simpler terms, it is the growth of the export market relative to the world export growth (Chen and Duan, 2001). The competitive effect measures the change in exports due to the exporting country's improvements in competitiveness (Barbaros, Akgungor and Aydogus, 2007). The competitive effect indicates the improvement or the deterioration in the competitiveness of the exports, depending on whether it has a positive or negative sign. The underlying assumption is that this effect is independent of the other effects and it largely reflects the role of domestic factors of the exporting countries. (Turkekul *et al*, 2007). The second-order effect is a combined effect of competitiveness and structure (Barbaros, Akgungor and Aydogus, 2007). It is the change in exports due to the interactions between the exporting country's competitiveness and the importing country's imports (Chen and Duan, 2001).

A short-coming of the CMS model is that it does not provide information on the causes of any gains or losses of market shares. To compensate for that, the CMS model is used side-by-side with Porter's diamond model. The diamond model (Porter, 1998) identifies the determinants of competitiveness, namely those factors that either enhance or hamper competitiveness. The determinants are grouped into factor conditions, demand conditions, firm strategy, structure and rivalry, related and supporting industries, government and chance events. The advantage of the diamond model is that it evaluates all participants in the supply chain (Porter, 1990; 1998). While the approach points out the weaknesses and strengths of a sector, it also identifies critical success factors in the supply chain to which special attention can be paid with the objective of developing and sustaining competitiveness as successfully as possible in years to come. The perceptions of the citrus exporting farmers about the impact of these determinants of competitiveness were measured using a 10-point Likert scale. The 10-point Likert scale was anchored by 1for 'impeding' to 10 for 'most enhancing'. The closer to 10 the index is, the more enhancing the determinant and a lower index denotes an impeding influence.

Semi-structured questionnaires were administered to the citrus export producers who were identified by the CGA. The questionnaires were used to establish citrus producer perceptions on the impact of predetermined environmental factors influencing the performance of the citrus industry. The questionnaires were mailed to the farmer clientele throughout the country so that all the growing regions, production and climatic conditions and cultivars were accommodated. The unit of analysis was the citrus producers engaged in export of their products. Questionnaires were emailed to the export farmers through the Citrus Growers Association (CGA) and physical administration was carried out only in the cases of the easily accessible farmers within the Kat River citrus growing area. A total of 151 responses were received and analysed out of an estimated 1400 citrus growers distributed across the nation including those in Zimbabwe and Mozambique (Philp, 2006). This gave a response rate of 10.8%. The percentage was representative enough as it embraced the different classes of exporting farmers ranging from the resource-poor smallholders, emerging and the large-scale commercial producers. Though South Africa exports the juices of citrus fruit juice, this study only considered the export of whole fruits.

3. Results and discussion

Differences in quantities demanded of each citrus cultivar were considered for the analysis of the competitiveness of the South African citrus industry. Each type was treated separately. The analysis adopted the following categories; oranges, grapefruit, lemons and limes and soft citrus. Various cultivars within each category were ignored.

A greater proportion of the citrus products are exported, while the balance is either consumed locally either as fresh fruit or in processed form (Figure 1). Although the industry experienced a decline in quantities of citrus fruit produced between 2002 and 2006, export quantities remained near stable to increasing and later rose as reflected in Figure 1. Despite an increase in total production for the 2011/12 season, Figure 1 reflects a decline in export quantities of citrus fruit. The locally consumed fruit forms the smallest portion of total citrus produced in South Africa.

Oranges constitute a greater proportion of the exported citrus products (Figure 2). The breakdown of exported citrus products (Figure 2) confirms that oranges constitute the highest amount (about 70%) of exported citrus fruits, followed by grapefruit.

Performance of the South African citrus industry

The Middle East, South East Asia, UK, Central Europe, Americas and Africa have been the major export market destinations for South African citrus products for the previous 5 seasons. The South African citrus products are not evenly distributed among these major destinations. The composition of the South African citrus exports (in volume terms) to different

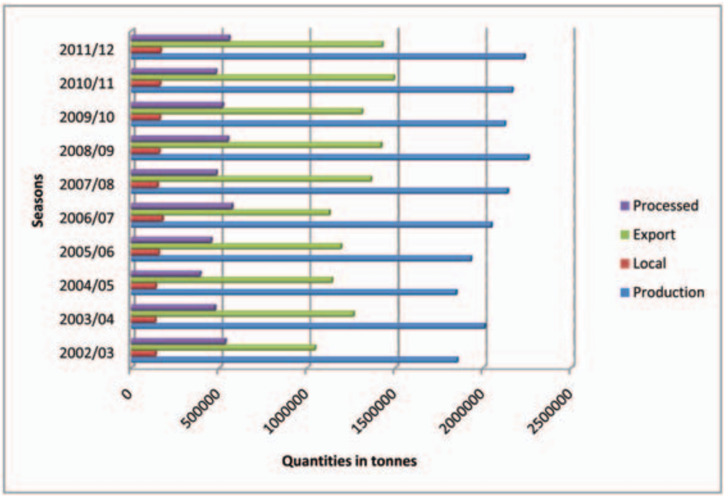

Figure 1: South African citrus production, processing and exports (Data according to CGA, 2012)

countries is summed up in Table 2. A greater proportion of grapefruit was exported to the Middle East where it enjoyed a market share of 76% in 2006 (Table 2). Lemons were also mainly exported to the Middle East where South African share amounted to between 36 and 82%. The UK accounts for a larger share of the South African soft citrus than other destinations.

Results of the Constant Market Share Analysis of the South African citrus fruits

The three factors used to explain the growth of a country's exports were analysed through the use of the Constant Market Share model (CMS). These are the factors relating to the growth of the export market relative to the world export growth (structural effect), improvements in competitiveness of the exporting country (competitive effect) and the combined effect of competitiveness and structure (Barbaros, Akgungor and Aydogus, 2007). The CMS analysis reveals that South Africa's export growth of lemons and Oranges is due to the competitiveness of its fruit in all the markets (Table 3). The trend for the import quantities in destinations of interest was generally stable, with the exception of fluctuating conditions for the oranges in the Middle East and Central Europe, as well as the increasing and sporadic situation for the lemons and limes in the Middle East and Americas respectively. Soft citrus is highly competitive in the UK, Central Europe and the Americas where the import trends apparently show varied trends. South African grapefruits and pomelos are competitive in the Middle East, South East Asia and the UK. However, the performance of the grapefruits is due to the structural effect in Central Europe.

Factors affecting the performance of the citrus industry

The results of Porter's diamond model were divided into factor conditions, demand conditions, related and supporting industries, strategy, structure and rivalry, government and chance events as indicated in Table 4 to 8. The perceptions of the exporting farmers were measured on a 10-point Likert scale. A lower index denotes an impeding influence while a higher index (closer to 10) shows a more enhancing the determinant. The demand conditions for this study entailed the export market-side challenges since the export market was under consideration. Table 4 shows that foreign market support systems, non-tariff technical barriers to

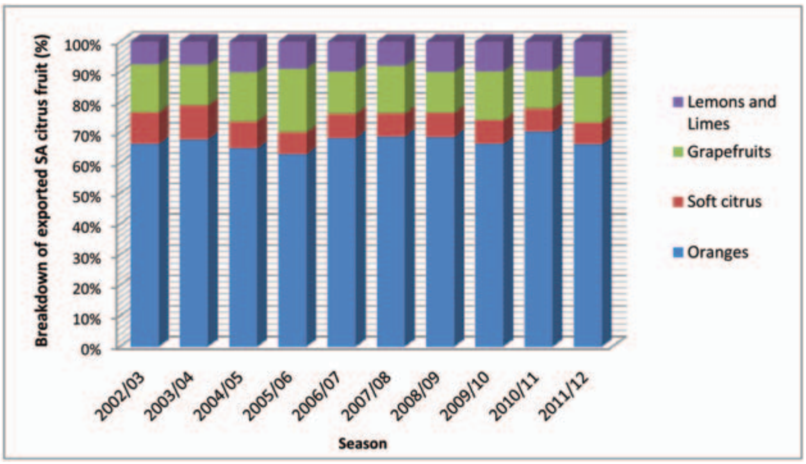

Figure 2: South African citrus fruit exports composition for each year (% of actual values). (Trend data according to CGA, 2012)

Table 2: Composition of South African citrus exports in different countries of destination

Country of Destination	Share of total South African exports (%)							
	2004	2005	2006	2007	2008	2009	2010	2011
Share of total South African Grapefruit (Incl Pomelos)								
Middle East	48.54	47.2	76.37	72.15	57.75	21.64	17.68	21.62
S.E. Asia	0.003	0.005	0.006	0.005	0.004	0.002	0.002	0.019
UK	26.85	32.27	37.67	45.70	36.86	28.84	31.81	35.40
Europe	25.43	30.99	18.59	21.39	15.40	26.80	13.45	14.73
Africa	4.61	4.28	4.59	6.37	4.94	32.70	27.71	29.43
Americas	5.57	6.397	6.74	6.06	5.09	29.51	6.85	7.11
Share of South African Lemon exports								
Middle East	56.58	82.32	45.86	36.99	62.51	26.28	28.42	23.28
S.E. Asia	21.49	27.36	27.86	27.19	59.19	55.87	23.17	24.30
UK	17.48	20.8	18.44	17.05	34.22	11.98	13.29	14.03
Europe	6.49	7.89	6.15	3.19	4.71	6.65	5.39	4.78
Africa	27.77	10.97	13.85	11.77	34.08	34.87	39.35	34.07
Americas	0.25	0.28	0.27	0.2	0.43	4.86	1.01	2.33
Share of total South African Orange exports (%)								
Middle East	46.65	49.56	46.08	44.5	58.55	21.09	21.13	20.20
S.E. Asia	31.79	42.97	45.1	60.83	47.92	22.34	26.59	23.27
UK	19.98	26.23	28.2	28.29	31.57	23.27	30.12	27.13
Europe	18.99	25.26	22.73	21.11	18.60	14.15	16.02	16.31
Africa	5.24	6.68	7.25	5.62	5.96	4.89	57.68	56.69
Americas	11.91	12.63	14.73	13.5	13.32	9.14	10.76	9.12
Share of total South African Soft citrus exports (%)								
Middle East	5.39	8.29	5.34	6.54	3.94	8.6	14.07	7.5
S.E. Asia	6.23	4.89	4.37	4.29	3.91	1.77	2.11	1.58
UK	11.39	13.53	13.52	17.57	19.02	13.29	15.60	14.74
Europe	3.31	3.38	2.62	3.31	3.21	3.36	2.95	2.97
Africa	9.59	9.69	8.44	8.24	6.66	35.26	42.45	27.24
Americas	5.795	5.595	5.02	6.16	6.38	2.09	2.18	1.84

Data average export composition to each market (CGA, 2009; 2012; DAFF, 2011) and import figures of the major destinations for citrus fruits (FAOSTAT, 2010)

trade (TBT) and trade specifications impact negatively on performance.

Changes in consumer preferences enhance the competitiveness of the industry with a score of 5.1. This concurs with Mabiletsa's (2006) findings that consumers prefer seedless, easy-peeling cultivars with very excellent internal and external qualities which are highly favoured in the global market. It is estimated that by 2020 the fresh fruit and vegetable sales would have grown by 4.2% (Mashinini, 2006). The increase in demand for the fresh fruit and vegetables is presumed to be a result of the demand for health, demand for fresh produce variety, freshness, and year-round availability (Henson, 2007), as well as quality and nutritious food stuff (Mashinini, 2006). The highly influential supporting and related organisations, institutions and departments for the citrus industry are agricultural input suppliers, the CGA and the Citrus Research International (Table 5). South African financial institutions and the National Department of Agriculture (now known as Department of Agriculture Fisheries and Forestry (DAFF)) were deemed not to promote the competitive advantage of the export farmers with a score of 3.5 and 4.5 respectively (Table 5). Institutes of higher learning had below average influence. The universities and the CRI are important for research.

All factors whose influences are sporadic and are subject to twists and turns were classified as chance events. All the aspects considered as chance events impacted negatively on the smallholder citrus producers' performance (Table 6).

Table 7 shows the impact of selected factor conditions on the competitive success of the smallholder citrus producers. Most factors are above average in enhancing the performance of the producers. However, worker skills, literacy and the availability of skilled employees are major factors affecting the competitiveness of the smallholder producers. The employment of personnel with the rightful skills may be very expensive for the farmers and in turn impact negatively on production cost. Nonetheless, it has to be addressed if the producers will be significant players in the citrus export market.

Government influence was deemed to negative on the industry's export activities (Table 8). The education policy, environmental policy and tax system on investments and risk taking have been found to have a slightly above average impact. The threat of new entrants, substitute cultivars, price strategy, adaptability and

Table 3: The Constant Market Share Analysis of the South African citrus fruits (2004-2011)

	Trend in import quantities (2004-2011)	Structural Effect	Competitive effect	Secondary effect
Oranges				
Middle East	+/-	-0.62	1.98	-2.08
S.E. Asia	=	-1.14	1.38	-2.23
UK	=	-7.38	0.82	-0.38
Central Europe	+/-	-0.36	-0.75	-4.65
Africa	=	0.39	0.01	-0.03
Americas	=	1.32	0.12	-0.04
Grapefruits & Pomelos				
Middle East	=	s	0.19	-0.46
S.E. Asia	=	-5.93	3.84	-0.001
UK	-	-7.38	0.82	-0.38
Central Europe	+	1.79	-0.21	-0.56
Africa	=	-1.17	0.03	-0.05
Americas	+/-	0.43	-0.15	0.01
Lemons & Limes				
Middle East	+	12.13	0.46	-2.86
S.E. Asia	=	-2.98	4.91	-0.42
UK	=	1.02	2.24	0.12
Central Europe	=	0.09	0.13	-0.04
Africa	=	-0.04	2.02	-0.21
Americas	+/-	10.41	0.03	-0.03
Soft citrus				
Middle East	+	18.53	-3.43	-14.02
S.E. Asia	+	34.28	-2.24	-18.59
UK	-	-38.71	8.99	-14.19
Central Europe	+/-	4.42	0.17	0.09
Africa	=	6.32	-3.92	-1.16
Americas	+	10.57	1.02	-0.51

(+)= increasing; (-)= decreasing ; (+/-)= fluctuating; and (=)= near stable trend

Table 4: The most important market side demand conditions affecting the performance of the South African citrus industry

Determinant of competitiveness	Rate
Market availability	7.5
Market size	7.6
Market information	7.2
Strict quality measures in the export market	5.6
Changes in consumer preferences	5.1
Market growth	7.4
Size and growth in the local market	5.5
Retailers in direct importation	6.5
Global supply chain integration	5.1
Competitive rivals from the developed nations	5.8
International market large enough to obtain economies of scale	6.5
Trade specifications	3.5
The challenges of management in an international environment	2.5
Non-tariff barriers (-quality and packaging requirements	1.5
-import licensing	2.5
-quotas	1
-Sanitary and Phytosanitary regulations	2.5
Global Partnership for Good Agricultural Practice (GLOBALGAP)	3.3
Hazard Analysis and Critical Control Points (HACCP)	3.4
Codex Alimentarius Commission (Codex)	3.1
Foreign market support systems for fruits	1.6
-The reference price or minimum import price system	1.7
-Subsidies and price supports (by Canada, USA, Japan and the EC	1.2
-import duties	2.5
Cultivar mix	1.3

Rated on a Scale of 1- 10 (10= most enhancing; 1= impeding). Average standard deviation =1.3

Table 5: Related and supporting industries conditions influencing the performance of the South African citrus industry

Determinant of performance	Rate
Supporting industries	
-Financial institutions	3.5
-Research institutions	6.0
-Transport companies	6.7
-Suppliers of packaging materials	6.5
-Agricultural input suppliers	7.3
-Electricity Suppliers (ESKOM)	8.2
Related industries and organisations	
-Nurseries	2.5
-Citrus Growers Association (CGA)	8.6
-Agricultural Research Council (ARC)	0.5
-Citrus Foundation Block (CFB)	1.5
-Exporting companies (*specify*) e.g. CapeSpan	7.1
-Citrus Research International (CRI)	8.2
-Perishable Products Export Control Board (PPECB)	6.5
-Fresh Produce Exporters Forum (FPEF)	2.2
-National Department of Agriculture (NDA)	4.5
-Institutes of Higher Learning e.g. universities	3.0

Rated on a Scale of 1- 10 (10= most enhancing; 1= impeding). Average standard deviation=1.5

flexibility were found to impact negatively on competitiveness.

This and other previous studies (Brooke, 2009; CGA, 2011; CGA, 2010) have found that the infrastructure, especially transport system, is a general challenge for exporters. This is one of the specific targets of potential address for efficient performance. Addressing transport problems will not only save the citrus industry but is a potential point for the enhancement of economic development since many industries and firms will benefit. This study identified that technical back-up of the citrus growers, especially the emerging and small-holder is an area needing serious support. The identification of critical areas through research enable the appropriate allocation of the insufficient funds as critical areas, services and potential target groups would have been spelt out.

Many issues have been raised as hindrances to competitiveness of the South African citrus industry in the global market. Porter's diamond model showed that trade specifications, challenges of management in an international environment, non-tariff barriers to trade, foreign market support systems for fruit producers,

Table 6: The most important chance factors influencing the competitiveness of the South African citrus industry

Determinant of performance	Rate
Economic stability	3.5
HIV/AIDS	2.5
Political stability	3
Price stability	3.5
Crime	3.4
Oil and fuel prices	2.8
Fluctuations in the exchange rates	1.2
Inflation	1.5
2010 World cup hosting by SA	1.5
Global economic recession	1.1

Rated on a Scale of 1- 10 (10= most enhancing; 1= impeding). Average standard deviation=1.3

Table 7: The most important factors conditions influencing the performance of the South African citrus industry

Determinant of performance	Rate
Cost of production	4.5
Labour -labour relations	7.0
-productivity	5.7
-worker skills levels	4.5
-staff training	5.3
-worker literacy	4.4
-worker aptitude	5.1
worker attitude	6.3
-availability of skilled employees	3.6
-influx of Zimbabweans (and other nationals) into the country	0.5
Natural factors -climatic conditions	6.5
Accessibility and cost of water	6.5
Citrus diseases e.g. CBS	4.3
- Pests	5.5
Infrastructure -type	5.9
-location	6.8
-user cost e.g. transportation	6.4
-communication systems	5.0
-electricity	4.5
Capital -cost	5.2
- availability	5.5
Access to Knowledge -cost	6.1
-quality	7.7
-availability of scientific, technical and market knowledge	7.5
-Extension capacity	8.0
Access to Technology -cost	6.9
-quality	7.1
-availability	6.3
-technical information flow	6.5
-scientific research	4.2

Rated on a Scale of 1- 10 (10= most enhancing; 1= impeding). Average standard deviation=1.2

exchange rate fluctuations, inflation and crime were the major factors impeding competitiveness of the industry. The list also included HIV and Aids, economic stability, labour policy, cost of production, worker literacy, pricing strategy, worker skills, adaptability, threat of substitutes, threat of new entrants, government support, trade policy, land reform, property rights issue and agricultural policy. The problem with exporters paying third parties for certificates of compliance still raises costs for citrus exporters. The factors enhancing the competitiveness of the citrus industry in the export market include market availability, market size, market information, market growth and the presence of research institutions.

4. Conclusion and recommendations

The CMS analysis proved that the competitiveness of the South African citrus industry's orange and lemon fruit in the period 2004 - 2011 is due to good performance and competitiveness. It is most likely that the shock of deregulation and other policy reforms have eased out. It is most likely that due to the asset specificity nature of the industry, the best alternative left to the producers was to step-up management and infrastructure development focused on ensuring fruit of good quality. Also, the South African citrus industry has been exporting its fruit for over a century now and has established reputation and relations with most of its

Table 8: The most important government and firm strategy, structure and rivalry conditions affecting the performance of the South African citrus industry

Firm strategy, structure and rivalry conditions	Rate
Adaptability	3.5
Culture	4.5
Structure	5.6
Flexibility	3.5
Pricing strategy	2.6
Managerial capabilities	6.1
Market power of buyers	6.5
Market power of suppliers	6.2
Threat of substitute cultivars	3.7
Threat of new entrants	2.5
Governmental factors	
Indirect support	4.5
Trade Policy	4.6
Land reform policy	3.5
Labour policy	2.5
Fiscal policy (general economic policy)	3.1
Education policy	5.5
Agricultural policy	4.9
Environment policy	5.5
Financial and taxation policy	3.7
Property rights issue	2.5
Impact of the tax system on investments and risk taking	6.3

Rated on a Scale of 1- 10 (10= most enhancing; 1= impeding). Standard deviation=1.4

traditional market destinations. It is easier to maintain an established market relationship than to venture into a new one especially in today's highly uncertain and competitive environment characterised by diverse health and food safety regulations, private standards, high demand for traceability, ethical trading and numerous food quality prescriptions. These are more in the traditional markets like Europe than the emerging markets like Russia.

Most of the factors affecting the competitiveness of the citrus industry are on the increase and, with the rapid globalisation of the agro-food industry, the food safety standards and high fruit quality demand may turn to be the best measure across borders, compelling all exporting industries to comply or run the risk of losing lucrative export markets. Maintaining or improving the competitiveness of the South African citrus industry remains paramount amidst the changes in the business environment, particularly those on the market side like the food safety standards and changes in consumer preferences. Switching and diversification of markets aimed at evading compliance with stringent SPS and TBT standards set by the importers can be weighed against financial implications for the exports. Market diversification may ensure continuous marketing of products, since a failure in one market may not necessarily lead to a total collapse of the industry. In such a situation, markets can offer size but not profits. Industries need larger customer base for economies of scale, but returns should not be compromised unless the shift in markets pays better than compliance with stringent standards in existing markets. Without compromising on return on capital invested in the production process, it is worthwhile for the industry to explore and sell its products in the most accessible markets.

Existing research collaboration with private research institutions, universities and government research institutions should be strengthened. Since SPS barriers have replaced tariffs as protectionist tool, a country's global market share is not necessarily measured by the quality of its product as set by the importer, but by the quality of its research and technical abilities. The South African citrus industry should brace itself to be a leading research industry that is able to come up with new cultivars in response to consumer needs such as easy-peeling, fruit seediness among others. Home-based development of new varieties should be done in concurrence with the consumer preferences. Such developments should be made with meaningful differences from competitors, not for the sake of being different. In today's consumer-centred global business, developments in products and cultivars should be continuously and consistently aligned with the trends in consumer demands and preferences. Strategies geared towards aligning research, development and extension programmes with the prevailing and anticipated market forces are beneficial for customer attraction, satisfaction and retention amidst competition.

The food safety standards have been found to have negative implications on the export competitiveness of the South African citrus industry. The negative influence of the private standards may have serious impacts on export flows of citrus from South Africa, especially upon the smallholder producers who are characterised by limited resources and technical incapacities. Technical assistance is needful especially for the smallholder farmers faced with challenges of compliance and verification of compliance standards especially from the EU.

Innovation, product mix, quality assurance and consistency in value improvement should be uppermost in the marketing strategies. There is no 'average' customer, especially with the globalisation of the agribusiness industry. It is easier to retain customers than to gain new ones especially with the high entry requirements characterised by traceability and ethical trading. Individual differences in consumer preferences and market segments exist, but, it is worthwhile for the industry to consistently create value aimed at winning the competitive marketing war.

All key players in the supply chain; the producers, exporting companies, packhouse owners, storage facility operators, transporters, input suppliers and packaging material suppliers need to be capacitated to handle fruit quality issues satisfactorily to avoid unnecessary fruit and fruit quality losses. Incompetency within any link in the chain, especially the current transport problem, will add to costs. The government needs to address infrastructural capacities, transport and harbours or ports efficiencies in order to smooth the flow of fruit exports to destination market. This will also reduce high transaction costs incurred which in turn improves profit margins. There is great need for government support for citrus producers engaged in export as they are faced with unfair competition from heavily subsidised northern hemisphere rivals and protected markets.

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CASE STUDY

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Why try Lean? A Northumbrian Farm case study

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ABSTRACT
The purpose of this research paper is to evaluate the applicability and potential benefits of Lean Principles to a farm business. This research opted for a case study research strategy that is implemented through in-depth personal interviews with different actors along the supply chain. This is augmented by further data collection from experts in the field of Lean. Using the Five Principles of Lean, Value Stream Mapping and the Seven Wastes this study suggests that there are benefits from applying Lean Principles to a farm business in terms of reducing waste and improving the quality of food supply. The present study makes a contribution to the validity of Lean principles when applied to an agribusiness context.

KEYWORDS: Five Principles of Lean; Farm business; Value Stream Mapping; United Kingdom; Efficiency; Effectiveness

1. Introduction

Lean is a production practice that aims to minimise waste along entire Value Streams and create more value for customers (Womack and Jones, 2003).

"Working from the perspective of the customer who consumes a product or service, 'value' is defined as any action or process that a customer would be willing to pay for." (Wikipedia, 2013).

Therefore, any use of resources that does not deliver consumer value is a target for change or elimination. This management philosophy has mainly been applied in manufacturing, notably in Toyota, and the Toyota Production System, from where Lean originates. The core usefulness and uniqueness of Lean lies in the scope that it covers by examining in one map all factors of production (Womack and Jones, 2003). The core analytical tools of Lean have also been widely applied in non-manufacturing areas (e.g. the NHS). For a farm this includes land, labour, machinery, buildings, variable inputs, time, financial performance, degree of value creation and produce quality attainment.

Lean is now viewed as a way of looking at any activity by breaking it down into process steps and removing waste at each step. A key point is to see each process step as part of a Value Stream and look for the value generated by that process and optimise that value across the whole Value Stream, making sure not to review any individual process in isolation from the whole.

The Toyota Production System was crystallised into the Five Principles of Lean (Table 1), as a method to identify value and eliminate waste.

The above principles served as the overarching discipline, followed and deployed in this study.

The Food Chain Centre in 2003-2007 applied Lean concepts to agri-food chains. These studies used Value Stream Mapping, Value Chain Analysis and Benchmarking to explore the potential of these techniques/concepts in delivering commercial benefits for the milk, red meat, grain and fresh produce industries (FCC, 2007). However, none of these projects applied Value Stream Mapping to a working farm. Moreover, there has been limited research looking at the relationship of farm gate quality of produce to consumer values. This paper has addressed some of these gaps.

Economies of scale, better equipment and smaller work forces have allowed many farmers to become more efficient. Efficiency gains have traditionally been measured focusing on one or more aspects of a given system such as gross margin per hectare, kg daily live-weight gain or field operation efficiencies. Lean thinking, on the contrary, proposes a holistic approach that integrates many of these measures and combines them to evaluate the impact of each decision on the 'whole' enterprise. For example, while assessing the impact of buying fertilisers on the basis of price, Lean would not only look at cost issues but also at the effect on the rest of the Value Stream within the enterprise (Cunningham and Fiume, 2003). Consequently, a Lean approach would assess the effect of buying a low grade fertiliser on quality, cost and income. The focus of Lean methods is on assessing the value adding of a task or input. It argues that a continuous focus on the attainment of product (beef/grain/milk) quality is the true measure of an effective farm process and not that of efficiency or yield alone. Lean is therefore both a method to analyse process efficiency and process effectiveness in delivering products. In order to assess the potential of using Lean, this study applied, between 2009 and 2011, Value

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Table 1: Five Principles of Lean (Womack and Jones, 2003)

Value	Specify value as demanded and defined by the ultimate customer
Value Stream	Mapping all design, physical production and information actions involved in producing and delivering the product values identified. Identify any non-value adding activity to remove. Ideally should involve 'entire value chain' i.e. complete supply chain.
Flow	Make remaining value adding actions and processes flow continuously, (without hold-ups) towards end demand.
Pull	Produce only what is pulled (demanded) by the end customer, attempt to eliminate as much inventory stocks as possible.

Stream Mapping to all production activities carried out on a lowland combinable crop and beef breeding farm in the north of England.

2. The case study farm and method

This study applies the case study method as the main research tool to address the objectives of this research.

The selected case study is a family-owned lowland mixed farm in Northumberland. It has the following enterprises: winter cereals, oats for porridge, wheat for biscuit, oil seed rape for cooking oil and barley for malting and the beer market. It also has a pedigree Saler beef herd for breeding and beef. The land is ring fenced and the farm yard is centrally located. The land has high yield potential. In the beef enterprise all young stock are taken to beef and breeding purposes, males as bulls finished at 15 months and heifers taken to beef or sold as bulling animals. The arable machinery policy is self contained with almost all operations being conducted in-house. Agronomy management is guided by an Agronomist and the Farm Manager's experience. There is one full time member of staff alongside the Farm Manager and the Principal of the business. Part time staff are taken on by the farm for harvest and planting operations

To acquire financial information, a technique advised by Newcastle University was followed to allocate costs and income to the farm herd and crops and to identify fixed costs. Value Stream Mapping was applied at the whole profit centre (herd and crop) level to measure the value adding nature of processes on the farm. The maps included the time taken to perform each task, total cycle time, labour used, machinery used, land allocation, variable inputs, staff skill and produce yield and quality.

Brainstorming with technical experts in the field of Lean, arable and beef was performed to identify the underlying drivers of value creation within the farm and provide perspective of the value adding nature of farm processes. Based on the results of the brainstorming sessions, areas for improvement were identified and plans proposed to improve enterprise performance. These plans were worked through to show the impact on process time, quality of output, cost and income and the feasibility of execution.

Lean asserts that all actions across the food supply chain should be focused on delivering consumer value. Consequently, the farmer as a supplier of agricultural raw material constitutes an important link in the food chain to achieve consumer value. This study has focused on quality parameters of grain and beef and their relationship with final consumer value demands. Walking of the Value Stream (Womack and Jones, 2003) was undertaken through interviewing all customers upstream and downstream from the business to identify if farm produce quality specifications demanded by each supply chain company were related to, and aligned with delivering a tangible final consumer value.

3. Current State Value Stream Mapping of the farm enterprise

The present study creates a Value Stream Map incorporating all tasks, inputs and processes for each profit centre on the farm. It is important to recognise that mapping the Value Stream must consider the crop or herd as a whole. This allows the Farmer to calculate the total processing time and cycle time for crop or herd and importantly the separation and allocation of fixed resources and labour to each farming activity. The 'Current-State-Map' (see Figure 3 in results) follows the manufacturing process from start (at the farm) to finish.

This study follows the methodology recommended by Womack and Jones (2003) to record all aspects within a business at the profit centre and process level to create the 'Current State Value Stream Map'.

Table 2 and Table 3 show the data that was recorded for this study.

From this data key measures used in Lean can be calculated (Table 4)

4. Identifying waste through the Value Adding analysis and the Seven Wastes

Each farm enterprise was analysed in terms of the Seven Wastes (Table 5), e.g. in terms of inaccurate resource allocation, the amount of farm product outside contract specification, or unnecessary conveyance. E.g. on the case study farm it was decided to relocate the fertiliser store to minimise conveyance and increase spreading output.

Value Stream Analysis argues that there are different actions occurring along the Value Stream and should be assessed in terms of their cost and value creation (Womack and Jones, 2003). For instance, there are steps such as planting the seed to grow a crop that are essential and Value Adding (VA). There are other processes that do not directly create value but are unavoidable. These are termed Necessary and Non Value Adding (NNVA.) An example of NNVA in agri-food chains would be multiple sampling of grain to

Table 2: Process Specific Data Collection

Name of process, e.g. feeding of bulls or T3 fungicide on wheat.
Labour, which member of staff involved.
Variable input quantity, i.e. seeds, fertiliser, sprays, feed used in the process.
Time taken from start of task to completion in hours.
Machinery used
Breakdowns or failures in process.
Amount of time in process not spent doing the task itself, e.g. transport fertiliser long distances before actually applying it. Conveyance time is calculated as separate to the application of the product.

Table 3: Profit Centre (Crop / Herd) Specific Data Collection

The amount of land used in the enterprise.
The total amount of processing time involved (by adding together task completion times)
The total cycle time, i.e. the time from the start of production to finish, e.g. ordering of seed to sale of harvested grain.
The total amount of seed, feed, fertiliser, fuel ordered and used.
Produce Quality inspection points.
The whole enterprise quality of product output against contract requirements in percentage terms.
Financial performance i.e. the gross margin of the enterprise.

Table 4: Key to Measures Used In Lean

Cycle Time (hr) = Total time from start of production cycle to point of sale and delivery.
Total Processing Time = Sum of all Individual process completion time.
Gross Margin per Hour = Enterprise Gross Margin / Total Processing Time (in hours)
Gross Margin after Labour = Gross Margin per Hour–Hourly Wage Rate

assess quality at each step of the chain, each handling the same information but common practice due to business structures and 'due-diligence' (FCC, 2003). Finally, a Non Value Adding (NVA) action is where a process or input is not required to make the product and therefore it should be eliminated.

5. Results of the case study

Identifying consumer value from supply chain interviews

The results of this study indicate that many grain quality parameters and beef carcase traits are primarily related to factory process efficiency and output. For example, high bushel weight and low ad-mix in grains allowed for higher factory yield and less waste in an oat processing facility. Similarly, optimum beef carcase conformation and fat grading ensures higher value cut quantity and minimises carcase trimming to efficiently suit pack size and beef fat level required by the final consumer. Therefore, these gains in processing efficiency could allow bringing cheaper products to the consumer. In order for this to happen, the savings in processing costs and higher factory yield must be passed on to the consumer.

Summarising, the application of Lean methods to the selected farm would allow for consumer value creation as Lean thinking would suggest (see Figure 1A/1B and Figure 2).

Consumer value knowledge is then used to appraise the efficiency and effectiveness of the farm business, systems, processes and inputs in delivering the consumer values identified.

Mapping the value stream, value adding and waste analysis

Overall profit centre value stream map

The crop or herd specific data gathered was used to create a 'Current State Value Stream Map'. All processes involved in the growing of the wheat crop (Figure 3) are shown alongside the total time taken to perform the process and the staff member involved. The quality of output is also shown. This map is the first step in analysing consumer value generation, namely to appraise the overall farming system deployed and to identify if process steps are complimentary to each other or in conflict to generating value. E.g. Drill output is limited by plough output, or seed order is too late to achieve early drilling, or labour assigned to a job could be improved through operator change or training. When

Table 5: The Seven Wastes of The TPS and an eighth waste (Liker, 2004)

1. Overproduction	Production for which there are no orders, wasting of resources and employees time.
2. Waiting (time on hand)	Employee down time due to delays in process. Capacity bottlenecks, processing delays, equipment downtime, lack of raw materials.
3. Unnecessary transport or conveyance	Carrying work in process (WIP) long distances, creating inefficient transport, or moving materials, parts or finished goods into or out of storage or between processes
4. Over processing or incorrect processing	Taking unneeded steps to process parts. Inefficiently processing causing unnecessary motion and producing defects. Waste is generated when providing higher-quality products than is necessary.
5. Excess inventory	Excess raw material, WIP, or finished goods causing longer lead times, obsolescence, damaged goods, transportation and storage costs, and delay. Also extra inventory hides problems such as production imbalances, late deliveries from suppliers, defects, equipment downtime, and long set-up times.
6. Unnecessary movement	Any wasted motion employees have to perform during the course of their work, such as looking for, reaching for, or stacking parts, tools etc. Also walking is waste.
7. Defects	Production of defective parts or correction. Repair or rework, scrap, replacement production, and inspection mean wasteful handling, time, and effort.
8. Unused employee creativity (Liker 2004)	Losing time, ideas, skills, improvements, and learning opportunities by not engaging or listening to your employees.

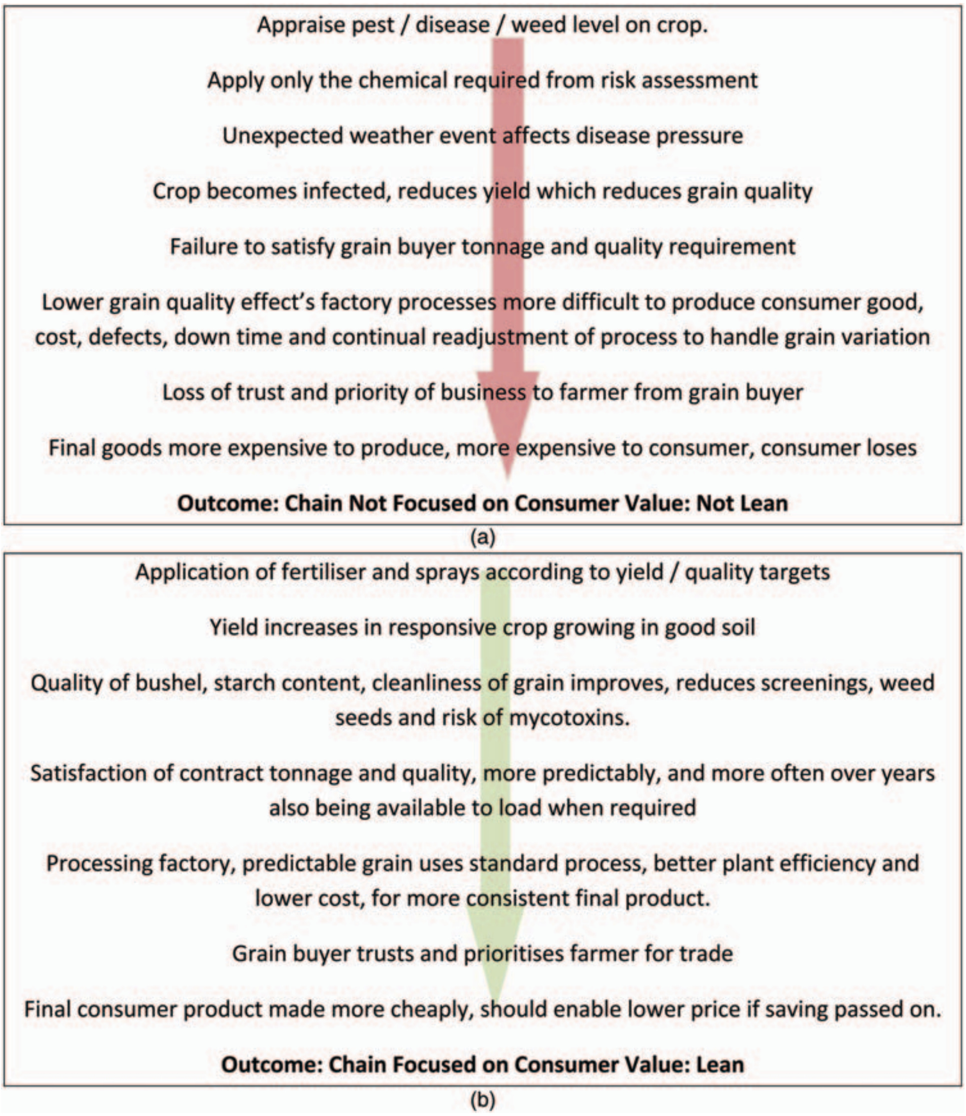

Figure 1A: Possible Chain Reaction of On-Farm Practice Effects on Consumer Value: Thresholds only to Guide Arable Inputs
Figure 1B: Possible Chain Reaction of on Farm Practice Effects on Consumer Value: Robust Programme

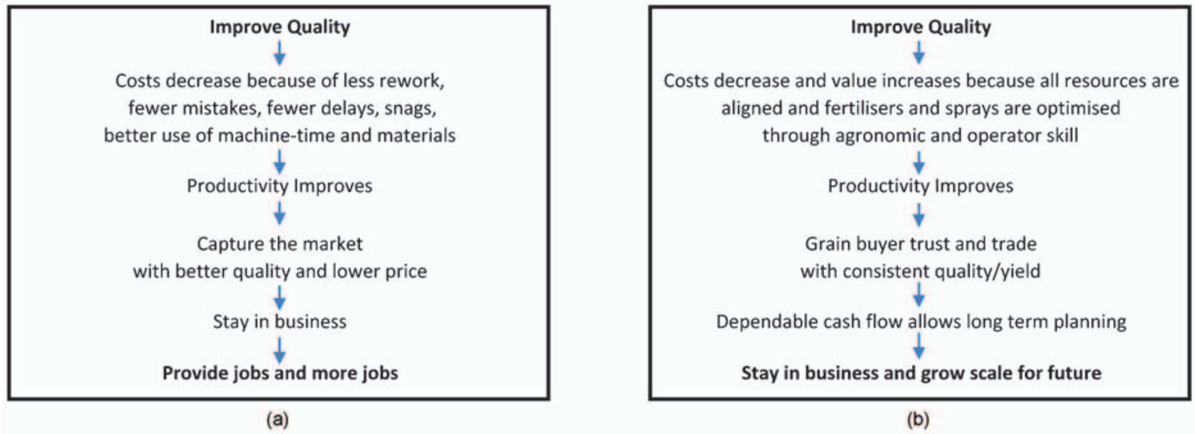

Figure 2A: Japanese Manufacturing (Deming, 1982)
Figure 2B: Lean Farm Philosophy

this map is used in conjunction with the gross margin and process specific data, the detailed 'Value Adding' analysis can take place.

Furthermore, mapping at the level of one crop or herd within the business allows the farmer to question the suitability of capital item allocation such as land, labour (men / skill), machinery and buildings, in order to evaluate efficiency and effectiveness by asking;

1. Is the produce quality and yield meeting consumer demand and value requirements? (Value as defined through customer interview and market intelligence). If not should the business cease or change?

2. Should there be a change of market outlet to increase product value?

3. Has there been accurate budgeting of fixed resources to the business?

4. Has the mix of capital deployed been successful in delivering consistent quality / value / yield?

5. Should there be a change in machinery policy to achieve better crops?

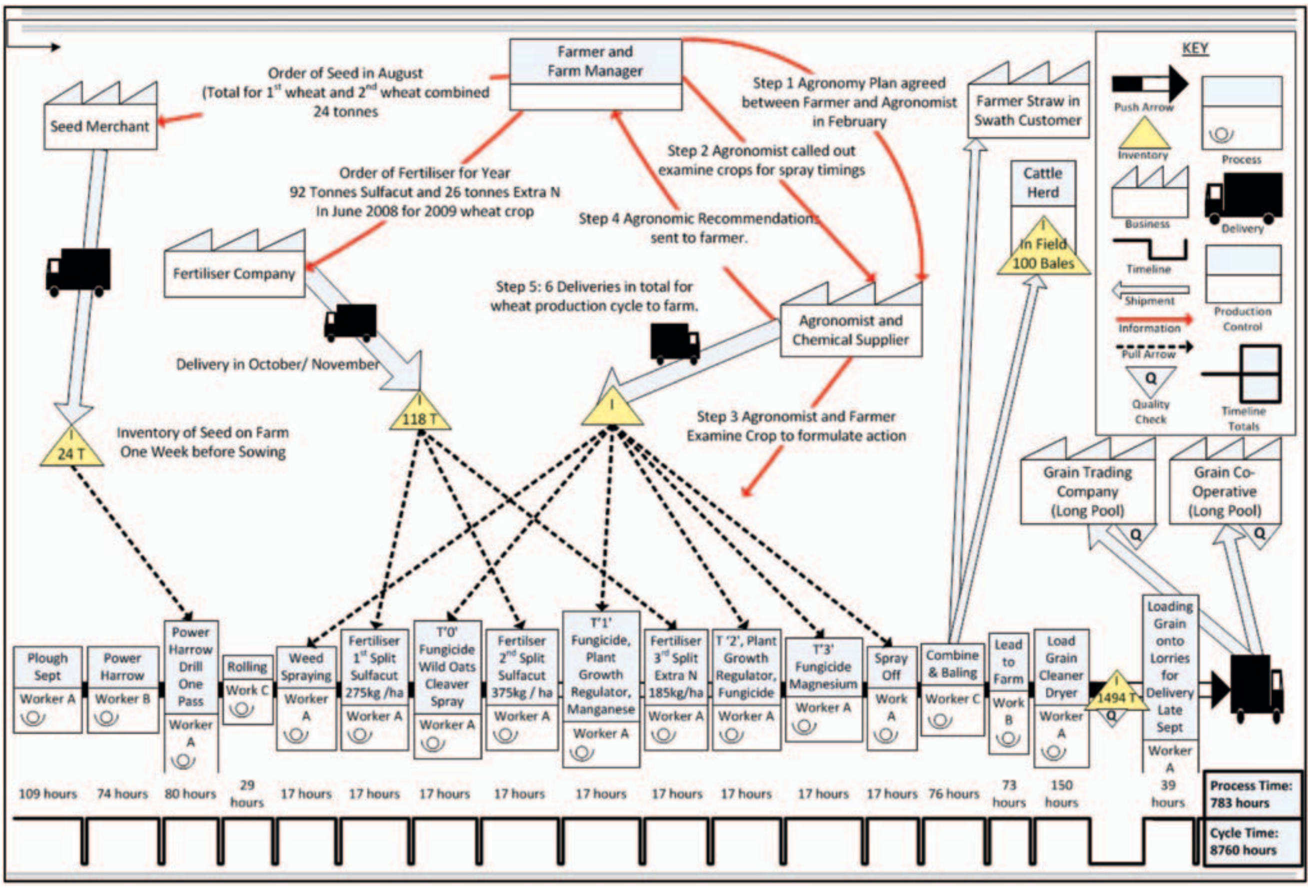

Figure 3: Value Stream Current State Map for Wheat Crop 2009, 100% biscuit quality

Table 6: Wheat Enterprise Process Waste and Value Appraisal from Brainstorm Example

Raw Material Inputs	Rate	Purpose	Growth Stage	VA	NVA	NNVA	Comment
Consort Seed	1st wheat 173kg/ha	Plant seed for new crop	1st-2nd week September	✓			no seed no crop is needed, rates could maybe be reduced
Consort Seed	2nd Wheat 183kg/ha	Plant seed for new crop (latitude treatment)	Last few days Sept / start Oct	✓			no seed no crop is needed, rates could maybe be reduced
Alpha Pendimethalin	3 l/ha	grass and broadleaf weed control	12 (2 leaves)			✓	reduced value adding if low weeds could rely on grain cleaner instead of weed killer
Moddus	0.1 l/ha	plant growth regulator	20/25 (tillering) (T0)		✓		high plant count from seed rate used = no need for Moddus tillering
Topik	0.075 l/ha	wild oat herbicide	20/25 (tillering) (T0)	✓			wild oat control essential for yield and quality high crop equivalent
Abacus	0.5 l/ha	non-ionic wetter	20/25 (tillering) (T0)	✓			needed to make best use of Topik

6. Are employee ability / skill suitable for the task?
7. Is there a bottleneck to flow of product through the system? (E.g. machinery work-rates)
8. Can there be a reduction in cycle and process time while maintaining product quality?

Analysing at this overarching business level addresses the first four of the Five Principles of Lean; Value, Value Stream, Flow and Pull and begins the perfection process.

Perfection can also be addressed by changing the overall system simply by optimising the first Four Principles to ensure maximum value potential is embedded to the farm.

However, ongoing Perfection through continuous process improvement is maintained and achieved by setting of efficiency and effectiveness Key Performance Indicators (KPIs) at the process level on a job by job or daily basis to maximise value delivery. This belongs more closely at the process, chemical or feed input level itself. This is because it entails 'perfecting' an existing farm system. The overall farming system itself has to be right in the first instance and is achieved by examining the business model closely through the first four principles contained within Value Stream Mapping.

Process specific data

The Value Stream map is accompanied by Data Sheets containing the 'Process Specific Data', Value Adding Assessments and crop or herd Gross Margin (Tables 6 and 7).

The method used to initially appraise the Value Adding nature of farm resources and inputs was performed by brainstorming with technical experts in beef, arable and Lean. The appropriate Value Adding Status (VA, NNVA or NVA) was then granted to the specific process, resource, technique or input. This accompanied by a comment to show justification for the Value Adding status granted, (Table 6 and 7).

At this point the farmer can calculate the gross margin per labour hour by taking the total gross margin from the data sheet and dividing by the total number of process hours (Process Time) from the 'Value Stream Map'.

Areas of waste and value issues identified from the value stream maps and data sheets

Results indicate that there is scope for Lean improvement centred on changing market outlets and more efficient allocation and utilisation of fixed cost resources, such as land, labour skill, machinery and buildings to add value, I.e. changes to the overall farming system.

The study experts also identified that variable inputs such as fertiliser, sprays and feeding are crucial to realise the yield and quality potential of land and genetics i.e. consistent value adding (VA). This is not to approve the overuse of chemicals and fertilisers, rather the more judicious value orientated use, as environmental protection is also a consumer value that the farmer has to balance and provide.

Maximising the degree of value generation of fertiliser, feed, seeds and sprays are important to realise the value potential by any farming system and are managed through accurate budgeting, cost / benefit risk

Table 7: Labour, Machinery Use, Total Task Completion Rate, Waste and Value Appraisal

Staff	Tractor	Implement	Total Time Rate	VA	NVA	NNVA	Comment
Worker B	JD 6910	New Holland 650 Round Baler	1.6 ha/ha	✓			value adding, fertiliser value and straw price trade off however
Farmer	JCB Loadall	Drying limited by dryer flow and outlet	10 tonnes /hr			✓	separate grain quality, reduce overtime work with larger hopper
Any Staff	JCB Loadall	Loading Lorries for Delivery of Grain to off-farm	29 tonnes/ 45 mins			✓	bigger bucket, more automation, possibly conveyer fill lorries

assessments, proficient application methods and setting KPIs to plan work timings and techniques to monitor performance.

Pedigree Saler beef herd

The data collected in this process suggested that:

1. Opportunity to sell more heifers for breeding not beef, (Bulling Heifer Customer Interview).

2. Change in market outlet gives an opportunity to sell more heifers as bulling animals at 15 months of age as opposed to 18 months for beef. This policy shortens the keep (cycle) time of the females at a competitive pricing point, compared to keeping longer and selling for beef. Shortening the cycle time will free up grazing, fodder and shed capacity to keep more breeding cows, or, reduce grassland requirements by 5%. This has the potential to increase gross margin per labour hour and per hectare.

3. There is excess capacity in terms of too much grassland allocated to the herd. Potential to plough up 30% of grassland for the arable enterprise. This will align resources more accurately and further increase gross margin per hectare.

4. There is a need to focus on maintaining and improving genetics through considering the use of Estimated Breeding Value's or using cattle weighing records linked to dam to assist in replacement selection and to ensure feed resources are efficiently processed through the animal to achieve target selling dates and maximum gross margin.

5. There is an opportunity to finish bulls 1-2 months faster at 13-14 months to the same slaughter weight by introducing full meal diet earlier after weaning. Therefore reducing meal demands by 9 ton.

Arable

The data collected in this process suggested that:

1. Marketing was an area in need of improvement based on Benchmark data. Short term grain storage limited autonomy by the farmer to make independent grain marketing choices. Grain is end user ready at the farm level, so end user sale options could be explored. Therefore consumer market intelligence for beer, porridge, biscuit and cooking oil should be obtained and frequently updated.

2. Grain quality assessment post-harvest in shed occurred too late to segregate and allocate more effectively to end user requirements.

3. BASIS and FACTs agronomy training would be needed by the Farm Manager to better understand integrated crop management techniques to protect crop quality and yield against variable weather and agronomic conditions and to maximise value.

4. Inefficiencies were identified in the drying, grain conditioning and combining process. These were generated by bottle necks arising from: the intake due to a small hopper, too small a grain bucket and insufficient combine capacity.

6. Future state mapping business improvements and effect of implementing Lean

In order to address identified areas for improvement a plan was drawn up to show the net effect of implementation, in terms of cost, time (process and cycle time) and income. Tables 8 and 9 show the livestock Lean plan.

Note that use of time in Value Stream Mapping allows for the calculation of Gross Margin per Labour Hour. Examples of Lean implementation effect within the arable crops are also listed.

Example of arable results

1. Land freed up from the herd allocation has increased the arable area by 7%.

2. More automated drying plant, larger bucket and intake hopper has delivered 48 hours of labour time saving per harvest.

3. Relocation of fertiliser store has realised 20 hours of process time saving through avoiding unnecessary conveyance.

4. Planned storage of 900t grain in freed-up building (due to reduced cattle housing needs) will deliver storage charge savings. The upgrading of building and plant cost show the potential to be paid back through storage charge savings alone in 4 years.

5. Earlier biscuit wheat quality assessment is being examined in conjunction with research partners. The aim to have combine mounted protein sensors for harvest segregation of grain according to protein for

Table 8: Potential Financial and Time Effects of Plans on Beef Herd Current State

	Cycle Time (hrs)	Process Time (hrs)	Total Variable Cost as % to show change	Total Output Sales as % to show change
Current State	Heifer 13,800 Bull 10,920	1,198	100%	100%
Quad / in shed		0	+0.6%	
Improve stocking density calculations and plough up 30% grassland for arable				Creates greater beef output per hectare through intensification
Diet (introduce meal earlier to bulls)		- 16 hours	- 8%	
Selling heifers sooner bulling, not beef	minus 5,040	-44 hours	-2.6%	Releases 5% grass and one shed for arable
Selling bulls sooner	minus 720	-20 hours		
Future State	Heifer 8,760 Bull10,200	1,118	90%	100%
Net Change	Heifer -5,040 Bull- 720	-80	- 10%	

Table 9: Potential future state beef herd gross margin increases (in % terms)

Potential % Increases in Beef Herd Gross Margins			
Total Herd	Per hectare	Per process hour	Per hour after labour cost
24%	116%	23%	60%

segregated storage and drying. This will allow consistent delivery of quality to buyers. Ultimately the field protein maps to help guide nitrogen policy to improve the consistency of delivering the desired grain quality parameters in a field by field basis.

6. Staff training has allowed each member to be skilled in all tasks, so preventing over reliance on any one person in particular. FACTS and BASIS training has allowed the farm manager to more precisely manage the agronomy and ensure greater focus on value adding and waste reduction.

Managing processes for consumer value effectiveness and efficient resource utilisation

The following are some examples of management that have been implemented at the process level to ensure daily operations realise the value potential of the new farming system. A key benefit is it empowers management with a simple method to ensure the new Lean farm system is on track.

Pedigree Saler beef herd

1. Forward purchasing of feed to achieve target daily feed cost, if necessary.
2. Use of efficiency KPIs in the weighing of cattle to identify if daily live weight gains are on target to meet target weights for heifers and bulls at weaning, mid winter, spring and selling age.
3. Use of efficiency KPIs for target feed intakes, accurate weighing of feed over winter, reduce feed losses in feeding process e.g. spillages. This data then works out the actual cost per kg of live weight gain, against target cost.
4. An effectiveness KPI for systematic inspection of bulling heifers with alternating vehicles; quad, land-rover and on foot to optimise temperament post sale for the customer in a new farm environment. To make the heifers 'Hill Farm Ready' and increase customer satisfaction.
5. Bulling period 6 weeks for heifers, 9 weeks for cows.
6. Semen test and trim bulls feet 1-2 months before each mating season.
7. In tightening stocking rates, sward improvement and more frequent applications of fertiliser adopted to maintain grass supply.
8. Rotational grazing in three blocks to extract extra grassland utilisation.
9. All bulling heifers and fat bulls to be sold by end of May every year, to ensure that the grass budget is met.

Arable

1. Quality assessments of grain before movement off farm and for every load off farm, linked to the field where it was grown.
2. Consideration of other inputs in the Value Stream for example, timings of fertiliser, soil fertility and plant density from seed rate before deciding on the need for growth regulators. (Hence the benefit of Value Stream Mapping)
3. Use of agronomic response curves (cost/benefit), crop equivalence, and timing for weeds and thresholds for pests are used to guide product need, choice and quantity.
4. An effectiveness lead purchase policy for pesticides based on budget price and quality of ingredients, i.e. brand names that ensure robust chemical suspension in mixture (i.e. chemical not settling out). This ensures

correct crop coverage, reduces scorch and increases yield value adding potential.

5. Attempt to apply inputs in optimum weather and soil conditions e.g. fertilizer to reduce losses through the nitrogen cycle, and pesticides to optimise crop coverage, reduce drift and evaporation or run off. To avoid the 'not-as-value adding' application days.

6. Use of efficiency KPIs to maintain target daily harvesting and cultivation work rates to meet target drilling dates.

7. All straw, except for beef herd need, incorporated to the soil, reduces cycle and process time and ensure more-timely drilling.

8. Matching of fertiliser and fungicide rates to fulfil the genetic yield and quality potential of varieties and the yield potential of the soil.

9. Soil maintenance of indices, organic matter and use of low compaction equipment.

Five principles of Lean in context of the case study farm

The majority of tangible effects on the case study farm that made the largest step change in output and time benefits arose from correctly implementing the first Four Principles of Lean

7. Conclusions

Lean may offer an opportunity for British farmers to increase their level of competitiveness by reducing waste and improving the quality of food supply. This strategy may certainly allow farmers to differentiate their produce within the supply chain. However, for Lean to be successfully applied farmers need to be acquainted with the principles of Lean. Farmers may be able to bring in the required skills through a new manager or consultants although this would also represent an extra cost for them.

Table 10: Five Principles of Lean in a Farming Context

Principle	On Farm Case Study Example	Tangible Effect on Case Study Farm
Value	• Change of selling technique through grain forward selling. • Selling heifers for breeding not beef.	Selling forward embeds value (hence the degree of value that can be added by the inputs). Breeding heifer selling increased sale price 25% per animal compared to beef (2012)
Value Stream	• Removal of duplication and shortening cycle times. • Accurate budgeting of land, labour, machinery and buildings. • Focus on ensuring complimentary effect of process steps, e.g. effect of seed rate on crop canopy therefore need for growth regulator.	More accurate grass budgeting and change of heifer market destination has released 30% of grassland to arable cropping with no reduction in cow numbers. Saving of 9 tonnes of concentrates through earlier bull finishing. Reduction in beef herd cycle time of 5000 hours.
Flow	• Aligning machinery capacities to reduce processing time. • Matching labour skill to a task to achieve 'right first time' and reduce rework, and therefore process time. (e.g. re-drilling a crop). • Shortening cycle times also reduces process times.	Saving in whole farm process time of over 200 hours per year, equivalent to 25- working days of 8 hours. Saving in process time has reduced overtime hours and facilitated improved timeliness of crop and herd processes to underpin optimum value generation.
Pull	• Keep in touch with supply demand forecasts for each value stream. Reports of the ultimate consumer market intelligence are e-mailed, e.g. Dunhumby Data, or Trade Journals. • Farmer has established key network contacts in product value stream. • In order change crop grown to meet a predicted shortage, or delay signing a contract to maximize grain price, or when to store or sell.	Avoided low prices e.g. for oat crop added 40% to the price per tonne, through taking notice of final customer supply and demand market intelligence and taking the decision not to sell and wait.
Perfection	• Reviewing and implementing of the previous four principles. • Maximise crop value generation effectiveness by pesticide and fertilizer inputs by using response curves in conjunction with spreading technique and weather / soil conditions to aid timeliness and choice of chemical applications. • Set effectiveness KPIs for produce quality attainment e.g. heifer temperament or grain protein and efficiency KPIs for target growth rates/feed intake or field work rates.	All crop harvested and planted in 2012 in adverse weather conditions through benefits of reduced processing time demands and maintaining target daily work rates. 100% of all bulling heifers last year on spec on time for early sale and sold from 50% 80% of bulls in U /R grade in at target slaughter age / weight from 60%.

Summary of the benefits of Lean and Value Stream Mapping to a working farm

1. Value Stream Mapping offers a step by step method for a farmer to review his/her business in its current functional reality, to identify value generation and waste.

2. Correctly implementing the first Four Principles of Lean to improve the overall farming system deployed in line with the most profitable market outlets can provide a step change in efficiency, farm output and the consistency of product quality.

3. Value Stream Mapping focuses on the generation and delivery of consumer value by all production factors this aids root cause analysis of poor product quality by guiding the farmer to identify links between farm process and product quality. Customer interviews explore the link between farm produce qualities to consumer value. This serves to align farm activity to consumer satisfaction across the supply chain.

4. All enterprise factors of production, physical, financial and human resource are encompassed in one map for ease of visual analysis. It offers a gross margin per labour hour, assists in the reviewing and budgeting of fixed resource allocation and helps identify bottlenecks to flow of farm operations, such as machinery capacities.

5. Shortening the Cycle and Process time of an enterprise reduces resource demand and cost and this has potential to improve profitability. This facilitates the releasing of resources for further enterprise intensification or alternative use. The resulting savings in labour time reduce the overtime hours and improve staff quality of work through less fatigue.

6. Once the farming system has been structured for optimum value through the first Four Principles of Lean. The Fifth Principle Perfection can be managed through the use of efficiency and effectiveness process techniques which help the farmer to optimise the conditions for maximum value generation of each farm process. In turn, using KPIs offer a pro-active daily management method to measure the delivery of consistent product quality and the utilisation of resources allocated to ensure targets are being met.

Value Stream Mapping also serves as a method to appraise the introduction and potential impact of a new system to a farm. E.g. A farmer may decide to trial minimum tillage equipment; the Value Stream Map will help calculate the extra fixed costs, savings in time and fuel, cost of extra herbicide, effectiveness of crop establishment and staff training incurred by switching from a plough based system. This demonstrates the all encompassing nature of Value Stream Mapping and therefore the value of Lean techniques in strategic farm planning as well as for farm business review.

Difficulties encountered in applying Lean to farming

A central problem with the implementation of Lean is in calculating the financial value that is being added by a process or input. For example, yield increase from fertiliser is influenced by other practices such as the use of fungicides which enhance yield. The method used–in this study - to understand the value adding nature of inputs was to engage with industry experts who looked at each input step by step and assisted in the allocation of appropriate VA, NVA or NNVA status.

However, maximising the value generation potential by each agronomic or feed input is addressed by following precise process management using KPIs to monitor process success for each enterprise, such as understanding the cost benefit response curves for inputs or measuring the cost per kg of daily live weight gain.

Therefore, it is the cumulative value generation of the whole system in terms of optimum market orientation, consumer satisfaction, resource allocation, and lastly utilisation through using KPIs that is important.

Staff training is critical to drive home the importance of careful working practice, which can ensure produce quality and minimise breakdowns. As described on the case study farm, the Farm Manager has worked with staff to perfect working practices by focusing on the relationship to enterprise performance with a 'right first time' discipline while introducing more refined process management.

Other farms, sustainable intensification and food waste

'Feeding 9 billion people by 2050 with less resources' (Beddington, 2009) is a topic of concern for the farming community and society in general. Although Lean is not the sole answer to this challenge, it can ensure a focus on efficient resource utilisation while protecting product quality. Improving consistency of product quality delivery by agriculture can also give considerable efficiency savings to the supply chain and ultimately the consumer, through greater grain or meat processing factory yield and less logistical waste: For example, less grain lorries being re-directed back to the farm or alternative buyers because grain is not up to specification at the factory or grain store. Farmers therefore need to focus more closely on knowing the quality of produce before it leaves the farm.

Combining the Lean efficiency and quality effectiveness gains as demonstrated on the case study farm in beef and cereals could be extended to good effect to other similar farms as a model to analyse and improve farm performance.

Furthermore as a postscript, the recent report (Global Food: Waste Not, Want Not) by the Institute of Mechanical Engineers (IME) states that

"It is Estimated that 30-50% (or 1.2-2 billion tonnes of all food produced on the planet is lost before reaching a human stomach" (IME 2013)

Particularly waste at the value stream business interface level, (30% loss between food supply chain companies (Institute of Grocery Distribution (IGD) 2011) calls for efficient and effective utilisation of natural resources and focus on solutions to minimise whole chain food losses alongside better flow rate of produce in aligning supply and demand along the value stream.

If 2 billion tonnes of food could be utilised to feed people, this could help cap rises in food inflation.

Lean principles are certainly equipped in part to address this challenge, if implemented across supply chain companies and consumers in a co-ordinated fashion.

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BOOK REVIEW

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Agribusiness management

Freddie Barnard, Jay Akridge, Frank Dooley, John Foltz

Fourth edition, published 2012 by Routledge,130 Milton Park, Abingdon, Oxon OX14 4SB, UK. (www.routledge.com). ISBN: 978-0-415-59696-1 (paperback). Price £45, $US85, 460 pages, 52 tables and figures. E-book, ISBN: 978-0-203-12418-5 (£45).

This is a generalist text designed for a wide readership including instructors and their students but also manager practitioners. It attempts to bring together all the functional areas of management as well as both day-to-day and strategic perspectives. Whilst it suggests that it is suitable for an advanced academic course, the relatively small number of references cited are mainly statistical sources, other textbooks or limited to a few key authors, thus it is probably best treated as a very comprehensive overview with an all-encompassing scope of topic. From a practitioner's perspective (without the benefit of university education and/or the need to provide citations) many of the theories/techniques described, however, could be considered more as 'advanced' than basic, and whilst most are not given more than a couple of paragraphs each, there is comprehensive coverage of the most relevant ideas, concepts and tools which might be recommended to agribusiness management. For those agribusiness people who might wish to be economic with their bookshelf space, this edition is good enough to provide an aide-memoir but may be insufficiently detailed for successful application in a practical scenario.

The current edition is, by account of the authors, not simply revised but an almost completely rewritten text designed to take account of the rapid changes in technology, connectivity and globalism in agribusiness since the third edition. On the first page of the main text, however, it refers to 'food and fiber production' but fails to recognise agriculture's increasing role in *fuel* markets. Similarly, from a European perspective, the multi-functional aspects of agriculture with respect to maintenance of landscape, wildlife, biodiversity and environmental sustainability are not well covered. The examples and statistics are largely centred on the USA. Whilst this is understandable (and the general principles are broadly valid on a global basis), others in the English-speaking world may find it necessary to supplement the text to demonstrate national variations in habits, processes and policy, and to provide adequate learner satisfaction. The tax and legal references and some of the terminology are also particular to America. Somewhat surprisingly, given the claim to take into account of globalism and the noted importance of U.S. agricultural productivity to global food supplies, there is scant consideration of fluctuations in global commodity markets, the effects of non-acceptance of GM in Europe, and other global environmental and consumer trends which may impact the value of commodities, both at home in the USA and for export.

Chapter 1 provides a good summary of the differentiating features of the agri-food industry in comparison with other industry, though it fails to mention the high dependence on bare land with unique physical, geographical and biochemical features in different areas. Chapter 7 provides a good coverage of different approaches to pricing. Chapter 11 contains a useful discussion about effective interest rates on borrowings and sources of finance though, as previously stated, there is little consideration of alternative terminology used in other parts of the English-speaking world (e.g. 'accounts receivable' in the USA is known as 'debt factoring' in the UK).

In this reviewer's opinion, the photographs are the most disappointing aspect of this book. The photos and their captions were at best unsophisticated and at worst unrelated to the text. Captions were often trite, superficial and condescending (e.g. 'Man and woman planning. Planning efforts should be forward thinking and directed towards specific goals'; photo showed middle aged couple in a field with a paper file). Sometimes the caption was interesting but the photo was little more than a vaguely related snapshot (e.g a man apparently looking at an indiscernible cherry in an orchard is used to illustrate the importance of accurately identifying each grower's crop for a cooperative – a problem requiring more than a quick glance at an individual fruit!). Another photograph of 'Landscaping' (two girls planting a tree in a housing estate) was used to illustrate 'Determining the optimal use of specific inputs is an important decision for agribusiness managers'. Equally it was difficult to see why wind turbines had been chosen to illustrate agribusiness marketing activities, or dairy cows to illustrate market segmentation. The overall effect of the photographic content and captioning is to distract and detract from the textual content rather than enhance it. It would often have been better to have had no captions, and in many cases, no photograph.

On the plus side this is a very useful text for American students studying agriculture at AAS level in community colleges and for first or second years in a Bachelor degree programme. It covers the scope and function of agribusiness management, and tries to take account of the variety of sizes, forms, and commercial activities of different parts of the food supply chain. It covers all the basic management functions of business (marketing, finance, operations and human resources) and provides contextual information through market statistics and an overview of current issues plus a basic guide to economic forces in the macroeconomic environment. It is written in an accessible style which should be easily comprehended. It provides a useful encyclopaedia but a more thorough discussion of the appropriateness of different policies and approaches for different firms of varying sizes within assorted parts of the food chain is beyond its scope. Thus it is less appropriate for more advanced levels of study. It provides answers to questions along the lines "what can I choose from?" but is less able to answer "how do I decide which I should choose?" It is a solid enough introductory text but, considering that the authors undertook a thorough rewrite, a greater consideration of international issues (including alternative terminologies, and the effects of different policy environments) was sadly lacking. Similarly the lack of attention to the pictorial content was an unnecessarily devaluing feature. For these reasons the sales of this book, unfortunately, may not reach their true potential, as it is more likely to be listed as recommended or additional reading (if at all) rather than required reading on courses outside the USA.

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The rise of illicit rural enterprise within the farming industry

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ABSTRACT
In this viewpoint article we seek to make the farming community aware of the increasing presence of organised criminals and crime within the farming community. In the past decade there has been a discernible rise in the level of organized criminality in rural areas especially in relation to farm crime across Britain and Europe. This has been reported in the media in many European States and is exacerbated by the financial crisis and by a lack of cooperation between member states and agencies.

KEYWORDS: Rural crime; policing; theft; organised crime

1. Introduction

Since the Rural Policing Act of 1839 (or Rural Constabularies Act), rural policing and in particular the rural police station has been an integral part of the framework of policing in Britain. In this viewpoint article, we discuss several inter-connected emerging trends which should be of concern to the rural and farming communities. Rural policing is a specialised and under-appreciated policing role which is increasingly under threat. There are three linked constituent parts relating to the demise of the rural police officer. This imminent danger can be ascribed to:

- the closure of rural police stations;
- a decrease in the number of police officers based in and operating from rural police stations;
- the reduction in training in rural matters for police officers.

All three of the above issues are obviously inter-connected and should be of interest to farmers. This situation is part of a longer term withdrawal of policing services in rural areas (Smith, 2010).

The imminent demise of the rural 'Bobby' and the closure of rural police stations both have potential consequences for farmers in terms of increasing crime levels. According to our research, between 2000 and 2012 over 1,000 police stations have been closed in the UK and many more have been placed on reduced opening hours. This can be viewed as a strategic and operational withdrawal from the current concept of rural policing. Indeed, the closures are significantly altering the rural landscape of policing. The closure of police stations impacts on the number of police officers actually policing the rural area and also impacts upon the loss of core rural policing skills. Our research reveals that rural community policing skills are not taught at the Scottish Police College, nor by the National Police Improvement Agency in England. The current financial recession in the UK has created political, financial and organisational pressures which have driven this spate of closures across the United Kingdom and Ireland. This slow and inexorable closure of rural police stations is worrying enough without taking into cognisance the potential for organized criminality in rural areas.

For example, in the same period, the landscapes of rural crime and criminality have also changed in that there has been a noticeable increase in the levels of the organisation of crime groups involved in committing rural crimes. Crime is becoming more organised and entrepreneurial as organised rural crime groups target or operate from rural areas are aware of and exploiting this gap. Both of these trends have unintended consequences in that they have created a set of circumstances which provide an increased opportunity for indigenous and international serious and organised crime groups with the capability of targeting rural areas.

A recent article by Sergi and Lavorgna (2012) on the expansion of the Italian Mafia into rural crimes such as the theft of farm machinery and tools, the theft of livestock, and into unregulated butchery practices, clearly evidences the danger that serious and organised crime groups can pose to rural areas when they seek to expand their criminal activities in the current economic recession.

Whilst there is no evidence that we are aware of that the Italian Mafia are routinely operating such practices in the UK, it does appear that indigenous UK and Eastern European organised crime groups are targeting the UK by stealing tractors and other items of heavy plant for resale in Europe and on the African subcontinent. In addition, there is evidence that British based organised crime groups are also becoming more organised and prolific at exploiting criminal opportunities that present themselves in rural areas. We therefore, examine and highlight the changing landscape of rural crime in a UK wide context to map and detail how it is changing as well

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Table 1: Criminal Opportunities

Rurality as a base for operations	In this scenario the urban criminal will use rural houses and buildings for the illicit production of various criminal commodities. Alternatively, they will use rural dwellings as safe houses and rural areas for illegal stashes. Also, in this group would be categorised the so called 'greenbelt bandit and settled criminals'.
Rurality as a criminal playscape	In this scenario, organised urban crime groups target the countryside for the purposes of poaching, hare-coursing, badger- baiting and dogfighting and similar activities
Rurality as a target market	In this scenario, both urban and rural based organised crime groups target the countryside to steal tractors, plant, farm machinery and tools, scrap metal, fuel and to engage in sheep and cattle rustling.

as drawing out practical issues which the farming, police intelligence community and policy makers can utilise in initiating future planning initiatives. The evidence for the practice of such rural criminal entrepreneurship is not immediately self evident unless one knows what one is looking for.

2. The changing nature of policing rural crime

According to recent figures released by the National Farmers Union (NFU Mutual) theft from farms in the UK has reached new levels, as the estimated cost of theft to UK agriculture tipped £52.7 million in 2011[3]. However, agri-crime and farm theft are but one feature of rural crime. Although serious and organised crime and the policing thereof are normally associated with being an urban phenomenon, rural areas present unique opportunities for the serious and organised criminal to exploit. To date, there have been few serious studies which have examined the changing nature of rural crime, criminality and policing.

It is necessary to articulate a few of the basic ideologies around which the policing of rurality is governed. It is generally regarded that:

- urban areas are the natural habitat for the serious and organised criminal;
- there is less crime in rural areas–known as the rural idyll thesis;
- the majority of rural crime is committed by urban criminals–known as urban marauder thesis;
- rural crime is somehow less serious than urban crime and therefore requires less of a policing presence.

Rural areas provide alternative criminal opportunities for the urban based organised crime group. The relationship between the urban based organised criminal and rurality forms part of their ongoing modus operandi as shown in Table 1:

The countryside can prove an attractive operating environment for organised criminal groups because there is less police surveillance and therefore less opportunity of being stopped and searched. Rural policing (where it exists) is organised around the policing of villages and as a general rule, local policing is not designed to interact with and patrol remote rural areas. As a result, urban criminals frequently own and use off road motorcycles and four wheel drive vehicles which can easily navigate off-road terrain.

Our perception of the rural criminal is a socially constructed one of the loveable rural rogue and small-time thief (Smith and McElwee, 2013). Consequently, little consideration is given to the existence of organised crime groups consisting of rogue farmers and other members of the rural community such as farm workers or anyone who has previous experience of farming who knowingly conspire to commit such crimes. Of interest is the concept of the 'Rogue Farmer' (Wiber, 1995; Smith, 2004; Heffernan, Nielsen, Thomson and Gunn, 2008; Smith, 2010; Smith, 2011 and Smith and McElwee, 2013) which we believe is a subject worthy of serious academic debate as well as being a subject of interest to the farming community. Moreover, Wilkinson, Craig and Gaus (2010) refer to the 'Exploitative Farmer' employing and exploiting migrant labour. We acknowledge and stress that this is a minority group within farming.

It is evident from our research that certain types of rural crime require the possession of rural social capital and a working knowledge of rural practices. For example, cattle and sheep rustling is one such crime which requires the complicity of criminals with a rural background. Knowledge of how to herd animals is a key skill as is ownership of a trained sheepdog and appropriate equipment. One also requires knowledge of the market for the resale of livestock. It is also evident that few urban crime groups would possess this type of knowledge. Although the existence of predatory urban crime gangs targeting rural areas is an established fact the existence of indigenous organised crime groups operating in rural areas, committing rural crime is less well known.

In the UK, there is no official definition of rural crime, nor any framework of how it should be recorded. Furthermore, in England and Wales, the Association of Chief Police Officers, have a portfolio for rural crime headed by a Chief Constable but its sister body in Scotland, do not. Furthermore, none of the other government agencies involved in the interdiction of rural crime have a working definition either. In investigating rural crime, there is inevitably scope of inertia and myopia in organisational matters which have the potential of being exploited by organised crime groups.

In an attempt to counteract this trend, there has been an increase in the implementation of innovative policing practices such as the introduction of Parish Constables; Rural Special constables; Village Bobby schemes; mobile police offices; the opening of temporary police stations in village halls and other community driven models such as farm, horse, shop and pub watches.

[3] In early June 2013, £1 was approximately equivalent to US$1.53 and €1.17

Some forces have pioneered the use of rural intelligence officers and rural community beat officers and the introduction of the wildlife crime officer has been a welcome innovation. However, such innovations are introduced piecemeal and the advantages are in danger of being lost due to the financial pressures brought about by the recession and the age of austerity.

3. The rise of the rural criminal enterprise

The National Farmers Union (Mutual Insurance) recently introduced an innovative scheme whereby it has sponsored two full-time police officers in its intelligence unit to tackle the rise in Tractor thefts. As a result of their work in 2011 the unit tracked down tractors stolen in the UK to Poland and Africa. In one high profile case, 'Operation Goldflake', five men including a businessman were arrested for the theft of tractors and mechanical diggers to the value of £500,000. These were exported to Turkey and Iraq. This is but one of many examples featured in the press.

Furthermore, our research has indicated that since the year 2000, there has been a rise in the incidence of rural criminal entrepreneurship. In particular, there has been an increase in the level of organised criminal activity centring upon food related crime. One such example is the Food Standard Agency's Operations Aberdeen and Fox into the fraudulent sale of thousands of tonnes of condemned meat into the food chain. So is the involvement of organized crime gangs in the theft of sheep and the illegal production of ''Smokies'' for the Halal Trade (Smith, 2004). Another example is involvement of organized crime groups in the illegal harvesting of shellfish and poaching. The 'Eurovet scandal' in which a businessman/farmer set up a company to import and sell unlicensed veterinary medicines earned the perpetrators between £6 and 13.5 million pounds (Smith & Whiting, 2013). Likewise, the so called 'Black Fish Scandal' in which a group of Scottish fishermen fraudulently entered undeclared fish into the food chain netted the culprits approximately £63 million pounds (Smith, 2012).

These cases are all connected conceptually as they relate to crimes which were not traditionally of concern to the police service *per se*. They are dealt with by various government agencies responsible for different parts of the legislative process. All of these crimes entail a multi-agency approach to deal with them and invariably all of them entailed the involvement of police officers in the joint investigations. Many of the accused in these high profile crimes are businesspeople or farmers who do not fit the typical profile of the urban organised criminal.

4. The need for a more organised response

Although the crimes discussed above may appear to be separate occurrences and individual activities, they point to an ongoing trend towards criminals targeting food-related crimes which is likely to continue in the future. Whilst we acknowledge that there is little available evidence to suggest that they are all committed and controlled by traditional organised crime figures there is, nevertheless, increasing evidence that rural crime is becoming more organised and lucrative to such organised crime groups. There is, therefore, always the danger that such groups may seek to expand into the UK market.

5. Conclusion

We argue that there is a need for:-

- The development of a universally accepted definition of what constitutes rural crime and that this should be implemented UK wide;
- The formulation of a unified rural crime policy and plan to be implemented UK-wide which lays out the strategic response to the threat;
- That rural policing be placed back on the police training agenda;
- That a specific rural crime tag be placed in crime recording databases;
- That there is a greater degree of cooperation between agencies and a sharing of intelligence between these agencies and the police;
- More sponsoring of rural crime specialists following the NFU mutual model.

There is also a need for designing new and different methods and ways of policing and for teams or squads of rural police officers to be created, drawn from different agencies, along the lines of the Australian Rural Crime Team model or the Danish Food Standards Agency Flying Squad model.

Although many of the indigenous (dis)organised criminal groups are not managed with the same ruthlessness that Italian and Eastern European Mafia undoubtedly are, their criminal activities are nevertheless still lucrative. Many of the rural crimes discussed in this article are not crimes which one would traditionally associate with organised crime or be associated with serious and organised criminals. Yet the scenarios discussed above nevertheless demonstrate an increasing degree of organisation and sophistication by the criminals concerned. Thus rural-based organised crime groups may well be a new type of organised criminal group for the intelligence community to concern itself with. It has often been noted that organised crime is extremely adaptive. However, it is difficult to counter if there are fewer police on the ground in rural areas and there is no unified rural policing plan. Likewise, if the authorities are unaware of the markets and supply chains these organised criminal groups operate within, then there is a reduced chance that they will be effectively dealt with. What is disturbing is that the closure of so many rural police stations has been done without an Act of Parliament, let alone public consultation, thereby negating some of the net gains made by the Rural Policing Act of 1839. After all delivering effective rural policing without a policing presence is difficult.

The issues discussed herein are obviously exacerbated by the current financial crises in Britain and across Europe. This has created new markets and marketplaces for criminals to exploit. There is little sign that the current recession is about to end and even if and when it does, that it will result in a reduction of the criminal activities committed by organised crime groups in rural areas. As the crimes currently committed by these opportunist entrepreneurial criminals become more embedded in the criminal community, there is a danger that they will become more attractive to even more ruthless organised criminal groups and mafias.

This article also highlights the increasing gap between government policies and our law enforcement capacity to effectively police rural areas. Moreover, there is an increased danger that this could lead to an expansion of traditional organised crime groups in rural areas. The closure of rural police stations and the withdrawal of police officers and resources from the countryside must be addressed urgently before there is irreparable damage done. Whilst there is clearly a need to reduce the fiscal costs of policing, this has to be balanced against the needs of the individual communities. Withdrawing services without putting in place a workable strategic plan is not a sensible course of action.

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Characteristics, intentions and expectations of new entrant dairy farmers entering the Irish dairy industry through the New Entrant Scheme

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ABSTRACT

As part of the gradual expansion and abolition of EU milk quotas, the Irish government has approved the allocation of milk quota to a small number of new entrants to dairy production. The objective of this study was to describe the characteristics of new entrant dairy farm businesses developing within the Irish dairy industry in terms of geographical distribution, planned production system characteristics and intended operational scale and expected profitability based on an analysis of successful applications and business plans to the Irish New Entrant Dairy Scheme over a 3 year period. A total of 230 applications and business plans of entrants who received up to 200,000 litres of milk quotas through the New Entrant Scheme from 2009-2011, were analysed for the effects of region, age, household income, previous dairy experience, and education on overall business plan expectations. The results show that a youthful, highly educated and highly resourced group of new farmers are using the New Entrant Scheme to enter the Irish dairy industry. Applicant age has a significant impact on available investment equity and expectations, as younger entrants have less owned resources, are increasingly reliant on additional borrowing and have significantly increased expectations for the productive capacity of their potential farm businesses when compared to older entrants. The majority of new entrants are not planning to solely rely on new dairy enterprises and are instead maintaining reduced alternative enterprises or off-farm work. The results provide a further indication that quota abolition is likely to result in an increased regional polarisation of milk production within Ireland with increased intensity of production within traditional milk production areas in the south.

KEYWORDS: new entrant dairy farmers; pasture-based; characteristics; expectations; Ireland

1. Introduction

The introduction of milk quotas as part of the European Union (EU) Common Agricultural Policy (CAP) in 1984, constrained milk supply and provided stable and high milk prices for EU producers (Whetstone, 1999). Prior to the introduction of milk quotas, Irish milk production was growing by 7% per annum through increases in herd size and improved management to increase individual animal performance (CSO, 2011). The introduction of EU milk quotas curtailed this expansion and severely restricted industry development. While Irish milk production has remained stagnant since 1985, milk production in other countries such as New Zealand has increased by 77% in the last 20 years (Dillon *et al.*, 2011). It is now generally accepted that while milk quotas protected and supported milk production in less competitive dairy regions, as a social policy, this was achieved at the expense of the expansion potential of more efficient producers. (IPTS, 2009). The policy restricted the entry of new younger dairy farmers while maintaining existing smaller scale producers (Dillon *et al.*, 2005). Consequently, the CAP Health Check review in 2008 resulted in a decision to abolish milk quotas by 2015.

The temperate climate of Ireland is condusive to high productivity grassland swards and provides Irish dairy farmers with a cheap high quality food source (Dillon *et al.*, 1995, McCarthy *et al.*, 2011). Consequently, comparatively lower costs of milk production have been reported in Ireland in comparison with other countries (Boyle, 2002, Dillon *et al.*, 2006). More recent studies have concluded that EU milk quota removal will result in a proportionately larger expansion in milk production in Ireland (Lips and Rieder, 2005, DAFM, 2010). However, regional variation in profitability and competitiveness of milk production systems within Ireland may influence the geographical location of and potential

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for industry expansion within Ireland post-EU milk quotas. Brereton (1995) observed that the Irish grass-growing season ranged from 240 to 340 days per annum with a longer growing season occurring in the south of Ireland. Similarly, Ryan (1974) also observed significant regional and soil type effects on pasture productivity with DM production reduced by up to 25% on poorly drained soils where impeded drainage resulted in a shorter grazing season and reduced sward productivity (Brereton and Hope-Cawdrey, 1988). Brereton (1995) suggested that regional variation in pasture growth (11-15 tonnes DM/ha/yr) is large enough to impact the technical and economic efficiency on Irish farms and should be considered in terms of the development of future low cost systems of production. National Farm Survey statistics (Hennessy *et al.*, 2011) reveal that, while the average net profit return to owned resources on Irish dairy farms was [4]€711 /ha at a milk price of 30.6 cent per litre (c/l) in 2010, profitability is very sensitive to soil type and ranged from €841/ha on very good soils to €190/ha on poorer wetter soils. Regional variation in milk expansion post quota abolition has been suggested by O'Donnell *et al.* (2010) who hypothesised that future expansion in milk production in Ireland would originate from southerly areas with more favourable grass production characteristics and lower milk production costs are incurred. The same study also observed that location, farm size, age and succession were important influential factors which motivate producers to expand production in the future, while milk price volatility was the major deterring consideration amongst those not planning to expand.

The abolition of quotas will be preceded by a gradual increase in quota to member states (2% in 2008, and a further 1% per annum thereafter) to allow for a 'soft-landing' for dairy economies (IPTS, 2009). As part of this overall quota expansion, the Irish government also decided to offer one quarter of the 1% increase in total quota on a permanent basis to new entrants to the Irish dairy industry. The quota application process called for each successful new entrant applicant to provide a detailed 5 year business plan incorporating physical and financial plans in addition to information on the location of their planned enterprises. As the first opportunity for new entrants to join the Irish dairy industry since the introduction of milk quotas, this group of new dairy producers represent the initial evolution of the dairy industry in Ireland post milk quotas. This unique group are capable of providing a unique opportunity to examine the characteristics of new dairy producers entering the industry.

The objective of this study is to describe the characteristics, intensions and expectations of new entrant dairy farm businesses developing within the Irish dairy industry, in terms of geographical distribution, planned production system characteristics and operational scale and expected profitability based on an analysis of successful applications to the Irish New Entrant Dairy Scheme over a 3 year period.

[4] At the time of writing (January 2013), €1 was approximately equivalent to £0.82 and $US1.31.

2. Materials and methods

Data

The applicants for the 2009, 2010 and 2011 milk quota allocations were obliged to submit an application form detailing relevant experience and educational qualifications with an accompanying 5-year business plan and a map of the proposed dairy holding to the Department of Agriculture Food and the Marine (DAFM). The 5-year business plan included an audit of existing resources, stock requirements, the source and nature of planned capital expenditure in addition to expected income and expenditure for each year of the plan (DAFM, Accessed October 2010). There are a total of 230 successful new entrants selected over the initial 3 years of the programme based on supplying adequate information. The information submitted by successful applicants was used to describe the expectations of new entrants to the dairy industry over the five initial years of these new businesses.

Data handling

A total of 50 key variables describing the characteristics of new entrants and their future dairy farm plans were generated from the application forms and business plans data (see Table 1). New Entrants characteristics were categorized according to region, age, other income, previous dairy experience and educational qualifications.

Statistical analysis

Each continuous variable generated in this analysis was screened for normality using Proc UNIVARIATE (SAS, 1999). The effect of region, age, other income, previous dairy experience and educational qualifications on the collated continuous data derived from the submitted business plans and application form (farm size, cow numbers, etc.) were analysed using a generalized linear model (SAS, 1999) according to the following model:

$$R_{ijklmn} = \text{mean} + R_i + A_j + H_k + D_l + E_m + RA_{ij} + RH_{ik} + RD_{il} + RE_{im} + RAHE_{ijklm} + e_{ijklmn}$$

Where R_{ijklmn} is the result for a farmer in the region i, within the age category j, with household income k, with previous dairy experience l and educational qualifications m; R_i is the effect of the ith region of production (i= SE, SW and BMW); A_j is the age category (j= under 30, 31-40, over 40); H_k is the other income available (k=1-3); D_l is the previous dairy experience (l=1-4); E_m is the educational qualification (m=1-3) and e_{ijklmn} is the residual error term. The effects of region, age category, other income, previous dairy experience and educational qualifications were tested for significance using the residual mean square as the error term. For binary variables, chi square analysis was performed using Proc FREQ (SAS, 2006).

GIS mapping

Each application provided ordinance survey maps and land ownership or land lease documentation which included the folio numbers and Land Parcel Identification Scheme (LPIS) numbers. The geographical distribution of the new entrant farms was conducted

Table 1: Key New Entrant characteristics variables created from the dataset

Variable	***No. of descriptors***	***Data used to create the variable***
Region	*3*	South Eastern (*SE*) counties (Kilkenny, Tipperary, Wexford, Waterford, Wicklow and Carlow); South Western (*SW*) counties (Cork, Kerry, Limerick and Clare); Border Midlands and Western (*BMW*) counties (Galway, Mayo, Sligo, Roscommon, Leitrim, Monaghan, Cavan, Longford, Louth, Offaly, Westmeath, Laois, Meath, Dublin and Kildare)
Age	*3*	*Under-30*, *30-40*, and *Over-40*
Other income	*3*	*full-time dairying* (i.e. no other sources of income); *working spouse*; *another source of income* (which includes another farm enterprise as well as part- or full-time off-farm work)
Previous dairy experience	*4*	From a dairy home farm; those with long term certifiable experience working on dairy farms; those with shorter term or unverifiable experience; no dairy experience
Educational qualifications	*3*	Base requirement 180-hour Agricultural Certificate; a 2 year Advanced Agricultural Certificate; Bachelors degree
Farm descriptors	*8*	previous farm enterprise; total land in holding; land area owned; land area leased; amount of farms with single land block (around the parlour); percentage owning land; leasing; or both owning and leasing land
Expected stock and productivity	*7*	dairy cow herd size; stocking rate; milk yield per cow (kg/cow); milk yield per ha (kg/ha); milk solids per cow (kg/cow); milk solids per hectare (kg/ha); milk volume per farm (kg)
Expected income and profit	*12*	farm income (employed spouse, other enterprise, off-farm job, or none); percentage in receipt of Single Farm Payment (SFP); value of SFP received; other grants received; existing stock value; savings; percentage with existing debt; percentage seeking debt financing; total capital borrowed; total loan commitments outstanding
Planned expenditure	*11*	milking equipment; stock; buildings; roadways; machinery; water; reseeding; fencing; planning; electricity; total expenditure
Expected efficiency	*5*	profit per litre (c/l); profit per hectare (€/ha); profit per kg milk solids (fat kg plus protein kg) (€/kg MS); profit per farm (€/farm); profit per cow (€/cow)

using ArcGIS v 9.3 (ESRI, Redlands, CA, USA). New dairy farm co-ordinates were mapped against the existing national distribution of specialist dairy farms in addition to the existing density of dairy and non-dairy stock within Ireland at an electoral divisional (ED) level. A point density method was used to geographically map the farms, by creating a geographical area of Ireland divided into 300 cells, and each of these cells is given a neighbourhood or fixed radius and to measure only within that radius; the more farms within a given neighbourhood, the higher the point density. If there are no points (or new farms) within a neighbourhood, then that neighbourhood will represent no data or have a zero point density. The Average Nearest Neighbour Distance tool was used to locate areas of farm clustering or if several new entrant farms are located in the one area. It calculates an index based on the average distance between each farm (feature) and its neighbouring farm (feature), and the distances are then averaged for the neighbourhood being examined. The farms (features) are considered clustered if the average for a hypothetical random distribution is greater than the average distance, and dispersed if the hypothetical random distribution is less than the average distance. The distance observed divided by the distance expected equals the ratio by which the index can be expressed.

3. Results

New entrant profile

The general characteristics from the business plans and applications of 230 new farmers under the New Entrant Scheme are represented in Table 2. Year of application (2009, 2010 or 2011) had no effect on the expectations of the new entrant farmers. The average new entrant applicant is 36 years of age (ranging from 21 to 62 years), while 97% are male. There was a large variation in knowledge and experience of dairy farming evident from the dataset. As the 180hour Agricultural Cert is a minimum prerequisite for Irish dairy farmers to establish land ownership and join the scheme, all applicants have obtained this minimal formal agricultural education. In addition to the minimum requirements, a further 72% of applicants have completed a 2 year Advanced Agricultural Certificate in agriculture, while a further 21% have achieved a Bachelors degree level qualification. Fifty-eight percent of new dairy entrants are originating from previously beef enterprises, with 22% of all new entrants planning to become exclusively dairy farmers within 5 years. In terms of dairy experience, 44% of new entrants have a close relative in dairying (such as a parent, sibling or uncle) while a further 20% had no experience in dairy farming at the time of applying for milk quota under the New Entrants scheme, with the remainder having either

Table 2: General characteristics of New Entrants to the Irish dairy industry (2009-2011)

Age (yrs)	36 (range 21-62)
Proportion with relative already in dairy (%)	44
Proportion of farms previously in dairy (%)	35
Proportion with dairy experience (%)	80
Education (%)	
180 hour Agricultural Certificate	7
Advanced Agricultural Certificate	72
Bachelors degree in Agriculture	21
Previous Enterprise (%)	
Beef	58
Mixed	25
Other	16
Total land (ha)	58.08 (range 20-199)
Land leased/rented (ha)	23.09 (range 0-151)
Land owned (ha)	34.90 (range 0-107)
Expected production	
Herd size (No. cows)	71
Stocking rate (livestock units/ha)	1.73
Milk yield (kg/cow)	4,954
Milk fat plus protein yield (kg/ha)	654
Expected profitability	
Gross output (c/l)	30
Costs of milk production per litre (c/l)	25
Net profit per litre (c/l)	5
Net profit per ha (€/ha)	428

worked as dairy farm labourers or as work experience students on a dairy farm at some point during their agricultural education.

The average new entrant has a substantial land block of 58.1ha (ranging from 20-199 hectares) and of which 60% is owned. The potential land base available to the new dairy farmers is extensive with an expected average stocking rate of 1.73 LU/ha, withstanding 71 cows. The predicted production expected by the new entrant businesses is 654kg MS/ha (fat plus protein kg) and an average milk yield of 4,954kg per cow. Almost 40% of new entrants have existing loan commitments while seventy-nine percent are hoping to secure loan finance as they develop their dairy farm, within a projected full set-up investment cost of €190,114 or €2,677/cow. The average new entrant farmer expects to produce an average of 352,360 litres of milk at an average production cost of 25 c/l and an average gross output of 30 c/l (including a 27 c/l milk price and a further 3c/l from sales of dairy stock). The expected profitability of a new entrant dairy farms is 5 c/l, equivalent to €428/ha and €248/cow.

GIS mapping and regional distribution

The majority of new dairy farms (80%) are located in the south of Ireland (Figures 1, 2 & 3). Figure 1 demonstrates the density distribution of new entrant dairy businesses in comparison to the density of specialist dairy farms in Ireland by their respective county and region. In addition, figures 2 and 3 highlight the new entrant distribution in contrast to the density of both dairy and cattle populations, respectively. The effect of region on the characteristics, resources and expectations of new entrants is outlined in Table 3. Region has no effect on the size of the farm or the level of experience of applicants. Similarly, total SFP and other grant receipts are comparable for all regions; however, the value of existing owned stock is lower in the SW (€45,405) when compared to the BMW and SE regions (€73,513 and €69,397 respectively). While region has no effect on the expected total level of capital investment required, the level of borrowings required to finance expansion was lowest in SW (€62,831) and highest in SE (€106,092) while BMW was intermediate (€91,854). Region had no significant effect on production (planned herd size, stocking rate or the level of milk production per cow) and financial (net profit per litre and per hectare) expectations.

The effect of age

The effect of new entrant age on existing resources and planned milk production characteristics and expectations are outlined in Table 4. The proportion of new entrants below 30 years of age (U-30), from 30-40 years of age (30-40) and greater than 40 years of age (O-40) was 26%, 45%, and 29%, respectively. While the total land area planned for dairying was unaffected by age, the area of owned land increased with increasing age (21, 35, and 47 ha for U-30, 30-40, and O-40, respectively). Age has a significant impact on the level of available equity for investment in dairy set-up. Only 63% of the U-30 group had an SFP income in comparison to 89% and 97% for 30-40 and O-40, respectively. Consequently, older new entrants have a significantly larger SFP (€18,874 and €24,925 for 30-40 and O-40, respectively) in comparison to U-30 (€10,246). New entrant age had no effect on either the level of required borrowing or the total level of capital investment planned. There was also no significant age effect on the planned herd size during the first 5 years, however stocking rate and milk solids output expectations were lower ($P<0.01$) for older applicants (30-40 and O-40). Age had no effect on the expected profitability from milk production in terms of either profit per litre or profit per hectare.

The effect of other income

Sixty-six percent of new entrants have another income source originating from either the continuation of alternative agricultural enterprises or an off-farm job, a further 12.2% have a working spouse, while only 21.8% of the new entrants intend to be full-time specialist dairy farmers with no other additional income. There was no significant effect of other income on the value of existing savings or levels of SFP or other grant awards received. Similarly, other income had no effect on planned investment in milking facilities, stock or other infrastructure, nor on total planned expenditure or business development. Farms planning to be specialist dairy production units expect to have higher ($P<0.05$) stocking rates (1.94 LU/ha) and milk output (5,094 kg milk/cow and 747kg MS/ha) compared to either those with other income sources (4,932 kg milk/cow and 630 kg MS/ha) or a working spouse (4,838 kg milk/cow and 657 kg MS/ha). Full-time specialist dairy farmers also expect to achieve higher profits per litre (9 c/l) and per hectare (€733/ha) compared to either those

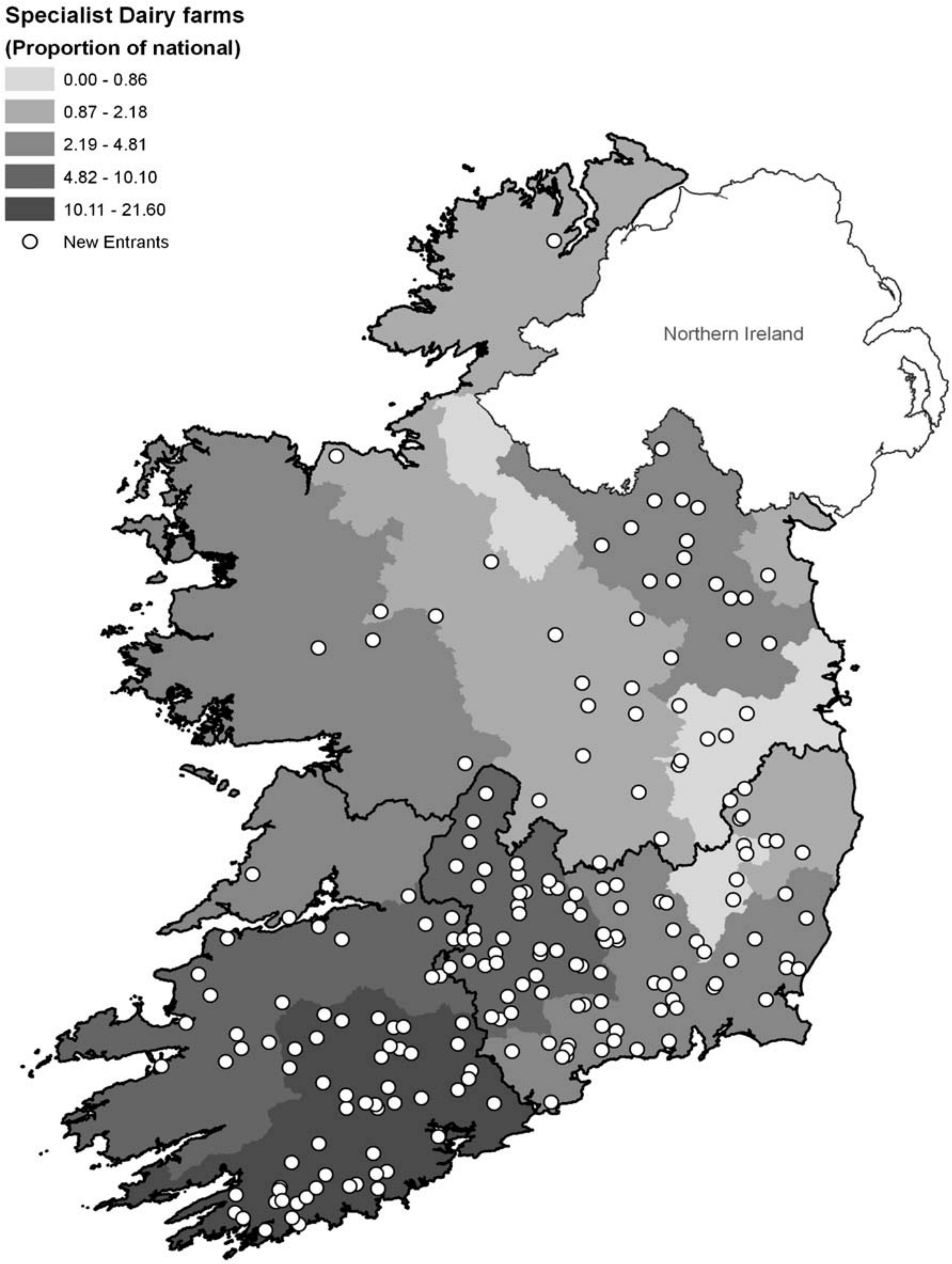

Figure 1: Regional distribution (South East, South West and Border Midlands and West) of new entrant farmers in contrast to the national proportion of specialist dairy farms in Ireland

with a working spouse (3 c/l and €231/ha, respectively) or those with an alternative income stream (5 c/l and €358/ha, respectively).

The effect of knowledge and experience

The majority of new entrants to dairying have gained dairy experience on their home family dairy farms (38%) or as dairy farm labourers (42%) while 20% have no previous experience of dairying. New entrant farm system productivity expectations were unaffected by educational qualifications or the level of previous dairy experience. Similarly, both the planned level of capital investment and the profitability expectations per litre and per hectare are similar for all new entrants irrespective of their level of dairy experience or educational qualification.

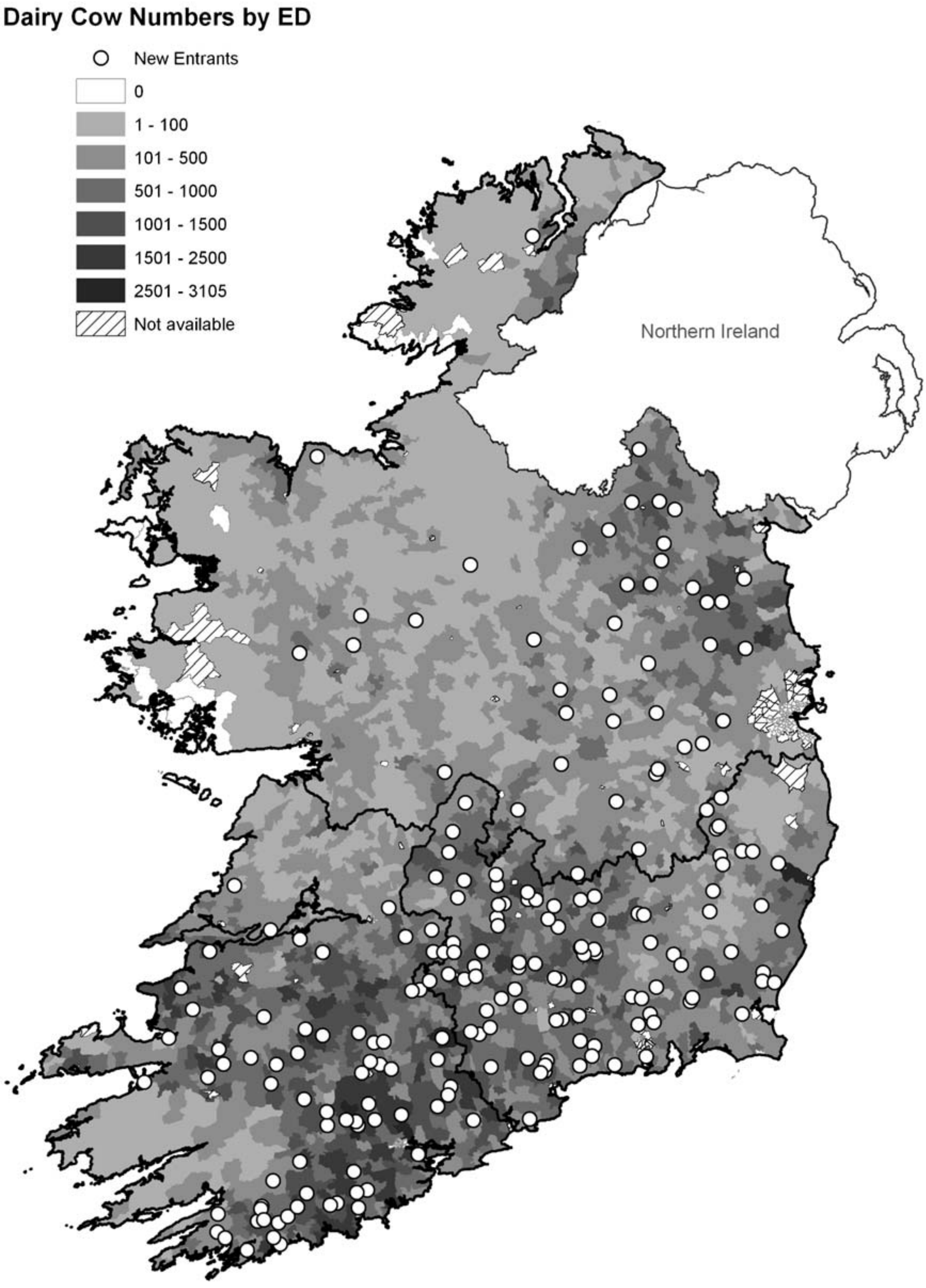

Figure 2: The distribution of new entrant dairy farms in contrast to the density of dairy cows in Ireland by Electoral District (ED)

4. Discussion

The development of a farm business plan is an essential process to help farmers to focus on the necessary factors for business success, by defining realistic goals to create a viable future enterprise (Johnson and Morehart, 2006). While the analysis of actual farm financial results of new entrants provide the ultimate measure of business success, an analysis of business plans of over 230 successful new entrant dairy farmers highlight the available resources, knowledge and experience and expectations of those entering the Irish dairy industry. The importance of personal attributes (knowledge and experience, education) and expectations in motivating farmers to make significant changes to their farming activities has been widely recognised (Sumner and Leiby, 1987, Gloy *et al.*, 2002, Lockheed *et al.*, 1980, Kumbhakar *et al.*, 1991). This study indicates that the

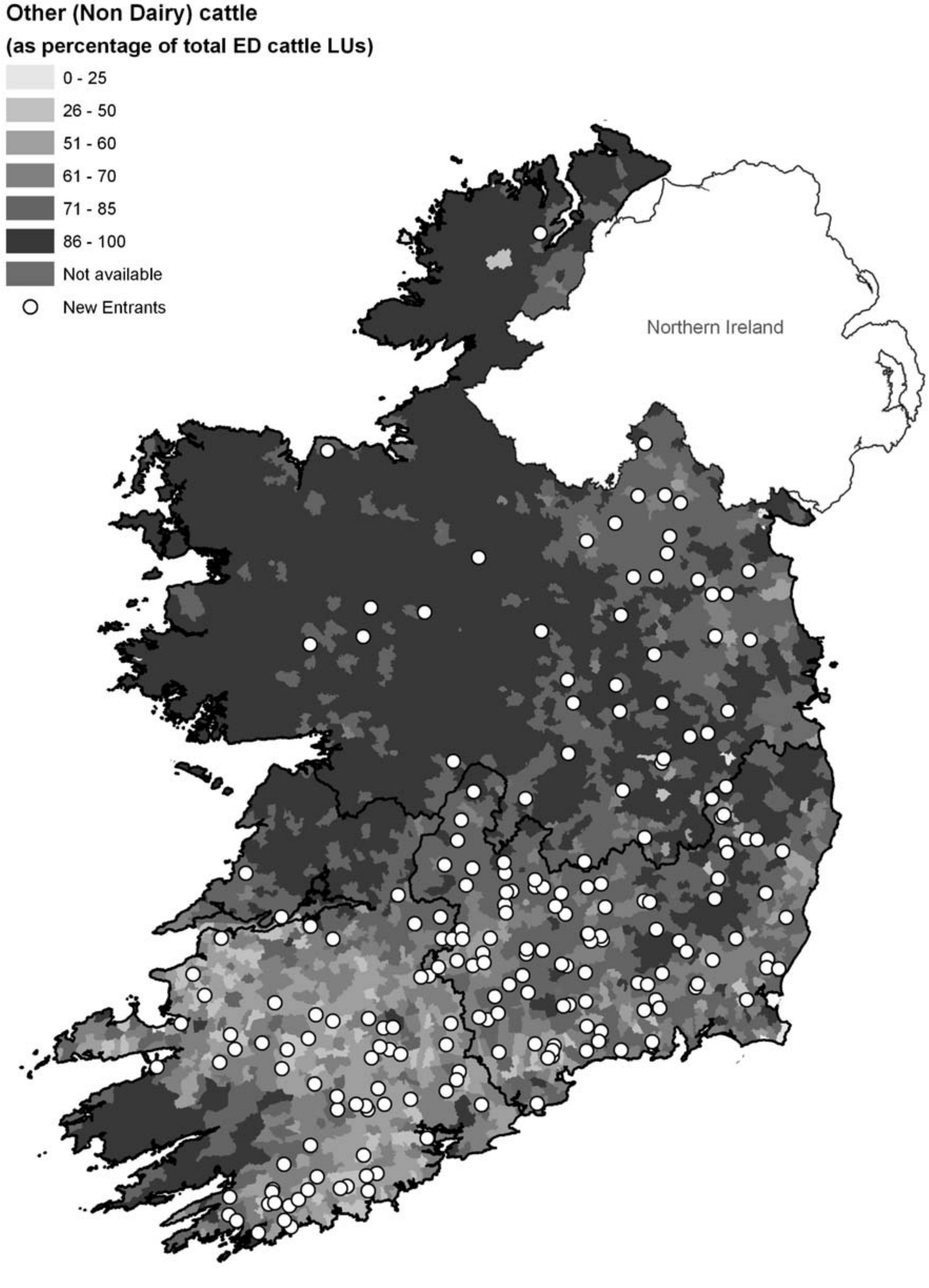

Figure 3: The distribution of new entrant dairy farms in contrast to the density of non-dairy cattle in Ireland by Electoral District (ED)

New Entrant Scheme has successfully motivated new dairy farmers to make a monumental change in their lives and set-up their new dairy enterprises. The current evaluation of new entrants to the Irish dairy industry provides a unique opportunity to identify the characteristics and expectations of new dairy farmers in addition to the potential evolution of the industry post EU milk quota removal in 2015.

The BMW region of Ireland, while representing 47% of the national land mass, currently accounts for just 25% of national dairy production (CSO, 2010). Shalloo (2004) estimated that the profitability of milk production in the BMW region is reduced by 38% to 58% of that possible on drier southern soils based on a comparative analysis of milk production results. Consistent with these findings, O'Donnell *et al.* (2010) concluded,

Table 3: The effect of region on the characteristics and expectations of new entrants to the Irish dairy industry

	BMW	SE	SW	s.e	P-value
Regional Distribution (%)	18.8[a]	45.9[b]	35.4[b]		***
Total land (ha)	61	60	53	3.3	
Land leased/rented (ha)	20	24	24	3.0	
Land owned (ha)	41	37	30	3.3	
Proportion with dairy experience (%)	67	83	83		
Available equity (€'s)					
Stock	73,513[a]	69,397[ab]	45,405[b]	7694.3	**
Single farm payment	19,256	19,929	16,453	2,057.6	
Other grants	5,121	3,832	4,850	571.5	
Financing expectations (€'s)					
Capital borrowing	91,854[ab]	106,092[a]	62,831[b]	10,070.3	*
Total investment	204,803	199,209	166,329	15,255.7	
Production expectations					
Herd size (No. cows)	73	71	68	2.8	
Stocking rate (livestock units/ha)	1.66	1.70	1.82	0.071	
Milk yield (kg/cow)	4,903	4,941	5,001	57.1	
Milk fat plus protein yield (kg/ha)	633	645	685	32.6	
Profit expectations					
Net profit per litre (c/l)	0.04	0.06	0.05	0.013	
Net profit per hectare (€/ha)	283	472	430	92.5	

[a,b,c]means with different superscripts are significantly different ($P<0.05$)

Table 4: The effect of applicant age on the characteristics and expectations of new entrants to the Irish dairy industry

	Under-30	30-40	Over-40	s.e	P-value
Proportion of new entrants (%)	25.8[a]	45.4[b]	28.8[a]		***
Proportion with dairy experience (%)	86.40	81.70	71.2		
Total land (ha)	51	60	61	3.3	
Land owned (ha)	21 [a]	35 [b]	47 [c]	3.1	***
Available equity (€'s)					
Single farm payment	10,246 [a]	18,874 [b]	24,925 [c]	1,920.6	***
Other grants	2,935 [a]	4,471 [b]	5,717 [b]	547.7	**
Financing expectations (€'s)					
Capital borrowing	94,796	84,003	88,882	10,074.6	
Total expenditure	189,869	178,475	203,739	14,991.0	
Production expectations					
Herd size (No. cows)	71	70	70	2.8	
Stocking rate (livestock units/ha)	1.95 [a]	1.68 [b]	1.64 [b]	0.068	**
Milk yield (kg/cow)	4,943	4,920	5,015	55.8	
Milk fat plus protein yield (kg/ha)	756 [a]	645 [b]	587 [b]	30.3	**
Profitability expectations					
Net profit per litre (c/l)	0.08	0.04	0.05	0.013	
Net profit per hectare (€/ha)	565	369	383	90.1	

[a,b,c]means with different superscripts are significantly different ($P<0.05$)

based on an attitudinal survey of existing milk suppliers, that future expansion in milk production would mostly occur in the south of Ireland. Similarly, the results of this study indicate that despite having a lower spatial density of specialist dairy farms, only a small minority (19%) of new dairy farms are to be located within the BMW region. As Figures 1, 2 and 3 demonstrate, these results provide a further indication that quota abolition is likely to result in an increased intensity of milk production within the already heavily concentrated traditional milk production areas in the south and east of Ireland.

Previous studies indicate that farmer expectations are intrinsically linked to prevailing industry and wider economic conditions in addition to market sentiment (Kelly *et al.*, 2012) however, there was no year of application effect on biological or financial expectations of new entrants in this study despite relatively large variation in actual milk prices during the study period (23.3 c/l in 2009, 30.8 c/l in 2010 and 35.5 c/l in 2011; CSO, 2011). The overall level of farm performance expectations of new entrants (4,954 kg of milk per cow with an average production cost of 25 c/l) are consistent with existing dairy industry performance norms (5,075 kg milk per cow and with production costs of 23c/l; (Hennessy *et al.*, 2011)) while an average expected milk price of 28 c/l is consistent with overall industry expectations (Binfield, 2008). The analysis of new entrant farmer credentials indicates that a young and highly educated group of new farmers are using the New Entrant Scheme to enter the Irish dairy industry. With an average age of 36 years, this group of new dairy farmers are very young compared to either the existing demographic of dairy farmers (49 years) or the overall population of beef and mixed enterprise farmers (54 years) from which these new entrants originate (Hennessy *et al.*, 2011). In contrast to the findings of Mishra *et al.* (2009) who reported lower levels of available equity and higher debt-to asset ratios amongst newly establishing farm business set-ups in the United States, the results of this study indicate that newly establishing dairy farmers in Ireland have considerable owned resources and equity from which to establish these new dairy units (with average decoupled EU payments of €22,992 in comparison to €19,488 for the average existing dairy farmer; (Hennessy *et al.*, 2011)).

The impact of farmer age and experience on the expectations and likely performance of these new farm businesses is inconsistently reported in the literature. Within this study, applicant age has a significant impact on the resources and equity available in addition to the expected subsequent production. According to Davis *et al.* (2013) younger farmers will have a longer planning horizon than older farmers resulting in heavier investment in farm business growth. Although having less equity (savings, sales from previous enterprises, EU farm payments) and other assets (particularly owned land) and therefore requiring additional borrowings, younger new entrants (under-30 group) had significantly higher expectations for the productive capacity of their potential farm businesses. Mishra *et al.* (2009) similarly observed that younger farmers in the United States starting a new enterprise have fewer assets and concluded that, as younger farmers also have less experience at resource allocation, the financial performance of businesses run by younger farmers would be reduced. Summer and Leiby (1987) also found that older people tend to have fewer borrowings, and concluded that lower costs of borrowing result in larger farms and faster business growth. In contrast with these general findings, other studies have observed superior rates of technical development and adoption amongst younger farmers (Solano *et al.*, 2003, Connolly and Woods, 2010) which may compensate for their inferior financial position. Zepeda (1990) reported that younger farmers were 11 times more likely to adopt new technology resulting in superior technical performance. The results of the current study indicate that by initially setting-up with fewer financial assets, the overall profitability expectations of younger entrants are similar to older entrants due to superior farm productivity expectations.

Ninety-three percent of new dairy entrants have at least two years of formal 3rd level agricultural education and so it is unsurprising that the business plans reveal that new entrants intend to become relatively large scale and efficient producer's post-EU milk quota removal. In comparison with the average specialist dairy farmer who currently milks 57 cows on 50 hectares (Hennessy *et al.*, 2011), the average new entrant is planning to milk 71 cows on 58 hectares. The positive expectations of highly educated new entrants are consistent with the findings of Lockheed *et al.* (1980) who observed that a farms productivity increases for every extra year spent in formal agricultural education. Similarly, other authors have observed that educational qualifications have a positive effect on the financial performance of the dairy farm (Mishra *et al.*, 2009) resulting in increased technology adoption and improved on-farm technical efficiency (Kumbhakar *et al.*, 1991). The increased incidence of other income among new dairy farm businesses (78%) within this study is indicative of the elevated educational status of this group (Mishra *et al.*, 2009) while the reduced productivity and profitability expectations of farm businesses with a lesser reliance on dairy farm income is also consistent with previous findings (Foster and Rausser, 1991).

5. Conclusion

The analysed business plans and applications of over 230 successful new entrant dairy farmers highlight the existing resources, education, experience and expectations of those entering the Irish dairy industry in the lead up to EU milk quota abolition. The results show that a youthful and highly educated group of new farmers are using the New Entrant Scheme to enter the Irish dairy industry, and intend to develop larger scale and more efficient dairy farms post-EU milk quotas. Applicant age and other income has a significant impact on available equity and expectations of entrants as younger and specialised dairy entrants have less owned resources and significantly greater expectations for the productive capacity of their potential farm businesses when compared to older entrants or those with alternative income sources. The results also indicate that, with 81% of new entrants to dairying located in the south of Ireland, quota abolition is likely to result in an increased regional polarisation of milk production within Ireland with increased concentration of production in traditional milk production areas in the south and east of Ireland.

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REFEREED ARTICLE

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Food Security: How Rural Ghanaian Households Respond to Food Shortages in Lean Season

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ABSTRACT

A rural household, with little or no formal education and limited opportunities for non-farm income generating activities, will produce rather than purchase staples for household consumption. Many subsistence farmers are net-food buyers, often facing the challenge of ensuring household food security in lean seasons of production when their stock is exhausted (cyclical food insecurity). This paper determined the optimal farm plan, profit levels of crops, and farmer behaviour when given the option to purchase or produce food using a linear programming framework. Findings from the LP model show that capital is the most constraining resource for both male and female farmers. Making an additional capital of US$180 available to female farmers will increase their net income by US$823 but making one additional acre of land available to them will only increase income by US$200. As land reforms take time, addressing their credit needs is an appropriate short-term intervention.

KEYWORDS: Linear Programming; Relative profitability; Ghana; Gender; Purchasing food

1. Introduction

The increased variability in global food prices between 2007 and 2008 and concerns about food security for future generations has created a heightened awareness around the world with renewed commitments by nations to ensure food security. Farmers in Ghana have faced very high prices of inputs since the 1990s as a result of the structural adjustment programme, and are constrained by inadequate productive resources and services. The FAO State of Food and Agriculture report for 2011 noted that women face gender-specific constraints that reduce their productivity and limit their contributions to agricultural production, economic growth and the well-being of their families (FAO, 2011). Their limited access to productive resources is a result of cultural practices in bequeathing land and other properties.

In most developing countries, including Ghana, people eat food grown locally particularly since purchasing power in these countries is generally low. Though tastes are changing towards the consumption of imported food products, food consumption deficits occur in periods of high prices and production deficits. In Ghana, among the rural poor, the ability to produce food in one season does not guarantee availability of food for household members throughout the year. The Africa Human Development Report 2012 noted the challenge smallholder farmers face in selling their crops immediately after harvest, exhaust their food stocks a few months later and begin buying food at higher prices (UNDP, 2012).

IFAD recognizes that in Ghana, as in much of the rest of the world, rural women are making considerable contributions to household food security, either by growing food or by earning income to purchase food (IFAD, 1998). It added that household food insecurity is a seasonal problem in some parts of Ghana, such as the north, occurring every year between February and July.

A recent UN report notes that an effective response to the challenge of ensuring a food secure future for Africa is broad and cannot be narrowed to a single intervention, discipline or institutional mandate. It will take a coordinated response across sectors (UNDP, 2012). Food security is about availability, access, and utilization. Researchers have agreed that food insecurity is primarily a problem of low household incomes and poverty, and not just inadequate food production (Gladwin, et al., 2001; Pinstrup-Anderson, Pandya-Lorch and Rosegrant, 2001; Schuh, 1997). African governments need to reassess the role of agriculture within their national development strategy. According to Oxfam (2006), governments need to tackle the root causes of hunger such as poverty, agricultural mismanagement, unfair trade rules, and the unprecedented problems of climate change. Funk and Brown (2009) however argue that local agricultural production is critical to food security among the rural poor. Hence, if we can establish an understanding of what crops are

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profitable for farmers to concentrate on in alleviating poverty, it will inform policy as well as effective agricultural extension delivery in the fight against food insecurity. Even stronger outcomes will be achieved if research results are effectively communicated to the farming community.

Building a food secure continent requires transformative change that will be most effective if accompanied by a shift of resources, capacities and decisions to smallholder farmers, poor communities and women. New inputs and farming techniques can liberate farmers from cycles of low productivity and poverty (UNDP, 2012). The report however added that technology dispossesses or marginalizes smallholder farmers when misapplied and science that is compartmentalized and conducted far from where its results are used can lead to designs that are poorly suited to smallholder farms.

This paper examines the behaviour of rural households in Ghana when given the option of producing or purchasing food for household consumption in the frame of a linear programming (LP) model. Food security includes the ability to purchase food when it is not produced. A sensitivity analysis was carried out to observe farmers' response under different policy scenarios and the changes in the optimal farm plan. The relative profitability of food crop enterprises was calculated in order to determine the crops that are profitable and could be produced at a marketable surplus, beyond what is needed for the household's consumption. The Central Region of Ghana was used as a case study.

Due to their general risk aversion behaviour, farmers attempt to produce all they need for household consumption, especially when their monetary income levels are low. The role of women in food production continues to increase in the face of rural-urban migration and lack of incentives for agricultural production. Understanding the nature of male and female enterprises can inform policy in designing interventions for the farm level.

2. Food Security at Farm Household Level

Based on food production, availability, purchasing power, and access to common resources, participants in a survey in Bangladesh categorized food insecurity of households into severe or chronic, occasional or transitory, break even or food surplus (Mallick and Rafi 2010). Cyclical or longer term stresses such as seasonal harvesting patterns can result in long 'hungry seasons' between harvests (UNDP, 2012), yet research has not explored the specific mechanisms underlying seasonal effects of food security on rural households (Hillbruner and Egan, 2008). Seasonality affects rural livelihoods and can result in cyclical food insecurity in rural households (UNDP, 2012; Ellis, 2000; Hedzro-Garti, 2010). According to Hillbruner and Egan (2008), the magnitude of stunting and wasting in children fluctuates largely depending on the season. The role of rural areas becomes critical in the fight against seasonal food shortages. Because their production levels are so low, rural households often run out of the same food they produce, thereby facing food insecurity in lean seasons. As net-food buyers, rural households are producers, marketers and consumers of locally produced food. Melgar-Quinonez *et al* (2006) assert that household food expenditure consists of food consumed from own production, purchased, received as a gift or payment. It becomes necessary to analyse the possibility and willingness of rural households to purchase food so as to understand their behavioural patterns for policy formulation and interventions.

Households are plagued with managing a diverse range of challenges year by year. As they produce, they need to ensure sufficient availability of food till the next harvest. They also need seed for the next planting season and some surplus to sell to meet household financial needs. The income from selling the surplus enables them to pay school fees, buy school uniforms for their children, purchase clothing, and to ensure adequate nutrition for the household. Rainfall patterns are particularly important in determining household and national food security in Ghana. For most rural households, agricultural production is the main means of ensuring food availability all year round.

There are two seasons in a year, the major season and the minor season. The major season lasts from March till about July and the minor season begins early September. Minor season crops are harvested around the end of November and this food must last till June the following year. Besides, the minor season has a shorter rainy period and farmers reduce the size of their farms as a good harvest is not always assured, though it has to last for a longer period. This phenomenon results in food shortages during the long dry season till the major season crops are harvested. Farmers use diverse coping strategies including reduction in quantity of food consumed, shift to the consumption of less preferred foods, and purchase of food for household consumption. Maxwell, Caldwell and Langworthy (2008) consider eating less-preferred foods or reducing portion size as modest dietary adjustments and reversible strategies.

Most of Ghana's staple food consumption is met by domestic production and the country is said to be self-sufficient in the production of maize (Armah and Asante, 2006). Ghana's food self-sufficiency ratio is estimated at 100 percent for starchy staples, 30 percent for meat and 60 percent for fish, 80 percent for cereals, except for rice which is 30 percent (Aggrey-Fynn *et al.*, 2002). Though agricultural production is a factor of household food insecurity, it is not the only cause.

The concept of food security encompasses access to and availability of food, the distribution of resources to produce food, and the purchasing power to buy the food where it is not produced at national, local and household levels. Producing a marketable surplus in one season may not mean sufficient food for the rest of the year. That is why certain rural farmers are compelled to purchase the same products they produce during lean seasons. The ability of rural households in sub-Saharan Africa to combine the right crop enterprises is critical for ensuring sustainable livelihoods.

The importance of gender equality in achieving development objectives and the need to close the gender gap in agriculture and other priority areas have featured much in FAO and World Bank publications (Meinzen-Dick, et. al, 2011). Due to the unequal access to resources and productivity-enhancing inputs, women often have lower yields and lower output, most of which is consumed at the household level.

Empirical evidence suggests that increasing women's control of resources has positive effects on a number of development outcomes of food security, child nutrition and education within the household (Duflo and Udry, 2004, Fafchamps, Kebede, and Quisumbing, 2009, Millennium Challenge Corporation, 2012). Men and women contribute in different ways and use different strategies for ensuring household food security.

A major source of inequality which is too often unrecognized is gender differences in access to resources and markets that result in forgone agricultural output, higher levels of poverty, and food and nutrition insecurity (Byerlee, De Janvry and Sadoulet, 2009). Meeting food needs in the future is increasingly dependent on the capabilities and resources of women. Women play a significant role in agricultural production, producing both food and cash crops in addition to processing, purchasing and preparing food for household consumption (Brown *et al.*, 1995). Africa has about 60 percent of the population living in rural areas and mostly engaged in agriculture (Wiggins, 2009), with women being responsible for about 80 percent of the food production (Kabeer, 1994). Empowering women to play economic, social and even political roles is beneficial to food security and development (Scanlan, 2004). This paper examines both male and female farm enterprises to understand their contributions to household food security.

3. The Data

The Central Region has had a high incidence of poverty in 1998-1999 (Ghana Statistical Service, 2000), but has made great strides in reducing the incidence of poverty, which is prevalent among small-scale food producers (Ghana Statistical Service, 2007). Ensuring food security and continuous and sustained improvements in income levels among small-scale farmers requires the cultivation of crops that bring income at frequent and regular intervals. The production of maize, which is a major staple crop, was used as a basis for farmer selection in addition to gender and farm size. The main maize producing districts in Ghana produce an average of about 10,000 metric tonnes per annum (MOFA, 2000) and the selected districts for the study (Agona, Assin and Mfantsiman) fall within this category. The region has the potential for increasing food production, improving food security and further reducing poverty. There are three main agro-ecological zones: Coastal, Forest and Transition zones with diversity in production systems. Temperatures are high with humidity of 60 percent, and bimodal rainfall patterns, which supports crop production in two seasons of the year.

The data consist of the crop budgets prepared by the Ministry of Food and Agriculture (MOFA) for various crops in the region for the year 2005. This is supplemented by an earlier survey which was conducted to determine farmer characteristics, describe the farming systems, farm size categories, cropping calendars and household labour availability. The crop budgets provide detailed information on various crop enterprises with the cost elements, output and selling prices. The respondent farmers fall within three size categories namely: large, medium and small-scale, and farmers were randomly selected from all categories. Farms that fall within the large scale category consisted of 22 percent of the respondents and these had farms of more than 5 acres (ranging up to 14 acres). The medium scale is between 2.5 to 5 acres, representing 43 percent of the respondents. The small-scale farms ranged from 1 to 2.5 acres.

The information from the cropping calendars was used to determine the labourdays needed for each enterprise and the months in which each activity occurs. The asset base of the farmers was used to determine the cost of tools. Crop enterprise budgets were prepared by gender to estimate the variable costs and profit levels for each enterprise, for a gross margin analysis. The information from the gross margin analysis was used for constructing the linear programming matrices. The LP matrix is for a representative male or female farmer and not for individual farmers. The results of this study provide insights into the characteristics and performance of farm enterprises in Ghana that are useful for policy formulation and development planning and the process of designing food security interventions in an effort to achieve the Millennium Development Goals, especially MDG_1.

Farming Systems, Gender and Food Security

The farming system that characterizes the Central Region of Ghana can be termed as maize-based, with cassava, plantain and cocoyam being important crops. Vegetables such as garden-eggs (or egg plant), tomatoes and pepper are important in certain parts of the Coastal Savannah Zones. Tree crops and perennial crops are also present in certain parts of the Forest Zone.

The most important cereal crop is maize, being the major staple food and traditional crop in the region. Farmers always grow some amount of it in each season, at least for household consumption. The storability of maize is a motivation for its production, giving farmers the opportunity to sell when prices are favourable. Income from maize was said to be quick and regular and to some women, it is termed as *obatanpa* (good mother). However, there is the problem of cyclical shortage of the produce for some farmers. As mentioned earlier, their stock runs out during the lean season. The only option then is to adopt coping strategies of shifting to the consumption of roots and tubers or purchase maize for household consumption. Because many of these farmers derive their livelihoods primarily from agriculture, income from other enterprises may be needed to purchase food when their stock runs out. For small-scale farmers, they will need to have money from other crop enterprises to support such food purchase.

Female respondents from the survey showed a lower resource endowment and lower level of education. Forty-six percent of the women never had any formal education, compared to only 5 percent of the men. Women had smaller land holdings, smaller farm sizes with strong evidence against the hypothesis that there is no association between gender and farm size (with a Pearson Chi-Square value of 9.00, which is significant at 5 percent confidence level). The majority of the female managed farms are less than 2.5 acres in size while male managed farms are between 2.5 and 5 acres. Forty-three percent of the respondents were within the ages of 41 to 55 years, 11 percent were under 30 years and 28 percent were between 30 and 40 years. A number of youth were found to be active in farming. About 46 percent of the respondents never used fertilizer or have once used it but stopped. Reasons they gave included high and unaffordable prices, lack of interest, beliefs that fertilizer adversely affects taste of farm produce, and lack of knowledge about its use.

4. The Linear Programming Analysis

Linear programming (LP) models predict the effects of possible changes to a system by asking 'what if?' questions (Hildebrand, 2001). The model maximizes total gross margins of the various enterprises engaged in by women and men farmers at their resource endowments. The sum of the gross margins is maximized to assess the income level and optimum farm plan. According to Hazell and Norton (1986), the problem is to find the farm plan, which is defined by a set of activity levels, which has the largest possible gross margin, but does not violate any of the fixed resource constraints. Abdoulaye and Lowenberg-DeBoer (2000) stated that a representative farm linear programming model is used with solutions at various land, labor and capital levels. As such, the model is constructed for a representative farm rather than for individual farms.

According to Tegene *et al.* (1988), the decisions confronting each farmer at a point in time can be represented as a plan for capacity utilization - allocating the available resources among alternative crops. LP models can show why households choose the livelihood strategies that they do, given their resources and constraints. They also predict the effects of different policy situations on farm enterprises by allowing for sensitivity analysis to the model and simulating the complex farming system of smallholder households by including the many different crops, intercrops and other activities (Gladwin *et al*, 2001).

The general specification of the LP's objective function is:

$$MaximizeZ = \sum_{j=1}^{m} C_j X_j \qquad \text{(Objective Function)} \qquad (1)$$

Subject to the following constraints:

$$\sum_{j=1}^{m} A_{ij} X_{ij} \leq b_j \qquad \text{(Resource constraint)} \qquad (2)$$

$$\sum Q_{jk} X_{jk} \geq d_k \qquad \text{(Food consumption constraint)} \qquad (3)$$

$$x_j, \geqslant 0 \qquad \text{(Non-negativity constraint)} \qquad (4)$$

(i=1, 2, ...m; j=1, 2, ...n), where:

Z is the sum of gross margins of the various activities in the year, C_j is the gross margin per acre of the j^{th} activity in the year, and X_j is the level of the j^{th} activity in the year. A_{ij} is the requirement of the i^{th} resource by an acre of the j^{th} activity in the year. These are the technical coefficients. b_j is the level of the j^{th} resource available for the year. Q_{jk} is the yield per acre of crop k in the j^{th} activity, X_{jk} is the acreage of the activity in which crop k appears in the year, n is the total number of activities in which crop k appears (n=m if all the activities contain crop k), and d_k is the minimum quantity of crop k required by a household for consumption.

The resources constrained are land, labour and capital according to the levels employed by the farmers in order to answer the question 'given their current resource availability, what would they do to maximize returns'? A sensitivity analysis was undertaken to show the effects of making more of these resources available to the farmers. In addition to fourteen cropping activities, the model focused on labour hiring, capital borrowing, purchase of fertilizer, land rental, selling of produce, storage activities, purchasing of output for consumption, and consumption of output. The combination of crop production and other activities is to determine the optimum farm plan which will result in the maximum income level or maximum value of the objective function.

Production activities include the growing of food crops, vegetables, and cowpea. The authors built a one-year model, with two cropping seasons–a major season and a minor season. Unlike Delforce (1994), household consumption is relevant in this model and the household consumption requirements are estimated and used in model construction. Buying and selling prices are differentiated according to the time of the year at which the activity occurs. The price at which the farmer buys the produce and the price at which it is sold if they produced it are not differentiated in the model (Table 1). Because these are small-scale farmers, their subsistence activities are all included as was possible, including how they respond to lean season shortages. Small-scale farmers have little influence on price and can be said to be price takers. They maximize their activities in order to maximize profit.

The objective of the LP analysis is to determine the optimal farm plan in order to understand farmer response to the options for ensuring food security, given the crops that are grown by the farmers. A separate matrix was developed for male and female farmers. The results of the LP analysis present a practical decision-making tool. Maize is presented in three forms in the model: maize that is consumed, that which is sold immediately after harvest, and maize that is stored to sell later or stored for consumption in the lean season. Storage capacity is made available by the farmers constructing some form of crib (local or improved) to store their maize. Cassava, cocoyam and plantain are not usually stored and are therefore consumed or sold immediately after harvest. Vegetables are neither stored nor consumed in large quantities. Their production however can generate revenue to enable the farmer meet other financial needs.

A simulation analysis was conducted to observe the optimal income level, the profit generated by the various crops and whether the farmers will purchase what they consume or take it from own consumption. This includes a unit increase in the amount of land available and an increase in the credit to a level beyond which the objective function value does not increase.

Table 1: Assumptions of the model

Variable	Assumption	Explanation
Prices of produce	Selling price for produce is the same as price at which produce is purchased for consumption.	Price at which produce is sold and the price at which it is purchased for home consumption is not differentiated. Prices are generally higher in lean seasons, but the farmer also benefits from this higher prices if they have produce to sell
Variable costs	Variable costs include seed cost, cost of tools used, fertiliser cost.	
Cost of capital	Cost of capital includes the interest rate, which is included to the level at which capital is used.	An interest rate of 40% was applied to capital. Capital repayment period is one year. Loan to farmers are usually given on short-term basis
Other costs	Other costs include cost of storage	This allows farmers to store their maize to sell at a later date when prices are higher or for consumption in lean season
Land rental	Two additional acres were available to female farmers and 3 to male farmers.	Land rental was at a fee. These quantities were doubled in the simulation analysis.
Profit generated by crop	Profit is revenue minus variable costs, where revenue is the quantity sold multiplied by the price.	At the optimal farm plan, this amount is profit earned by the farmer after all variable costs are deducted and after allowances for what will be stored and consumed are taken from total output.

Table 2: Profit calculation by crop for female and male farmers

		Amount Produced			Profit per Crop (US$)		
Crop	Measurement	Base Level	Increase in Land	Increase in Capital	Base Level	Increase in Land	Increase in Capital
Female Farmers							
Optimal income level (US$)		*1,089.1*	*1,292.3*	*1,911.7*			
Maize - Major	Mini-bags [a]	6	6	26.6			316.5
Maize - Minor	Mini-bags	6.5	6.5	6.5			
Cassava	Mini-bags	10	10	16.1			28.1
Plantain	Bunches	140	140	143.1			4.1
Cocoyam	Mini-bags	9.4	3.3	16.1	51.4	18.1	88.2
Cowpea	Mini-bags	0	0	15.6			383.3
Tomatoes	Mini-bags	89.6	107.6	112	1,177.3	1,413.8	1,472.1
Male Farmers							
Optimal income level (US$)		*2,257.0*	*2,283.6*	*3,361.2*			
Maize - Major	Mini-bags	6	2	27.2			325.5
Maize - Minor	Mini-bags	6.5	6.5	6.5			
Cassava	Mini-bags	10	10	10			
Plantain	Bunches	140	140	438.1			391.8
Cocoyam	Mini-bags	5.4	3.8	7.1	29.4	21.1	38.9
Cowpea	Mini-bags	0	0	15.4			379.3
Garden eggs	Mini-bags	396.4	402.1	480	2,431.7	2,466.3	2,944.1

[a] 1 mini-bag of maize is 50kg, and 1 mini-bag of cassava is 45.5 kg.

5. Linear Programming Results and Discussion

The model analyzes the crop enterprises farmers engage in, the amount of labour needed for the various enterprises, level of input use, the output levels of the different crops, the capital availability for the farmer, and the amount borrowed. The model allowed for the consumption of food either from own production or from purchased products to meet the consumption requirements. The optimal income level recorded in the base model was about US$2,257[4] for male farmers and US$1,089 for female farmers (Table 2). Women in the study area face the same labour requirements and input and output prices as their male counterparts, though they are constrained with smaller farm sizes, less credit facilities, and have relatively lower output levels for some crops.

Among the resources, credit was found to be the most limiting factor for both male and female farmers. The capital base of the farmers does not match with increases in prices of inputs and they are unable to benefit significantly from grain price increases due to low levels of production and yields. An improvement in the non-farm economy in rural areas can help overcome the capital constraint to some extent, as well as help reduce poverty. A strong non-farm economy can give them multiple options of getting out of poverty with

[4] In early June 2013, US$1 was approximately equivalent to £0.64 and €0.76 (www.xe.com)

Table 3: Food consumption patterns

Produce	Requirement	Source of Produce		Cost to Farmer for Purchasing (US$)		
		From own Production	Quantity Purchased	Base Model	Increase in Land	Increased Capital
Female Farmers						
Maize: - Major	4 Mini-bags	All	0	-248.5	-248.5	-3.9
- Minor	3.5 Mini-bags	All	0	-269.7	-269.7	-2.8
- Major Stored	2 Mini-bags	All	0	-275.9	-275.9	-5.4
- Minor Stored	3 Mini-bags	All	0	-293.6	-293.6	-4.1
Cassava	10 Mini-bags	All	0	-102.1	-102.1	-1.6
Plantain	140 bunches	All	0	-28.6	-28.6	-0.5
Male Farmers						
Maize - Major	4 Mini-bags	All	0	-255	-255	-9.2
- Minor	3.5 Mini-bags	All	0	-265.8	-265.8	-7.7
- Major Stored	2 Mini-bags	All	0	-285.8	-285.8	-11.1
- Minor Stored	3 Mini-bags	All	0	-292.7	-292.7	-9.3
Cassava	10 Mini-bags	All	0	-125.7	-125.7	-1.5
Plantain	140 bunches	All	0	-33.8	-33.8	-0.9

1 mini-bag of maize is 50kg, and 1 mini-bag of cassava is 45.5 kg.

the ability to earn additional income to invest in the farm enterprise and to purchase food when the need arises.

The female farmers are neither renting any land in the major season nor using up all the land in the minor season. Having an additional acre of land in the major season will increase the net income by US$200 for female farmers. However, making less than US$200 available to them in the form of credit will increase their net income level by US$822. Further, the answer to the question of what is enough capital for these women was explored. These farmers have very little money to invest into their farm enterprises and the only way they can cope with increases in the price of inputs is when they have the opportunity to borrow capital to invest in the farm. Without additional capital, making more land available to them will not be beneficial. Land is useful only in the context of more capital.

Given their current resource endowment, results from the sensitivity analysis show that the optimum level of capital for female farmers in order to almost double their net income is US$180. The objective function changes considerably with increased capital while using the same amount of land. Considering the difficulties women have in accessing land, policy intervention, at least in the short term should be credit availability. A higher level of capital (beyond the optimal level) does not improve the solution at the current resource endowment. For male farmers, the optimum amount of capital is US$380. The objective function value for male farmers only increased by US$26 with a unit increase in land but went up by US$1,078 with the optimum credit level. Increasing credit beyond this level does not make a difference for male farmers either. Again, credit is an important factor for male farmers.

Profit from Various Crops

The profit generated for each crop based on the optimal farm plan was calculated to observe how the crops performed. This was done for the base model and repeated for increased land and capital level and the results shown in Table 2. The highest profit generating crop was garden-eggs for male farmers and tomatoes for female farmers. The level of profit for some of the food crops depends on the enterprises which enter the optimal farm plan. More maize, plantain, and cowpeas were produced and sold with increase in capital (Table 2).

The profit from maize is appreciable considering its importance for both food and cash. Production of maize, cassava and plantain are necessary for household food security. Maize could have been more profitable but much of it is used for household consumption, creating a difference between quantity produced and quantity sold. The maize that was sold by both female and male farmers with increased capital was stored maize, which attracts a higher price, although maize storage comes at some cost. All the staple crops, except cocoyam did not enter the optimal plan beyond what is needed to meet household consumption requirements until capital level changed.

Purchasing Food for Household Consumption

To ensure food security at the household level, a consumption constraint was included in the model. This guarantees sufficient food to meet the food needs of all household members all year round. Average household requirements of maize, cassava, and plantain were used. Since food security includes the ability to purchase food for consumption, food purchasing activities were included whereby farmers have the option of purchasing or producing the staple crops they eat.

The model allows the farmer to choose between producing and purchasing what they consume. When given the option of producing or purchasing food for home consumption, the LP results show that farmers would prefer to produce for their household consumption (Table 3). This portrays a typical characteristic of subsistence farmers, and is consistent with the results from the survey. Both male and female farmers face the same prices for selling and purchasing farm produce. The values in the last column of Table 3 show the amount by which the objective function value or farm income will decrease if a unit of the product is purchased (i.e. the cost for purchasing the different farm products for consumption). The cost of purchasing food was very high in the base model and with a one unit increase in land. In the base model, purchasing maize costs female farmers between 249 and 294 US dollars per unit, depending on the type of maize and the season in question. This result is not very different for male farmers. The cost of purchasing food however decreased considerably for both male and female farmers when more capital became available. Addressing the credit needs of rural farmers is particularly important for household food security.

6. Conclusion and Recommendations

This paper answers the question whether or not rural households will purchase food when it is not produced. Discussions about food security should focus not only on ability to produce but also on the ability to purchase when it is not produced. When given the option of producing or purchasing food for household consumption, the LP results show that farmers would choose to produce for their household food needs, portraying a characteristic of subsistence farmers.

This result gives an indication of the response pattern of farmers in times of drought and other crises that cause food shortage. Coping strategies such as reducing food portions and shifting to less preferred food are adopted in times of crisis. Policy intervention should focus on credit availability so farmers can produce crops that give them higher revenue, and increase the possibility of purchasing food when it is not produced. Appropriate strategies must be adopted to insulate the poor against food price increases as there is little probability that farmers will purchase food when there are price shocks.

Despite the fact that farmers in the Central Region of Ghana produce a surplus of some farm products for sale in the local market, they always ensure that they have sufficient maize and major staple crops for household consumption. Producing staple food crops assures farmers of food security, and they seem to continue producing these crops even when it is not profitable to do so. Results of a sensitivity analysis in the frame of LP modeling show that both male and female farmers did not buy food for consumption in any of the scenarios. The opportunity cost of purchasing food reduces when capital becomes available. A crop such as maize is not only important for food security but can be produced to generate financial resources for the household. However, credit is critical for increased productivity and the production of a marketable surplus.

The amount of additional capital needed in order to almost double the value of the objective function for female farmers is only US$180 for the year. For male farmers, an amount of US$380 results in an increase in their objective function by US$1,078. Additional capital beyond this level does not improve the objective function. Among the inputs that were constraining, credit is one that requires short-term policy intervention as land reforms take longer periods. Considering the difficulties women have in accessing land, in the short run, credit availability should be the focus of policy intervention. Without additional capital, making more land available to them is not beneficial. Land is useful only in the context of more capital. There is a high risk associated with agricultural production and financial institutions are hesitant extending credit to small farmers. But a policy environment can be created that addresses the credit needs of farmers to ensure increased production and improved incomes.

For yields to increase, farmers also have the responsibility of adopting improved and good agricultural practices, and improved varieties. At the same time, policy makers may need to consider providing specific support systems towards the acquisition of specific inputs and market access.

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Measuring agricultural sustainability at the farm-level: A pragmatic approach

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ABSTRACT

With increasing political pressure to produce more food whilst being environmentally and socially considerate, alongside the need to cope with climatic extremes and financial instability, farming needs to become more sustainable. To monitor and improve understanding of sustainable agriculture, farmers will need additional tools to illustrate the impacts of their business decisions. However, current tools to monitor the sustainability of agriculture require measurement of variables that are rarely readily available. Moreover these tools exclude farmers in their development and interpretation. This paper suggests a pragmatic approach to creating a farm-based monitoring tool. We propose that farm-level indices of sustainability are initially based only on data that is readily available. Whilst this would increase its appeal to farmers and therefore participation rates, it may initially have little immediate value as a measure of sustainability. Therefore a 'design-action-design' cycle–the basis of adaptive co-management– must be employed to allow the tool to evolve. Starting from this pragmatic, bottom-up perspective, as data collection systems improve, more theoretically driven (i.e. top-down) site-specific variables of sustainability can be included to provide a more comprehensive tool. This paper illustrates the principles involved by (i) calculating a farm-specific composite sustainability index (CSI) for a commercial farm based on readily available data and (ii) emphasising the need to establish better data collection systems.

KEYWORDS: Composite sustainability index; policy; farm-level; pragmatism

1. Introduction: Sustainable agriculture

The concept of sustainable agriculture (SA) has become increasingly influential to agricultural policy (Legg 2006). The term SA is derived from the definition of 'sustainable development' used by The Brundtland Commission (1987): "development that meets the needs of current generations without compromising the ability of future generations to meet their needs and aspirations." Sustainable development focuses on sharing resources spatially and temporally. From this beginning SA has evolved to means many different things to different people (White 2013), so producing an operational definition has proven "extremely problematic" (Rigby and Cáceres (2001). This is not helpful for businesses which require measurable and manageable objectives in order to achieve policy goals and become more sustainable for the benefit of the business.

The range of definitions reflects, in part, our lack of understanding of how ecosystems functions are affected by farming and other anthropogenic interventions in the short- and long-term. However, such definitional flexibility has benefits. A term that remains elusive can be subject to wider interpretation and therefore assume the function of a 'boundary object' (Franks 2010). A boundary object is a concept/idea the meaning of which is 'understood' by everybody ("I know it when I see it" (White 2013)) even though that word's meaning is not necessarily the same for different stakeholders.

The notion of sustainability as a boundary object has two important implications for agriculture. Firstly, it becomes necessary for all stakeholders to jointly develop an agreed and more complete, site-specific understanding of the impacts of farming on key ecosystem services. Secondly, approaches which claim to deliver SA must be constantly monitored, evaluated and reassessed over time. These dual requirements have increasingly led conservationists to include all sources of knowledge in their efforts to develop a more complete, locally-based understanding of farming's environmental impacts (e.g. life cycle assessment (Cederberg and Mattsson 2000)). This trend towards closer collaboration between researchers, policy makers and practitioners has developed a community of interest focused on *sustainable science* (SS) rather than *sustainable development* (Kates *et al.* 2005). It has also led to the development of notions of active and passive adaptive co-management (Armitage *et al.* 2008).

Active and passive co-management both recognise that rights and responsibilities should be shared among those with a claim to environmental and natural resources (Plummer 2009). In their discussion of the differences between active and passive co-management, Rist *et al.* (2013) make it clear that both incorporate the

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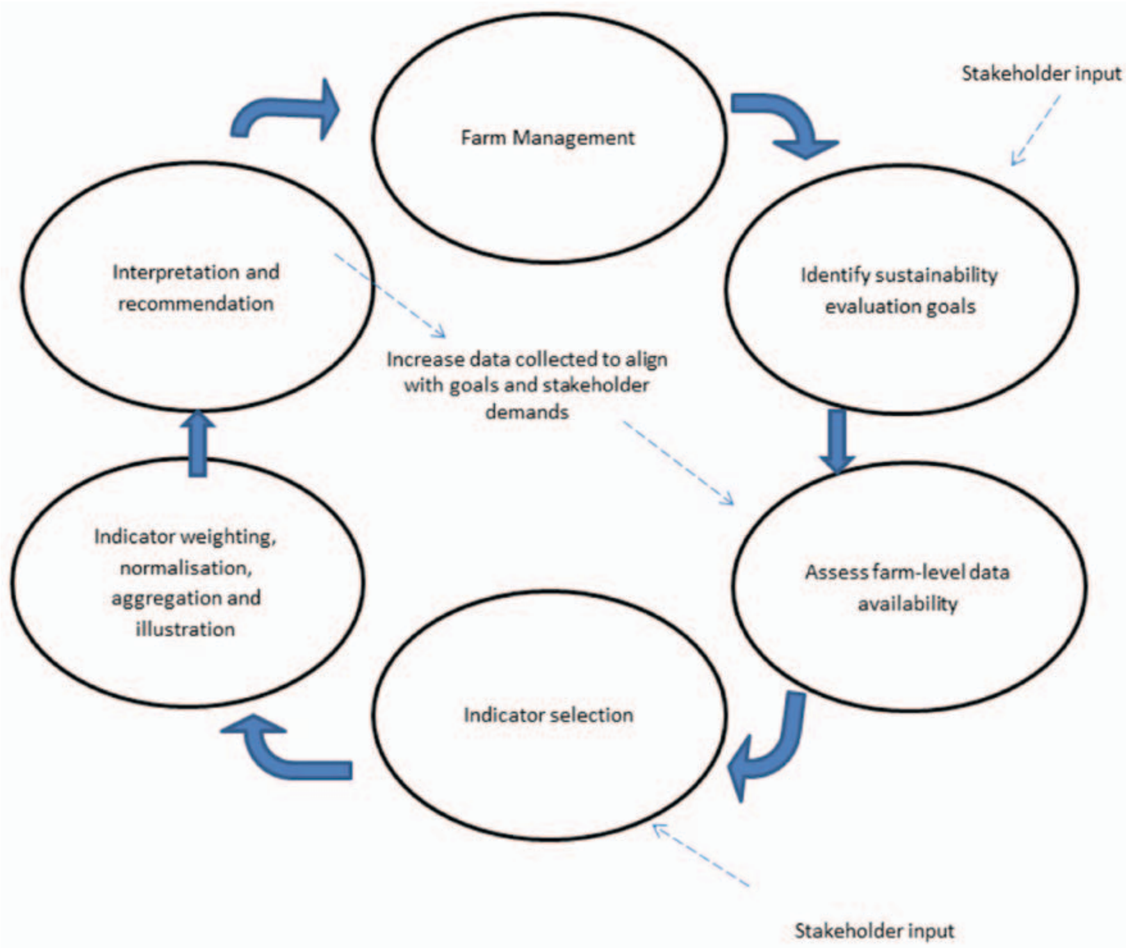

Figure 1: The concept of 'design-action-design' cycle in the evaluation of sustainable agriculture

need to modify activities as knowledge and experience grows. Both approaches incorporate the 'design-action-design' cycle. Adaptive co-management does so within a more deliberate experimental framework, while passive co-management is based upon a single course of action formulated using best available modelling and evidence (Rist *et al.* 2013). In this way, learning through experimentation (within a formalised framework, with informed and interested parties) can become instrumental in driving forward our limited understanding of agricultural sustainability.

Design-action-design

A 'design-action-design' approach to applying a specific sustainability measurement tool- the composite sustainability index (CSI)[2]- to quantify all aspects of SA is outlined in Figure 1. Indicators are based on measurements in order to record trends in relation to pre-specified policy objectives and targets. As the methodology develops, redundant measurements and new measurement requirements are identified.

As understanding of the environmental impacts of farm management decisions become clearer, management blueprints need to be revised and thereby the sustainability of individual farm businesses can improve. This is particularly important because whether a practice is sustainable depends upon the context within which the techniques and practices are used; what represents a sustainable technique will "vary both temporally and spatially" (Rigby and Cáceres 2001).

We argue for a bottom-up perspective to determine indicator selection rather than the top-down perspective because, despite a degree of uncertainty, action is required to evaluate SA (Rigby and Cáceres 2001) and we believe a pragmatic approach is the best way to move forward. Our starting definition of SA will be taken from the Sustainable Agriculture Initiative as the 'need to safeguard agricultural products, while protecting and improving the natural environment and social/economic conditions of local communities' (SAI 2010). Many variables might be used to reflect each component of the triple bottom line (a point that is discussed later), but the pragmatic approach would be limited by variables that are currently readily available. In this way, widespread participation is more likely because application is non-prescriptive. Individual farms are likely to have different data readily available therefore the initial index will vary across farms, with a degree of convergence developed over time to encompass information summarising the triple bottom line.

Over time the index will develop to more accurately reflect local sustainability targets as indicated by local environmental targets (e.g. Natural England's natural

[2] The CSI aggregates multiple indicators to provide a single value and/or a diagrammatical representation of the sustainability of a process. An indicator is a qualitative or quantitative measure that reflects a criterion and can be used as a standard on which a judgement or decision may be based (López-ridaura *et al.* (2005)).

character area priority concerns), economic requirements to maintain a thriving and successful business, and the resources demanded and supplied by the rural economy. Convergence will allow the indicator to be compared on a like-for-like basis between farms. Over time therefore, the variables measured and combined into a single sustainability index value will more closely reflect the farm's short- and long-term resilience and the ecosystem's ability to buffer shocks (Pretty 2008; Darnhofer *et al.* 2010). The initial pragmatically identified starting-point will quickly develop to use variables more closely aligned with the theoretically developed notions of sustainability.

The next section puts this approach into context by reviewing the literature to identify competing methods to assess farm-level sustainability. This is followed by a review of how the CSI is typically constructed and suggested methods to develop a farm-level CSI. Section 4 illustrates application of the CSI on a commercial farm. Section 5 discusses the benefits and disadvantages of the pragmatic, bottom-up approach compared to the theoretically driven, top-down approach. Section 6 concludes.

2. Methods to assess agricultural sustainability

The literature review suggests current agricultural sustainability tools are based on adapted versions of four main methods: life cycle analysis (LCA), green accounting, ecological footprinting and the CSI (Table 1). Whilst LCA is comprehensive (Cederberg and Mattsson 2000), it is also expertise- and time-intensive, which limits its applicability. It also doesn't typically include economic and social measures and struggles with qualitative data (e.g. biodiversity) (Lindeijer 2000). Green accounting incorporates the economic pillar of sustainability (Bartelmus 1999; Bartelmus and Vesper 2000; Halberg *et al.* 2005), but is also difficult to apply due to large data requirements and methodological fallibilities, particularly related to the estimation of monetary values for non-marketed public goods and other ecosystem services. It is generally not applied at the farm-level. Ecological footprinting developed by Wackernagel and Rees (1996) adopts a more pragmatic approach. Calculating the area of land used is relatively straightforward, and farm greenhouse gas (GHG) emissions and carbon sequestration can be estimated using LCA and on-line calculators (such as the Carbon Accounting for Land Managers calculator (CLA 2009) or the Cool Farm Tool (Cool Farm Institute (2012)). However, Ecological footprinting only assesses a portion of the environmental dimension of sustainability (i.e. land-use, GHG emissions and chemical outputs). On the other hand, it could form part of the holistic assessment.

Each approach has its advantages and shortcomings and each has been widely used. However, as it is generally considered necessary in sustainability evaluation to embrace all three dimensions and scales of rural land management- the assessment method needs to be multi-dimensional and the CSI approach is the only one with the capacity to achieve this.

The ideal CSI uses a straightforward, flexible and repeatable methodology to allow meaningful intra- and inter-farm comparisons (e.g. Nambiar *et al.* (2001), Rigby *et al.* (2001), Gómez-Limón and Riesgo (2009)). Like other approaches, the CSI can condense sustainability into a single data value which provides an efficient and easy to understand summary of status and trajectory towards targets for external stakeholders. The main drawback of the CSI approach is the difficulty practitioners have in agreeing: (i) which variables to use in the composite index and (ii) how to combine these variables in a way that best reflect each variable's contributions to sustainability. Nevertheless, it is because the benefits outweigh the disadvantages that studies have used the CSI methodology to measure sustainability across a large number of industries (e.g. steel OECD (2008)) and scales (e.g. village catchment, e.g. Izac and Swift (1994) to country, e.g. Bandura (2008), Esty *et al.* (2005)).

3. Composite Sustainability Index (CSI): methodological issues

A CSI is created from numerous component variables which are amalgamated to provide a summary of sustainability in a single value and/or informative radar web (sustainability web) (e.g. AMOEBA[3] (Wossink 1995)) . The variables that are typically selected reflect the researchers' notion of sustainability. To create a CSI, five methodological issues need to be addressed sequentially (Gómez-Limón and Riesgo 2009):

(i) Selection of the all the variables to be used in the CSI;
(ii) normalisation of each of these variables;
(iii) assigning weights to each variable which reflect that variable's contribution to that particular dimension of sustainability;
(iv) aggregation of these normalised values to create the mulit-dimensional CSI;
(v) presentation of the CSI so it can be easily and accurately interpreted.

This section illustrates the different approaches practitioners have used at each of these steps.

Selection of the component variables of sustainability

When selecting which variables to use, practitioners have typically started by defining sustainability and then traded the ease of obtaining data with the theoretical importance of the variable in their definition. One direct consequence is that studies have used a wide range of variables in their model (Table 2). Whilst this suggests that CSIs are highly subjective, environments and the threats to them do vary, so indicators do need to be country-, regional- and farm-specific. They will also depend on the development stage of the region and the intended use of the CSI (QIU Hua-jiao *et al.* 2005).

A study of Table 2 shows that selected variables tend to fall into one of two categories. They are either directly measured or ranked in relation to one another (e.g. those based on different management practices) (Nambiar *et al.*

[3] AMEOBA is a Dutch acronym translating to 'general method of ecosystem description and assessment'. The method depicts the sustainability of the business as a 'map' reflecting attainment of selected attributes.

Table 1: Details of a selection of agricultural sustainability assessment methods

Assessment tool	Principles	Merits	Drawbacks	Data requirements	Literature examples
Life Cycle Analysis (LCA)	Detailed examination of the environmental burdens arising from production.	Comprehensive account of a product's environmental impacts.	Rigid system boundaries make accounting for changes in the system difficult. Lacks social dimension. Requires time and expert input to apply.	Inventory of all flows from and to nature, (e.g. energy and raw material inputs) and their impact assessment.	Cederberg *et al.* (2000), Williams *et al.* (2006)
Green accounting (GA)	Extension of the conventional economic accounts to include natural resource use and abuse by economic activity (Bartelmus *et al.* 2003).	Provides incentives to improve the way we use natural resources.	Commodifies nature. Valuation must be continually updated. Difficult to apply money-metric measures of value.	Key ecosystem services, their physical parameters and means of valuation.	Grêt-Regamey and Kytzia (2007)
Ecological Footprinting	'area of productive land and water ecosystems required to produce the resources that the population [under assessment] consumes and assimilate the wastes that the population produces (Rees 2000).	Condenses complex impacts into a single intuitive number.	Fails to account for greenhouse gas emissions, national boundaries, intensive production and land degradation over time.	Land area occupied, farm emissions, land area used to produce the inputs produced off-farm (e.g. non-renewable energy, feed).	Van der Werf *et al.* (2007)
Composite Sustainability Index (CSI)	Aggregation of a combination of multidimensional indicators to formulate a composite indicator.	Summarises multiple measurements for ease of interpretation and comparison. Flexible approach	Indicator choice and weightings method are subjective. May conceal problems in the farm production process.	A range of measurements based on the set of indicators selected.	Rigby *et al.* (2001)

Table 2: Details of the methods used in ten research papers applying sustainability indicators at the farm-level

Authors	Country	Products	Sustainability dimension	Indicators selected	Aggregation and Interpretation	Output form
Castoldi and Bechini (2010)	Italy	Cereals and forages	Economic Environment	Variable costs Gross Income Gross Margin Nitrogen soil surface balance Phosphorous soil surface balance Energy Input Energy Output Energy Gain Load index algae Load index crustaceans Load index fish Load index rats Crop sequence indicator Soil cover index Soil organic carbon indicator	Summed stakeholder rank for each system are averaged for easy comparison	Global Sustainability Index
Gómez-Limón and Riesgo (2009)	Spain	Winter cereals Spring crops (maize, sugar-beet, Sunflowers, potatoes, etc.)	Economic Social Environmental	Income of agricultural produce Contribution of agriculture to GDP Insured area Agricultural employment Stability of workforce Risk of abandonment of agricultural activity Economic dependence of agricultural activity Specialisation Phosphorous balance Pesticide risk Use of irrigation water Energy balance Agro-environmental subsidy areas Mean area per plot Soil cover Nitrogen balance	Used a joint analysis with different techniques of aggregation and weighting methods. Aggregation methods compared were: weighted sum of indicators, product of weighted indicators, and a multicriterion function to represent total, partial and varying degrees of compensation. Weighting methods included statistical and expert-input methods	Composite Indicator of Agricultural Sustainability (CIAS) comparing rain-fed agriculture and irrigated agriculture
Williams et al. (2006)	UK	Bread wheat, potatoes, oilseed rape, tomatoes, beef, pig meat, sheep meat, poultry meat, milk, eggs	Environment	Primary energy used GWP Eutrophication potential Acidification potential Pesticides used Abiotic resource use Land use Irrigation water	Comparisons of ten commodities per tonne of product allows the reader to see which commodities are more efficient with respect to the indicators and yield (i.e. data is not aggregated into a single index)	Data in raw form per tonne of product and per hectare

Table 2 continued: Details of the methods used in ten research papers applying sustainability indicators at the farm-level

Authors	Country	Products	Sustainability dimension	Indicators selected	Aggregation and Interpretation	Output form
Pimentel et al. (2005)	USA	Corn, soybeans, corn silage, wheat, alfalfa hay, winter wheat	Environment Economic	Crop yields (Under normal rainfall and drought) Energy inputs Soil Nitrogen Nitrate leaching Herbicide leaching Soil biology Soil carbon Net return	No aggregation, highlights the significant differences found and proposes that organic farming is more sustainable	Indicator comparisons per hectare or percentages for the three systems in the study
Pacini *et al.* (2003)	Italy	Cereals, broadbeans sugar beet, milk, beef	Environment Economic	Nitrogen leaching Nitrogen run-off Nitrogen losses Phosphorous sediment Soil erosion Environmental potential risk indicator for pesticides Herbaceous plant biodiversity indicator Arboreous plant biodiversity indicator Hedge biodiversity indicator Crop diversity indicator Revenues Variable Costs Gross margin	No aggregation, yet the paper compares compliance of farms with environmental thresholds from literature and laws and regulations	Comparison tables between organic, integrated and conventional farms, data in raw form given per hectare or % area
Reganold *et al.*(2001)	USA	Apples	Environment Economic Social	Soil quality Adverse impacts of pesticides and fruit thinners Energy input: Output ratio Orchard profitability Fruit yields Size and grade Tree growth. Leaf and fruit mineral content Fruit maturity Consumer taste tests	No aggregation but inference of sustainability based on incorporation of external costs and valuation of ecosystem services	Comparative tables of soil quality, yield, environmental impact, economics and energy balances of the three systems
Rigby *et al.* (2001)	UK	Various	Environment	Seed source Soil fertility Weed control Pest/disease control Crop management	Weighted sum of scores. Wide ranging results show that other factors are involved in the determination of sustainability	Web diagrams comparing organic and conventional horticultural systems

Table 2 continued: Details of the methods used in ten research papers applying sustainability indicators at the farm-level

Authors	Country	Products	Sustainability dimension	Indicators selected	Aggregation and Interpretation	Output form
Nambiar *et al.* (2001)	China	Various	Environment	Agricultural nutrient balance Crop yield Fertiliser use efficiency/ Irrigated water use efficiency (%) Soil erosion *t*(soil/km2)/ soil saline content Input/output of energy Clay content (%) Soil depth (cm) Bulk density Available water capacity Organic matter Phosphorous soil surface balance Permeability Electrical conductivity Cation Exchange Capacity (CEC)	Weighted product of all sustainability components. Annual means for each region are calculated and compared	Agricultural Sustainability Index
			Economic	Income per labour Real net output per land unit		
			Social	Cultural level		
Haas *et al.* (2001)	Germany	Dairy	Environment	Application of herbicide and antibiotics Potential of nitrate leaching NH_3-emission Grassland (no. of species, date of first cut) Hedges and field margins (density, diversity, state/care, fences) Grazing animals (period, breed, alpine cattle keeping) Layout of farmstead (regional type, buildings, farm garden, trees, orchard)	Used estimated thresholds to normalise the data to graph using radar charts, therefore no single CSI is produced and systems are compared based on the 'space' they occupy in the graph	Inventory (schematic) of selected impact categories and indicators of Life cycle assessment for 3 system types
			Social	Housing system and conditions, herd management (e.g. Lightness, spacing, grazing season, care)		
Jansen *et al.* (1995)	Costa Rica	Various	Environment	Balances of N, P and K in soil	Linear programming model to aid achievement of sustainable land use at higher levels	GIS mapping of biocide index and nutrient balances for the four system types

2001). Directly measured variables require greater time and resources, whereas ranked measurements can add to the subjectivity of the study. However, ranked measures do allow positive and negative scoring reflecting the potential positive and negative impact of management activities (Rigby *et al.* 2001). Though selection of variables is typically guided by theory, additional subjectivity occurs in selecting the variables to use in the final index as those which reflect the same aspects of sustainability will need to be whittled down to prevent multicolinearity (overlap).

To help address these problems, a participatory approach which employs stakeholders expertise is recommended (Hodge and Hardi 1997; Speelman *et al.* 2007). For example, López-ridaura *et al.* (2005) obtained stakeholders' views through two rounds of interviews and selected from amongst the views offered using a hierarchical decision-making process. After identifying the objectives of the stakeholders, suggested variables were classified into one of the following sustainability attributes: productivity, stability, reliability, resilience or adaptability (López-ridaura *et al.* 2005). The second round of stakeholder interviews used these sustainability attributes to select the variables to use in the CSI and to estimate the weights to attach to each composite variable. Finally the selected indicators and their values were considered by their spatial scale (i.e. farm-level, regional, national or global) (López-ridaura *et al.* 2005). For this method to be acceptable it must include representatives across the entire stakeholder spectrum; a balanced and carefully selected interviewee group is necessary. Some studies use a hierarchical method to determine dimensions of sustainability and refine the indicator set so it meets the goals of the study (e.g. Hani *et al.* (2003), Zahm *et al.* (2006)). Other studies employ expert panels to select variables considered to be analytically sound, measurable and of policy relevance (e.g. Gómez-Limón and Riesgo (2009)). Alternatively, one can select component variables for a CSI by reference to the literature (Castoldi and Bechini 2010). Table 3 displays the large number of attributes of sustainability captured in a selection of published studies, which could inform the indicator selection process.

Normalisation

Once variables have been selected they need to be transformed onto a common scale in a process termed normalisation (Gómez-Limón and Riesgo 2009). This allows each to be compared with the others. Several approaches have been used to normalise variables (see OECD (2008) for a comprehensive account). The following have been applied at a farm-level:

(1) Use of site-specific tolerability ranges or reference values to scale variables (Eckert *et al.* 2000; Gómez-Limón and Riesgo 2009) these values can be hard to obtain unless their availability had formed the basis for variable selection.

(2) The min-max approach (OECD 2008; Gómez-Limón and Riesgo 2009), this is the observed value for the specific variable minus the minimum value in the data set for that variable divided by the range in the data set for that variable (OECD 2008). For example, if a selected variable has a value of 200, and the range and minimum values found in the dataset for that variable are 250 and 50 respectively, then the observation's min-max normalised value would be calculated as (200-50)/250 and equal 0.6. This is only useful to compare amongst those in the sample.

(3) In their comparison of different farm systems Maeder *et al.* (2002) took the values of the selected variables from one system as the reference values and used this to compare with the variables' values recorded in the other systems. This approach can be used when working with a small sample and when variables need to be interpreted relative to one another. It may be most useful when values need to compare change over time rather than between locations.

Weighting of the indicator values

Generally weights are assigned to each selected variable according to the contribution that variable makes to agricultural sustainability (OECD 2008). Again, stakeholder consultation can assist at this stage. For example, Castoldi and Bechini (2010) asked a sample of farmers, researchers, agronomists, decision-makers and environmentalists to assign weights to selected variables to reflect their views of the contribution each variable made to agricultural sustainability. Each agricultural system was ranked by applying the weights provided by these expert groups (Castoldi and Bechini 2010). A less involved method uses weights reported by a single expert panel (Zahm *et al.* 2006; Gómez-Limón and Riesgo 2009).

Other studies score the sustainability of different agricultural practices using their knowledge of sustainability-impacts and the scientific literature (e.g. Rigby *et al.* (2001) and Rodrigues *et al.* (2010)). For example, using the literature as a base for identify commonly used criteria of agricultural sustainability, Rigby et al. (2001) allocated a score to a range of farming practice based on whether that practice was considered to improve or diminish a farm's environmental impacts. Although open to criticism because of the added subjectivity, this approach facilitates the widespread application of sustainability indices. Moreover, if clear links between action and environmental impact can be identified, these links can be standardised even though they are estimated by different researchers.

Aggregation

The method chosen to aggregate normalised and weighted variables influences the 'compensation' permitted between them, i.e. it influences the degree to which favourable practices are allowed to offset harmful ones (Bockstaller *et al.* 1997). The method of 'summing of scores'[4] allows full compensation between the component variables, which may be sensible where variables are related. For example, a low level of animal diversity can be partially compensated by a higher degree of crop diversity (Zahm *et al.* 2006). However, full compensation is not appropriate for all indicators; a low level of nitrate leaching cannot balance a higher level of pesticide volatization (Bockstaller *et al.* 1997). Compensation between measures can be limited by assigning high weights to one (e.g. nitrate

[4] Summing of scores is where the value for each variable is summed to produce an aggregate value. This method allows some values to offset others as full compensation between values is permitted.

Table 3: Attributes used in the literature to assess farm-level sustainability

Attributes	Jansen *et al.* (1995)	Eckert *et al.* (2000)	Haas *et al.* (2001)	Nambiar *et al.* (2001)	Reganold *et al.* (2001)	Rigby *et al.* (2001)	Hani *et al.* (2003)	Pacini *et al.* (2003)	Pimentel *et al.* (2005)	Zahm *et al.* (2006)	Gómez-Limón and Riesgo (2009)	Castoldi and Bechini (2010)	Rodrigues *et al.* (2010)
Ecological integrity	X	X	X	X	X	X	X	X	X	X	X	X	X
Economic viability					X	X	X	X	X	X	X	X	
Energy efficiency		X	X	X			X		X		X	X	
Productivity	X	X		X	X	X			X				
Social Integrity				X		X	X			X	X		X
Diversity		X						X				X	X
Health and welfare			X							X		X	X
Landscape image			X							X			X
Produce quality					X					X			
Subsidy independence								X			X		
Reproducibility		X								X			
Longevity											X		
Risk aversion													X
Self sufficiency						X							
System efficiency		X											

leaching) and low weights to the other (e.g. pesticide volatization) relative to the importance placed on each variable. The literature uses three approaches to aggregate selected variables into a single CSI value:

(1) weighted product (e.g. Nambiar *et al.* (2001));

(2) weighted sum of score (e.g. Zahm *et al.* (2006));

(3) use of a computer algorithm, such as Principal Component Analysis (PCA), (e.g. Sands and Podmore (2000)).

Nambiar *et al.* (2001) summed the normalised variables and then multiplied these composite indicators together to form an Agricultural Sustainability Index (ASI). This approach allows the related variables in each composite indicator to fully compensate each other, whilst the multiplication allows partial compensation between the composite indicators (Gomez-Limon and Riesgo, 2009). PCA has also been used, but as this requires a large number of observations it cannot be used to assess the sustainability of small samples (Sands and Podmore 2000; Barrios and Komoto 2006).

Some researchers by-pass the aggregation stage, or add to the aggregate value, by using diagrams, such as sustainability webs, in which relative value of each variable/component indicator is illustrated without aggregation (Haas *et al.* 2001; Rigby *et al.* 2001; Hani *et al.* 2003; Speelman *et al.* 2007). This approach normalises each variable/component indicator to a value between zero (the centre of the web) and 1 (the edge of the web) with each variable/component indicators value assigned to its own 'spine'. This allows users to see clearly which attributes of sustainability have a strong and weak presence in the study. This transparency can complement the presentation of a single, summary CSI value as it allows users to assign to the data weights which more closely suit their own purposes and understanding.

Indicator relationships

Individual component indicators used to calculate a CSI are likely to influence each other (Speelman *et al.* 2007). For example, Speelman *et al.* (2006) analysed the trade-off between the retention of crop residue to reduce soil erosion and soil loss in a region prone to soil loss in Mexico. They conclude that 100% crop residue retention would negatively affect farmer's incomes, but 35% crop residue retention combined with free grazing, maximised net income, improved forage self-sufficiency and reduced soil loss. This implies that there are circumstances when the allocated weights need to be non-linear, that the influence of one variable on another must be permitted. However, this generally requires detailed knowledge of many interactions, information that is often simply not available. In these cases, evaluations may benefit from using reference values/regulatory targets (see for example Eckert *et al.* (2000), Gómez-Limón & Riesgo (2009)) using the approach which allows comparisons against a 'norm' or a 'tolerable range'. Additionally, researchers and stakeholders should consider the interactions between indicators at the weighting stage.

Section summary

This section has referred to many studies which have addressed the problems relating to summarising multi-variable conditions in a single value. In view of the wide range of definitions and dimensions assigned to sustainability, it is perhaps not surprising that there is no accepted agreement on the use of a restricted set of variables, agreement on the weights to assign to each variable and to the aggregation step. As a consequence CSIs are not used as yard-sticks in policy instruments despite their potential for comparing trends in sustainable resource use and sustainability over time, between locations and systems.

This study addresses these problems from a farmer-centred perspective. It is based on the assumption that CSIs are able to measure sustainability *over time at the same location*. It also takes into account the practical reality that such measures are more likely to be calculated if they can be implemented at little cost. To facilitate this, it is argued that CSI must be developed by utilising readily available information, but that variable selection will evolve through time using 'design-action-design' cycles. For example, data on important variables, such as percentage of inputs sourced locally may not exist in the initial years, and annual changes in selected variables will not exist in the first year of the study. New data recording systems would need to be established to measure variables for which data is not currently available. This may be relatively inexpensive to do, especially if examples of best-practice recording are exchanged between farmers.

4. Application of farmer-centred CSI: a conventional dairy system

An example of the calculation of a farmer-centred CSI using readily available data in the first stage in a 'design-action design' cycle used data gathered from the Newcastle University owned, 300ha tenant farm located 12 miles west of Newcastle upon Tyne near Stocksfield in the Tyne valley (OS grid reference NZ 064 657). The farm is at an average elevation of 112m, benefits from well-drained sandy clay loam soil and has an average rainfall is 630 mm/yr (MetOffice 2011). The principal enterprises are dairy and arable, though it has a small-scale vegetable enterprise and produces beef. The farm is unique in the UK in that a block of 135 ha is managed organically with the remainder farmed conventionally[5].

Step one requires the selection of variables to use in the CSI. An initial list of 43 indicators was drawn up based on those used in the literature listed in Table 2 (see Appendix 1). Each represents at least one of the three pillars of sustainability and taken together they embrace the majority of the sustainability attributes listed in Table 3. It is noted that the environmental pillar appears to be over-represented compared to the social pillar.

To prevent overlapping between variables, make the CSI more tractable and to reduce costs this list was whittled down in discussion with the farm manger, based on three criteria: (i) ease of availability of data; (ii) accuracy of measurement and (iii) coverage of all dimensions of sustainability. Farm data over a five year period (2005- 2010) was recovered from two computer

[5] The study calculated a CSI for the organic and conventionally farmed land, but only those values computed for the conventionally managed farmland are presented here.

Table 4: Selected variables for current study with definitions

Component Indicator	Units	Definition
1. Nitrogen (N), phosphorous (P) and potassium (K) balances	Kg /ha	The difference between N/P/K input and crop N/P/K requirements (calculated from cropping history, soil texture, target market, etc. using the UK Fertiliser Manual (Defra 2010))
2. Profit margins	£/ha	Income minus fixed and variable costs per hectare
3. Subsidy dependence	%	Percentage of income derived from subsidies (i.e. Single Payment Scheme payment and Entry Level Stewardship payments)
4. Productivity	t/ha	Grain sold off farm, excluding forage crops used on-farm
5. Diversity		
6. Field size	Ha	Average field size
7. Crop diversity	Index (H_s)	Shannon Weaver diversity Index based on the number of crop types and their respective proportions

programmes: Farmplan Computer System (part of Reed Business Information ©) Crop Manager and Farm Business Manager.

Ready availability of data is the prerequisite for this study which takes as its starting-point the farmer's perspective, though the fact that the farm was divided into organic and conventional production systems created data availability problems that might not be encountered on typical farms. Eventually six variables were selected, one of which (diversity) being a composite made up of two measures (Table 4).

The principles of easy access to accurate data and adaptability to local conditions means that the variables selected for another farm would most likely vary from this list (in content and number) at the first rounds of the 'design-action- design' cycle. This should not be seen as a problem given the intention to evolve the selection over time so more variables are available from which indicators can be selected.

The min-max method was used to normalise the selected variables (OECD 2008; Gómez-Limón and Riesgo 2009). Each variable will have a different optimum value, for example, the optimum nitrogen (N), phosphorous (P), potassium (K) balance is assigned the value of zero which represents ecological integrity, economic viability (i.e. the fertilisers are being used at optimum efficiency), and minimal health and welfare risk in terms of nutrient leaching (Table 5). To ensure high values signified positive effects on sustainability, indicators of poor sustainability, such as high subsidy dependence and high nutrient surpluses/deficits were inverted. The maximum and minimum values were derived from pooling variable values over the 5 year period, and the minimum value for each variable subtracted from its observed annual value which was then divided by the range of that variable within the 5-year period. In this way the normalised values reflect the variance within the system over five years, annual min and max values can be used on larger data sets.

To calculate the weights to assign to each variable, each indicator was scored against the number of attributes of sustainability it encompasses (in Table 5). The recorded value of each variable was therefore multiplied by this weight and the products summed into a single CSI. This approach was compared to using an unweighted CSI to investigate the significance of weighting. Unweighted CSIs were calculated by multiplying the normalised value of each variable by 0.17 (i.e. as there are six variables each is given a weight of one sixth), and summed for each year. These normalised variables are then presented in 'sustainability webs' (produced using Microsoft Excel 2010 © radar charts).

5. Research findings

The weighted and un-weighted CSI for each year is listed in Table 6. Both approaches show that the farm was most sustainable in 2007 and least sustainable in 2005. No clear trends can be deducted from either CSI (Figure 2) which infers that no progression or regression is occurring. Year 2005 and 2007 appear out of line with the sample average. The farm manager would most likely be able to identify the reason for this, but it may be caused by factors external to the farm and as such be beyond the managers control (such as input and output prices, weather and staff health).

The sustainability webs for each of the five years showing the underlying value of the selected variables is presented in Figure 3 – confirming the lowest value occurred in 2005 and the highest in 2007. Profit margin was highest in 2005 when subsidy dependency, crop variety diversity and field area were lowest, in terms of sustainability. Conversely, profit margin reduced in 2007 when these same variables and yields were highest. This suggests there may be a trade-off between profit margin and the other indicators. As mentioned above, the variable/composite indicator used to calculate the CSI value ideally needs to measure a different aspect of sustainability to keep overlap (i.e. correlation) to a minimum, but those in the example are closely related hence the notable trade-offs occurring. With the nature of agriculture, one could argue that a multitude of factors do interlink, thereby making the selection of unrelated factors difficult.

The results suggest that (i) the selected weights had little discernible impact on the CSI value and (ii) the variables selected are closely correlated with the year with no clear trend prevailing. This reinforces the need to develop this on-farm CSI within the 'design-action-design cycle' framework. To facilitate this it is important to develop tools that can assist farmers to measure and record a wider selection of variables each year. If these data were pooled across a larger sample of neighbouring farms they could be normalised using the min-max of the sample rather than from the same farm. Widening the sample across which variables are measured would also allow the CSI to be more use as a benchmarking

Table 5: Scoring of the selected indicators based on attributes from the literature

Measure	Sustainability attribute													Score	Overall weighting (score/ total score)
	Ecological integrity	Economic viability	Efficiency	Productivity	Social integrity	Diversity	Health and welfare	Landscape image	Produce quality	Subsidy independence	Self - sufficiency	Longevity	Risk aversion		
NPK Balances	1	1	1	1			1						1	6	0.24
Profit margin		1		1	1					1		1		5	0.20
Yields		1	1	1						1	1	1		6	0.24
Subsidies		1	1		1					1	1			5	0.20
Diversity	1					1		1						3	0.12
													Total Score	25	

The sustainability attributes in this table are those most commonly used in the literature.
NPK refers to nitrogen, phosphorous and potassium respectively.

Table 6: Aggregate CSI for the conventionally managed farm land over a five year period

Year	Weighted CSI	Equally-weighted CSI
2005	0.396	0.309
2006	0.593	0.667
2007	0.803	0.874
2008	0.484	0.540
2009	0.513	0.590

tool, we recognise it is of little value for such use as currently calculated.

6. Discussion

Rigby *et al* (2000) noted a key advantage of developing sustainability indices; it pulls 'the discussion of sustainability away from abstract formulations' and requires 'explicit discussion of the operational meaning of the term to be revealed': each variable within an indicator needs to be justified. However, this approach reflects a traditional top-down approach in which the variables needed for the index are specified before field work begins. The approach set out here reverses this order of priorities. It identifies those data that are readily available and selects from them the ones which most closely match policy objectives and targets. The example used here clearly suggests that this approach is unlikely to provide a particularly useful measure in the first year as readily available data are unlikely to provide an ideal match with the 'triple-bottom line'. Providing this is regarded as a starting-and not a finishing-point, and given sufficient support to allow development over time, a wider range of variables can be measured from which a more appropriate set can be used to illustrate a farm's sustainability trajectory. This discussion continues with a brief discussion of some of the additional key issues raised by this study.

Indicators and policy goals

It is most likely because of the methodological limitations, that CSIs have not been used by policymakers. The approach advocated here would improve the utility of CSI to a point where they may be considered within cross-compliance obligations or as an option in environmental stewardship scheme. Progress in science and policy is often made from adopting a pragmatic approach based upon a multi-period 'design-action-design' framework (as this is the basis of the scientific approach of observation, hypothesis, experimentation, interpretation leading to a newly formulated hypothesis).

As involvement of farm managers is essential, each needs to gain some advantage from participation. Some farmers will be able to benefit from using sustainability measures to brand products to give them a competitive advantage, or use them to help identify win-win activities on their farm (for example reducing the expensive use of surplus fertilizers). These benefits suggest there will be a pool of farmers who would voluntarily calculate CSI values, but others will need additional incentives. One approach to assist on-farm development would be to provide technical data collection and

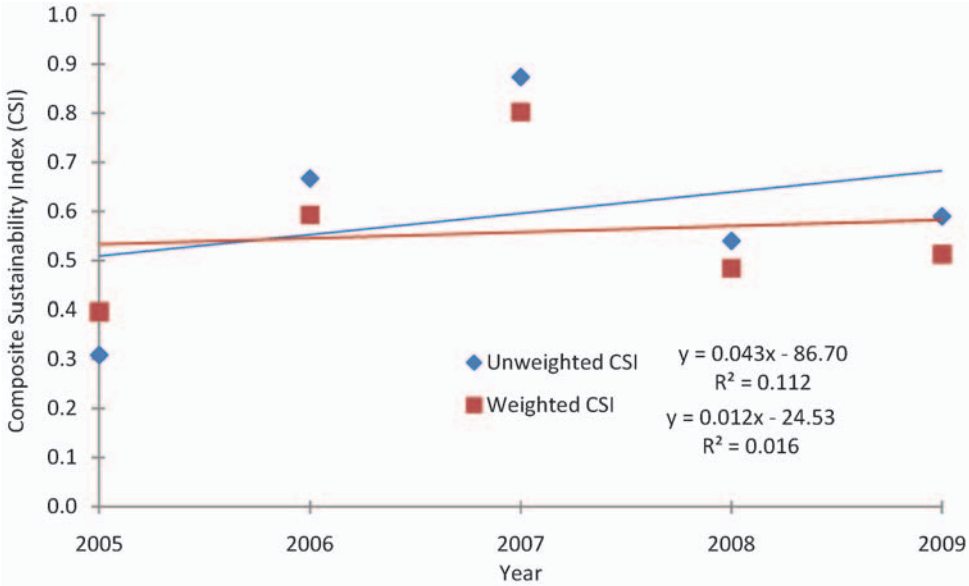

Figure 2: Composite Sustainability Index trends for a conventional dairy system

recording support to a pool of neighbouring farmers who are willing to develop a CSI. This will increase the speed at which the index becomes more useful and the likelihood that farmers will find value by incorporating the environmental consequences of their farm management decisions into their activities.

The inherent difficulties of the indicator-based approach

The inherent difficulties related to the lack of consensus on the definition of 'sustainable agriculture' have proved a barrier to its practical usefulness (Gómez-Limón and Riesgo 2009). However, because the concept of sustainability has remained flexible it has been 'adopted' as a desirable goal by a wide range of stakeholders. Moreover, given the site-specific nature of environmental and rural economy objectives and targets, it is not desirable to select the same set of variables to measure CSI at every location (Bell and Morse 2008)[6,7]. However, it would be desirable to rapidly agree which variables should be collected by farmers from similar eco-systems as this will facilitate inter-farmer data collection efforts. With benchmarking performance within that local pool one can identify those management activities which improve, and those which worsen a farms sustainability index.

Another reason why the reviewed studies use different variables is because the objectives of each study vary. This would not be the case in this use of the CSI as the objective across each farm system would remain constant, but the choice of variables would be more limited than the literature suggests.

Usefulness to policy makers

It is suggested that the operational feasibility of sustainability indicators may be at the expense of technical soundness in its initial years. Crabtree and Bayfield (1998) refer to a report by Ross (1995) which claimed that community input into the development of indicators is required. But they argue that 'the process of developing and using sustainability indicators is an evolutionary one', and that there 'can be no agreed pattern or template for the process'. The present study accepts that location specific initiatives, based on the principles of the active or passive adaptive co-management process, are required to develop more efficient and practical measures of farming's contribution to national sustainability targets.

What this, or indeed any other, approach will not be able to deliver is measurements of the 'unmeasurable' no matter how theoretically sound or policy relevant that measure may be. For example, a CSI might be improved by including a measure that reflects soil health/quality (Nambiar *et al.* 2001) which is a primary indicator of sustainable land management (due to its contribution to plant productivity and impacts on water and air quality (Doran 2002)). However, the definition and measurement of soil health is contested, so in keeping with the philosophy of this study only those variables which are simple to measure would be included. For example, the annual soil vegetative cover (measured as a proportion of the farm area) can be used to as an indicator of the risk of soil erosion, and the extent to which temporary leys are used to improve soil organic matter content.

Usefulness to the farmer

Ultimately the success of this approach to measure sustainability will be judged by the farmer. Whilst the processes of measuring and computing data are unlikely to pose any conceptual problems, the principle of allowing annual changes to the variables included in the index, and its interpretation, may well do. Yet this facet is integral to the potential benefit of this approach. Not only would indices calculated in the initial years likely to be of less value, but farmers would need to have this principle carefully explained because it involves them

[6] For example, water use efficiency is less relevant on (most) UK farms than on farms in arid countries.

[7] Including the use of 'pesticide' might be a sensible indicator to compare conventional farms but it would be inappropriate to use it to compare organic farms.

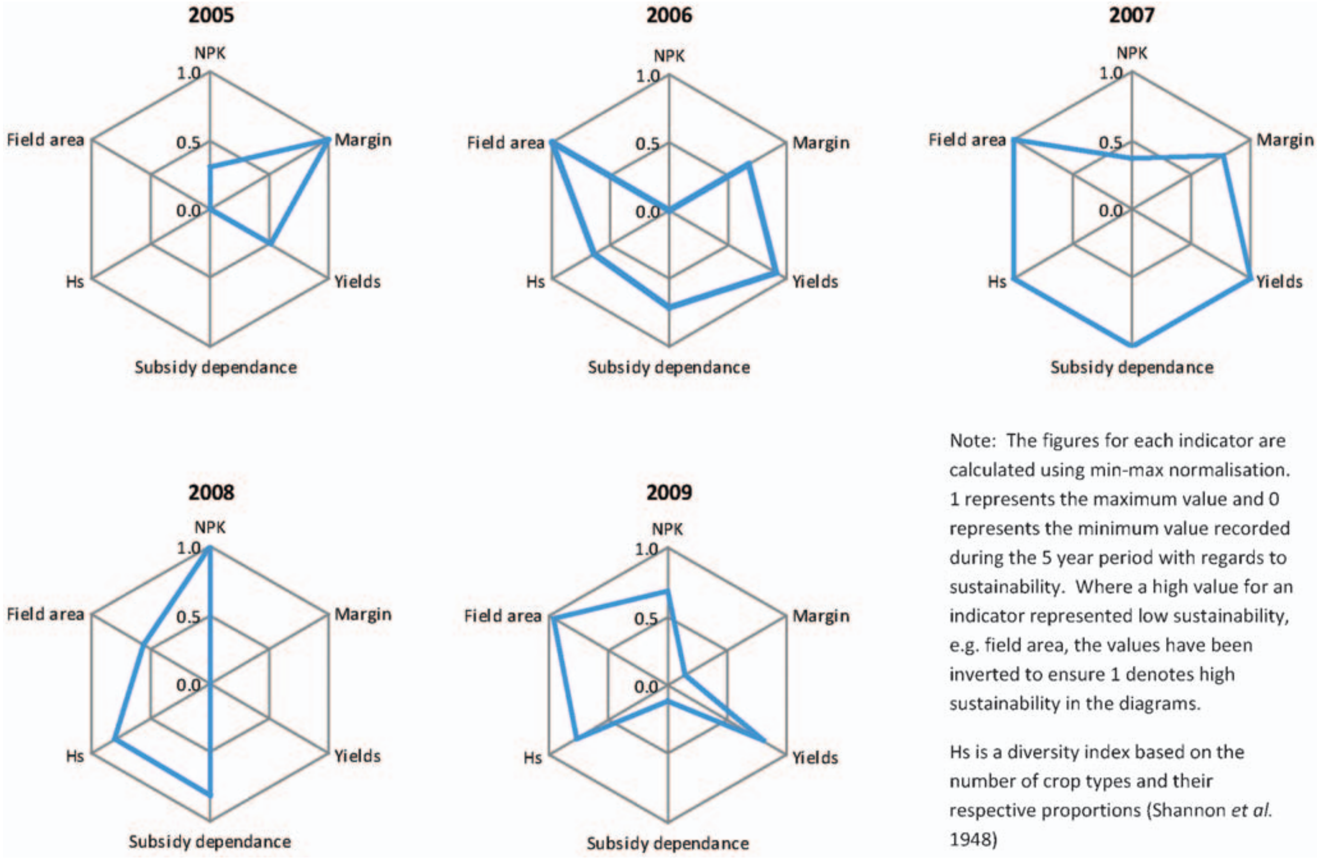

Figure 3: Sustainability webs for a conventional dairy based farm system

making, perhaps initially annual, changes in their compliance activities.

Important to this would be the agreement on the weightings of each variable. Farmers may be mostly interested in the economic viability of their farms, and so would like to assign higher weights to the economic variables however this view is associated with the weak sustainability (Cabeza Gutés 1996) and will not be shared by all stakeholders. It is likely that the weights would be affected by the change in the variables collected each year.

Interpretation of CSIs

All stakeholders would also need to identify which variables can be influenced by factors within the manager's control; there would be little point constructing a farm-specific CSI totally based on exogenous variables. Moreover, some variables will be more predictable than others, for example, annual yields are likely to be more predictable than annual profits. Other indices have problems of interpretation that would need to be addressed. NPK balances can identify nutrient surpluses[8], but does a nutrient deficit equate to the same level of unsustainability as nutrient inputs are suboptimal? (Defra 2010). When interpretation difficulties add to farmers' costs, for example the need for more regular soil tests, some may argue participants need financial support so they are not financially disadvantaged by their voluntary participation in the scheme. However, soil testing to improve nutrient management would result in more accurate nutrient application, thereby crop growth is optimised, nutrients are not wasted and financial savings incurred. Perhaps, financial incentives would be required for measures that do not result in win-wins.

The case study demonstrates how a farm can compute its CSI and present the data using sustainability webs. The example given did not show any specific trend on the farm because farm decisions had not been informed by the availability of the index over those 5 years. However, demonstrating trajectory is an important part of interpreting a CSI so key factors which managers can influence can be identified (Guy and Kibert 1998). Moreover, as annual improvements to data collection are required, some form of on-farm support will be needed initially. In principle, this should not be a problem as financial and advisory support is currently available to facilitate participation into ELS and HLS. In practice finance will likely need to be withdrawn from another programme given current austerity budgets.

Scale of measurement

Traditionally the basic management unit affected by public policy initiatives is the farm holding. Therefore an assessment of sustainability is needed at the farm-level. However, at one extreme, field-level evaluations would illustrate greater variance (but provide greater detail (Castoldi and Bechini 2010)) than the aggregated,

[8] These data are routinely recorded by farms in nitrogen vulnerable zones (NVZ) (a UK legislation targeting high risk areas for nitrate pollution which imposes limits on nitrogen application and involves maintenance of mandatory annual records of fertilise usage), so the data management techniques and processes are well understood and could rapidly be extended to farms in non-NVZ areas.

regional or national level evaluations (OECD 2008). Field scale evaluations may be particularly useful for assessing change in sensitive areas, for example land abutting nature reserves. This would place additional demands on data recording, but would be technically possible; for example, farms in a NVZ must record nutrient balances field by field (Defra 2009).

Problems with the farm-specific composite variables for sustainability

Incorporating the social pillar of sustainability proved a particular problem in calculating the case study CSI. Social variables used in the literature such as 'risk of abandonment of agricultural activity' (Gómez-Limón and Riesgo 2009), 'animal welfare' (Haas *et al.* 2001) and 'consumer taste tests of produce quality' (Reganold *et al.* 2001) provide conceptual and measurement difficulties. They would also be costly to determine on a farm by farm basis. However, variables such as 'subsidy dependency' and 'profitability' are more readily measurable. If variables such as 'contribution to the local economy' and 'percentage of produce sold locally' are considered to be locally important then farmers need robust tools to help calculate them.

Comparisons with other pragmatic approaches

The 'Agri-Environmental Footprint Index' (AFI) is designed to evaluate the effectiveness of agri-environment schemes (Purvis *et al.* 2009). AFIs are directed by policy objectives, so their focus is well-defined and do not include all aspects of sustainability. However, lessons learnt from applying AFI include the need for processes to be participatory and measures to be context specific (Purvis *et al.* (2009); Louwagie *et al.* (2012); (Mauchline *et al.* 2012)). AFI involves a hierarchical process encompassing a set of indicators nested firstly within management practices and then within three aspects of environment: natural resources, biodiversity and landscape. These indicators of management practises and the three aspects of the environment are weighted and summed to produce the single value AFI score (Purvis *et al.* 2009). The aim is to deliver a focused evaluation that is sufficiently flexible to accommodate different farming contexts within a consistent framework; an approach that our study also favours using the triple bottom line as the basic unit of evaluation.

The 'Public Goods Tool' (PGT) has been developed to evaluate farms in organic entry level stewardship (OELS) (Gerrard *et al.* 2012). The tool has a pragmatic approach to producing an easy to understand sustainability web that is inexpensive to produce. Through thorough stakeholder consultation, the authors identified eleven public goods, the delivery of which was assessed by discussions with farmers based on questions and answers and illustrated with graphics. This offers an alternative 'starting point' to our proposed method. The case study shows how important the selection of a starting point is for the speed at which the CSI becomes widely useful, however the PGT is based on scores rather than actual measurements, so may be less accurate and does not consider data availability.

Addressing subjectivity

The literature review shows the subjectivity inherent in different approaches to developing a CSI (Böhringer and Jochem 2007). Many consider it disadvantageous to rely on the views of closely affected stakeholders. The social dimension of sustainable development, and the location specific nature of summary measures, means subjectivity is unavoidable and must be managed rather than eliminated (Kemp and Martens 2007). Subjectivity does not necessarily imply compromise in accuracy and trustworthiness if methods of work allow consistent and robust repeatability across observations (Harper and Kuh 2007). Moreover, as a boundary object, it is not possible to define sustainability without involving a wide range of stakeholders (Castoldi and Bechini 2010). Acknowledging this will help develop not only the initiation of CSIs but also their improvement.

7. Conclusions

Current policy directives and up-coming CAP reforms emphasise the need to develop measurements of farm-level sustainability which have practical value to farmers and policy makers. We have examined the utility of CSI for this purpose, but methodological and data weaknesses mean on-farm CSIs have not been added to the policy-maker's toolkit. Additional improvements are needed, but progress appears to have stalled; though recent initiatives, such as AFI and PGT are offering new approaches to the problem, their widespread application is still limited.

The argument presented here supports their approaches. For agricultural sustainability to have meaning at the farm level it must be measureable, and pragmatic approaches to establishing sustainability measures are required. This would involve a step change in how CSI are conceived and calculated. Rather than aiming to develop an instantly ready-to-use score/value, it is proposed to use that data which is readily available, within a 'design-action-design cycle' dynamic framework. With appropriate support, this pragmatic, bottom-up perspective, will deliver the data improvements needed to allow on-farm CSIs to more closely reflect sustainability and allow convergence between the variables used among similar farms in similar locations. The speed with which this can be done will be critical to the balance between cost and value. It is suggested that the approach outlined be tried out on a voluntary basis initially, with farmers assisted by specialist advisors who can help them compute their farm's CSI and advise on data collection and recording strategies. The availability of grants would assist the process should farmers need to investment in equipment and/or training.

Sustainability webs and CSI values will incorporate change in variables over time and illustrate individual business's trajectory over time and with respect to other businesses. The CSI would help farm managers take account of the effects of their business decisions on the natural and social environment. This improvement would increase the value of the CSI to (i) policy makers, allowing them to be incorporated into with cross-compliance obligations or entry level stewardship of the Environmental Stewardship Scheme and (ii) to farmers within a benchmarking framework, assisting in the spread of best practice and enabling users to identify areas where they can improve.

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Appendix: List of potential sustainability indicators rated by ease of application

Indicator	Methods/definition	Difficulty rating* (0-10) 0=extremely difficult, 10=extremely easy	
		Conventional	Organic
Variable costs	Expenses (£) that change in proportion to productivity	10	10
Profit	Product gains (£) less all costs	2	2
Profit per hectare	Real value of agricultural production minus the real cost per Ha	9	9
Product revenue	Return per product (£ per unit)	9	9
Compensation payments	Single farm payment (£)	9	9
Agri-environment payments	Environmental stewardship and countryside stewardship schemes (£)	9	9
Energy Balance	Kcals/ha using input/output focus (Sum of the energy in petrol, lubricants, pesticides, fertilisers, seeds and machinery - energy of the crop above ground biomass)	2	2
Balance of N in soil	The difference between N contained in the inputs (fertiliser, manure) and outputs (crops) (kg N/ha)	10	10
Balance of P in soil	The difference between P contained in the inputs (fertiliser, manure) and outputs (crops) (kg P/ha)	10	10
Balance of K in soil	The difference between K contained in the inputs (fertiliser, manure) and outputs (crops) (kg K/ha)	10	10
Adverse impacts of pesticides	Using the Environmental yardstick for pesticides (EYP) (Reus and Leendertse, 1999) based on active chemical ingredients half life and Koc value (sorption coefficient of the pesticide) as well as site specific soil and meteorological conditions using simulation programming.	2	2
CO_2- emissions	CO_2 is estimated from fuel and electricity use.	8	8
CH_4- emissions	CH_4- is estimated from the number of livestock multiplied by emissions factors for western Europe (IPCC 1996) (in CO_2-equivalents for GWP_{100})	8	8
N_2O- emissions	N_2O is based on number of livestock, N excretion of animals (kgN/animal/yr) and the fraction of this N that is manure N (%/100) estimated from animal waste handling method (IPCC 1996). Field burning of agricultural residues; characteristics (IPCC 1996 worksheet 4-4). Emissions from soils are estimated from synthetic fertiliser use, fraction of synthetic fertiliser N applied that volatilizes, area of cultivated organic soils, fraction of N that leaches.	2	2
Crop rotation indicator	Average suitability of each previous-successive crop combination rated 0-10. E.g continuous successions of the same crop given a low score. Companion cropping given high score.	4	4
Biodiversity; Number of grassland species	Index 1-5 (≤22=5, 23-25=4, 26-28=3, 29-31=2, ⩾32=1)	4	4
Biodiversity; Time of first cut	Index 1-5 (5 May=5, 10 May=4, 15 May=3, 20 May=2, 25 May=1)	8	8
Biodiversity; density of hedges and field margins	Relative frequency Index 1-5 (low=5, average=3, high=1)	4	4
Biodiversity; diversity of hedges and field margins	Index 1-5 (low=5, average=3, high=1)	7	7
Biodiversity; state/care of hedges and field margins	Index 1-5 (poor=5, average=3, very good=5)	7	7
Biodiversity; fences	Index 1-5 (none=5, medium density small fences=3, high density broad fences=5)	4	4
Length of grazing period	Length of grazing period and the typical look of the cattle and the layout of the farmstead (garden, trees, orchard) (two separate indicators) (scored 1-5)	10	10
Farmstead layout	Proportion of the farmstead that is the same as it was 40 years ago (%) or score from 1-5 how traditional the farmstead is.	9	9
Crop diversity	The quantity of different crop types on farm that occupy an area greater than 0.25 ha.	8	8
Specialisation	% of land covered by principle crop	8	8
Mean area per plot	Mean size of the fields that make up the farm (ha)	8	8
Soil cover index	% of soil cover by crops in one year (averaged over the four seasons)	4	4
Farm yard manure application	On what proportion of the farm is farm yard manure applied? (%)	8	8
Soil Erosion	Movement of soil (t/km^2)	1	1
Soil Quality	Several measurements, E.g. Bulk density (cm^3), Cation Exchange Capacity (CEC), Nutrient concentrations (%).	2	2
Seed Source;	Proportion conventional/organic (%)	9	9
Seed source; own farm supplied	Proportion sourced on site (%)	10	10

Appendix: Continued

Indicator	Methods/definition	Difficulty rating* (0-10) 0=extremely difficult, 10=extremely easy	
Farm self-sufficiency; Calve replacement	What proportion of the calf replacements are from the farm? (%)	9	9
Farm self-sufficiency; fertiliser	What proportion of the fertiliser is sourced on farm? (%)	10	10
Abiotic resource use	Includes most metals, many minerals, fossil fuels and uranium for nuclear power. Quantified in terms of the mass of the element antimony (Sb). Information required; Abiotic resources used and relative quantities.	4	4
Land use	Yields are scaled up or down using linear coefficients derived from Moxey et al (1995) for different land grades. Required information; land grade and respective yields.	8	8
Crop Yield	Direct yield (kg/ha)	10	10
Animal housing system and conditions, herd management	For example heard management is rated according to lightness, spacing, grazing season and care (1-5) according to specific thresholds.	5	5
Agricultural employment	Hours on farm divided by area (hours/ha)	4	4
Stability of workforce	% of the demand for labour during critical periods. The higher the value for this indicator the less stable is the population in rural areas.	4	4
Risk of abandonment of agricultural activity	Index constructed to a range from a maximum of 1 (farmer less than 55 years old on above average income) to 0 (farmer more than 70 years old and below average income)	9	9
Economic dependence on agricultural activity	% of farmer's income derived from agriculture. Higher dependence, higher stability.	7	7

*Ratings provided by farm manager

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Effects of scale, intensity and farm structure on the income efficiency of Irish beef farms

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ABSTRACT

Data envelopment analysis (DEA) was employed to develop a model of income and scale efficiency for Irish beef farms. The objective was to identify and quantify management, farm structural and intensity indicators of efficiency for over 400 representative farms over two production systems and two years. Bootstrapping techniques were employed to measure and correct efficiency scores for sampling bias. Less than 10% of the sample exhibited constant or increasing returns to scale. The remaining farms exhibited decreasing returns to scale meaning that they were larger than optimal scale. Greater income efficiency was associated with lower levels of concentrate feeding and lower overhead costs per livestock unit (LU). Fragmentation, paid labour and capital investment were significantly negatively associated with income efficiency. There was a positive relationship between market gross output per LU and income efficiency. Negative market net margins tended to be subsidised by greater off-farm income on smaller (more scale efficient) farms and by greater direct payments on larger (more scale inefficient) farms. Consequently, prospects for increasing beef output via scale expansion are negative in an external environment of declining subsidies and reduced off-farm employment in rural areas. Increased output from Irish beef farms must therefore come primarily from farm system structural changes rather than scale changes, otherwise farm income efficiency will decline.

KEYWORDS: Suckler beef production; efficiency; DEA; scale efficiency; bootstrapping; whole-farm comparative analysis

1. Introduction

Farm level comparative analysis

Agricultural economists have for centuries sought to identify and measure the management and structural differences between successful and unsuccessful farms (Sheehy and McAlexander, 1965). The objective of such comparative analysis is to identify specific farm systems and strategies likely to increase farm level profits (Fleming *et al.*, 2006). However, many authors have been critical of some common measures of profitability used in farm comparative analysis. For example, gross margin per hectare (GM/ha) is commonly used as a profit measure when comparing farms employing pasture-based production systems (McCall and Clark, 1999; Crosson *et al.*, 2006). There are two substantial criticisms made of the ''partial accounting'' nature of this measure:

1) The exclusion of fixed or ''overhead'' costs from gross margin calculation means that farm systems which employ inherently higher ratios of fixed costs to variable costs appear to achieve greater profits (Firth, 2002; Shadbolt, 2012).
2) The expression of profit on a per hectare basis neglects the productivity of other assets employed. It creates a bias in favour of farms which substitute other fixed assets (e.g. buildings or machinery) for land in their production system (Farrell, 1957; Fleming *et al.*, 2006; Shadbolt, 2012).

The solution to the first criticism is to include the full economic cost of farm production (where such data is available) so that long-term as well as short-term profitability can be deduced (Tauer, 1993). The second criticism applies to all measures of profitability which use a single factor of production as the scale denominator, e.g. profit per cow, profit per labour unit. A solution to this is the measurement of *whole-farm economic efficiency*. This concept is based on the principles described by Farrell (1957) and further developed by many economists in the subsequent decades (Shephard, 1970; Charnes *et al.*, 1978; Fried *et al.*, 2008). Whole-farm, rather than partial measures of efficiency permit more robust specification of strategies associated with improved profitability and economic sustainability over both the short and long-run (Tauer, 1993; Stokes *et al.*, 2007).

Efficiency and Irish beef production

Beef farming, relative to other pasture based enterprises, has been characterised by low measures of productivity

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and efficiency and consequently poor profitability and economic sustainability in many countries (Farrell, 1957; Boyle, 2002; Rakipova *et al.*, 2003; Thorne, 2004; Newman and Matthews, 2007; Deblitz, 2010; Barnes, 2012). In Ireland, the majority of beef enterprises are run either subsidiary to other farm enterprises or off-farm employment (Central Statistics Office, 2012). Most beef farms are also subsidised by government direct payments (Hennessy *et al.*, 2012). Over half of all beef produced in Ireland originates from the 'suckler' (beef cow) herd of 1.1 million cows. The remaining beef is produced from the culls and un-bred progeny of dairy herds. Irish suckler farms are typically small scale, (average of 14 breeding suckler cows) and located on the least productive soils in the wettest climatic regions of Ireland (west and north-west) (Central Statistics Office, 2012). The Irish agri-food industry have set strategic targets for increased output from the primary agriculture sector including an increase of beef output value by 20% from current values of €1.55 billion per annum (Food Harvest 2020; DAFF, 2010). To achieve this, an increase in the number of 'market oriented' beef producers is proposed. Given the high dependence on direct payment subsidies on cattle rearing farms (202% of family farm income in 2010 (Hennessy *et al.*, 2011)) increased output from Irish beef farms can only be economically sustainable in the medium to long-term if accompanied by increased farm level efficiency.

This article aims to 1) describe a model of efficiency for alternative Irish beef production systems, 2) to identify management related drivers of efficiency and to 3) identify farm scale, intensity and structural characteristics likely to facilitate profitable expansion of Irish suckler beef production.

2. Methodology

Productivity and efficiency

Fried *et al.* (2008) defined productivity as a ratio of aggregated outputs to aggregated inputs and efficiency as the ratio of measured productivity to potential productivity. Data Envelopment Analysis (DEA) is non-parametric method of efficiency calculation devised by Charnes *et al.* (1978). It is a non-parametric in that the modeller does not specify the functional form, but rather it is specified by the decision-making units (DMUs) or farms comprising the modelled dataset. The production frontier is the isoquant connecting the most efficient (i.e. 'best observed practice') DMUs in the dataset (see Figure 1). These farms exhibit an efficiency score of one and the convex isoquant created by joining their production functions 'envelops' farms below the frontier which have an efficiency score of less than one (Shephard, 1970). Efficiency models can be either output oriented (output maximising) or input oriented (input minimising). Figure 1 illustrates output oriented efficiency calculation under models of variable returns to scale (VRS) and constant returns to scale (CRS). Efficiency measured to the VRS frontier assumes that all farms are operating at optimal scale, while if measured to the CRS frontier it is assumed that all farms can achieve the scale of the most scale efficient farm in the sample. In this example of a single input, single output production system, points C, F and D are fully efficient farms represented by points on the convex VRS production frontier. However under the assumption of CRS only farm F is fully efficient. Points A and B represent inefficient farms, where the distance from the x axis to point A or B divided by the distance from the x axis to point A' or B' indicates their efficiency scores. The output oriented efficiency score of farm A (ES_A) under VRS can be calculated as:

$$ES_A = pA/pA' \quad (1)$$

This study employed an output oriented DEA model using the FEAR software package in the R language (Wilson, 2009). The efficiency scores calculated by this model therefore imply that an individual farm can improve its efficiency (where efficiency < 1) by employing the existing resource set in a more favourable manner so as to increase output value, while maintaining current input levels. An output oriented model was deemed appropriate given that farmers are more likely to reduce production rather than improve production system efficiency when faced with a constraint on inputs (Tauer, 1993).

Farrell (1957) decomposed economic efficiency into the sub-components of technical and allocative efficiency. However this approach was not feasible for an efficiency analysis of Irish beef farms due to the dearth of recorded common measures of physical output by which to calculate technical efficiency. This is due to the considerable heterogeneity of the physical nature of output both within and between farms. The highly diverse distribution of age, gender, breed, and marketing strategy variables for cattle sold from beef farms contrasts with the relatively homogenous milk output of dairy farms. Consequently, this study calculates income efficiency using whole-farm financial rather than physical data. While this constraint prohibits calculation of technical efficiency it avoids the potential pitfall of making subjective judgements and assumptions around the nature, quantity and quality of physical outputs in the absence of standardised empirical data.

The DEA model was preferred to parametric models such as stochastic frontier analysis for three main reasons:

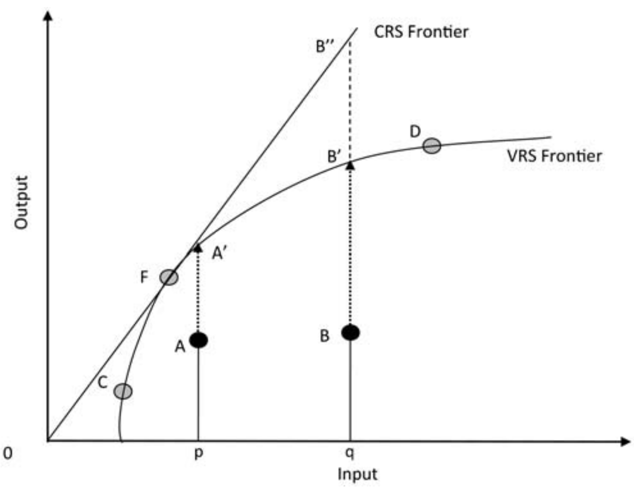

Figure 1: Illustration of output oriented efficiency under assumptions of variable returns to scale (VRS) and constant returns to scale (CRS)

Table 1: Efficiency model inputs, outputs and intensity indicators for two beef farm systems for 2009 and 2010

	Cattle Rearing				Cattle Other			
	2009		2010		2009		2010	
	Mean	(S.D.)	Mean	(S.D.)	Mean	(S.D.)	Mean	(S.D.)
Sample size	228		218		187		249	
Inputs (all per farm)								
Utilised agricultural area - ha	41	(25)	42	(30)	44	(31)	48	(33)
Livestock units [1]	40	(31)	41	(40)	57	(48)	55	(47)
Labour units [2]	1.05	(0.35)	1.06	(0.40)	1.09	(0.48)	1.08	(0.50)
Concentrates - € [3]	4,126	(4,737)	4,350	(5,632)	6,194	(8,100)	7,641	(9,757)
Fertiliser - €	2,389	(1,977)	2,680	(3,153)	3,579	(3,985)	3,493	(3,468)
Other variable costs - €	5,921	(4,073)	6,110	(6,324)	7,304	(6,327)	8,340	(14,038)
Overhead costs - €	13,092	(10,454)	15,100	(13,754)	16,168	(13,071)	18,182	(15,369)
Direct payments - €	17,942	(12,198)	18,552	(14,763)	22,121	(18,057)	22,326	(18,712)
Outputs								
Family farm income - €	9,164	(11,415)	9,808	(11,641)	14,218	(17,509)	15,454	(20,579)
Intensity indicators								
Stocking rate	1.15	(0.47)	1.12	(0.47)	1.36	(0.48)	1.31	(0.52)
Market gross output/livestock unit - €	378	(135)	449	(176)	421	(194)	509	(266)

[1]1 suckler cow = 0.9 livestock units. 1 lowland ewe = 0.2 livestock units
[2]Labour units = the total paid and unpaid labour units employed annually on the farm
[3]€1.00 = $1.32 US Dollars = £0.82 GBP (January 2013)

1) It enables consideration of inputs with differing units of measurement;
2) It permits both income and scale efficiency to be easily measured;
3) Specification of production system functional from is not required in DEA in contrast to parametric efficiency models (Latruffe *et al*., 2005).

Point 3 is especially important given the considerable heterogeneity of production systems prevailing on Irish beef farms. Table 1 lists the inputs and outputs used in calculation of the efficiency model. Note that whole-farm output was net income or family farm income (FFI measured in Euros/farm). FFI includes income from subsidiary enterprises such as sheep as well as market derived income from cattle and farm direct payments or subsidies. "Other variable costs" refers to all direct costs allocated to the farm livestock enterprise excluding fertiliser and purchased concentrate expenditure. "Overhead costs" refers to all farm fixed costs in addition to direct costs such as fuel and lubes which are not directly allocated to a livestock enterprise. All income efficiency scores referred to in the paper should be interpreted as output-oriented VRS income efficiency scores unless stated otherwise.

Data and model specification

Farm input and output data from the Teagasc National Farm Survey (NFS; Hennessey *et al.*, 2012) was used. The NFS is an annual voluntary survey of approximately 1,100 farms representative of 100,000 farms, providing data to the Farm Accountancy Data Network (FADN). For this study 'specialist beef' farms were analysed using 2009 and 2010 data. Specialist beef farms were defined as those farms which earned 66% or greater gross output from their beef enterprises. These farms were subdivided into 'cattle rearing' (CR) and 'cattle other' (CO) categories. Cattle rearing farms are primarily suckler (beef cow) farms while CO farms are primarily beef finishing farms. Table 1 shows the sample size and main farm characteristics for each farm category for 2009 and 2010.

Efficiency score bootstrapping

Because the statistical estimators of the efficiency frontier were taken from a finite sample, a form of sampling bias may exist in the derived efficiency scores (Efron, 1979; Banker *et al*., 1984). To correct for this bias, a re-sampling procedure known as 'bootstrapping' was applied to the dataset as described by Simar and Wilson (1998). By generating 10,000 Monte Carlo pseudo-samples from the dataset, a bootstrap bias term was calculated for each farm. This bias term was then subtracted from the corresponding efficiency score to give a bias-corrected income efficiency score (BCES). It should be noted that all efficiency sample induced bias is negative, in effect a one-sided error term as explained by Fried *et al.* (2008). All further reference to 'income efficiency score' of a farm or DMU in this paper is BCES.

Analysis of explanatory variables

Following calculation of BCES, farms were divided into terciles ranked on BCES and statistical differences in explanatory variables between these income efficiency ranked groups were identified using a Mann-Whitney test (Table 4). The effect of some explanatory variables of particular interest on BCES were further analysed by ranking and grouping farms in quintiles based on the value of the continuous explanatory variable of interest. Statistically significant differences in BCES between these quintiles are denoted in Figure 2 for six variables. Significant differences for the explanatory variable quintile analysis were determined using the confidence interval method described by Latruffe *et al*., (2005). If the 95% confidence interval BCES value for one data-point was less than the 5% confidence interval BCES of another data-point within a system and year these data-points were identified as significantly different.

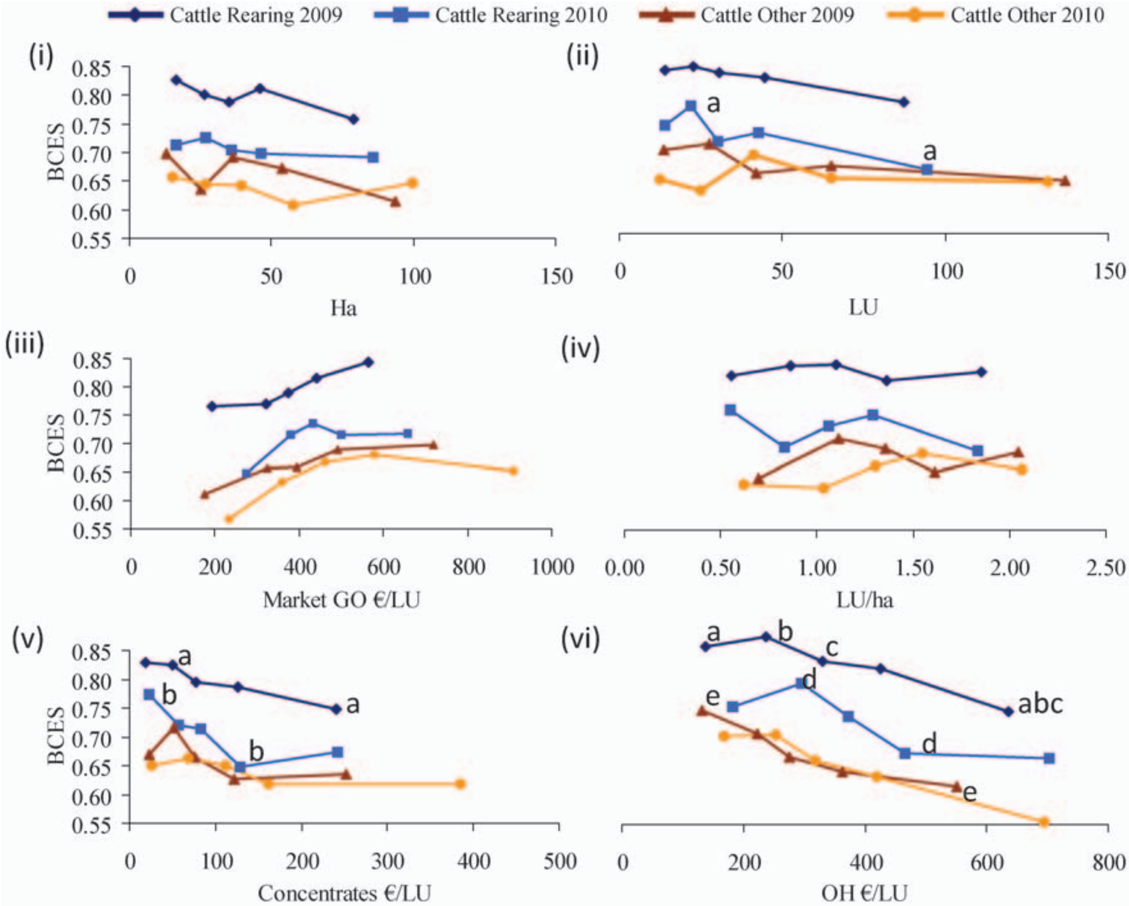

Figure 2: Effect of six quintile-ranked explanatory variables on bias corrected income efficiency scores (BCES) for two cattle systems and two years
Ha = hectares; LU = Livestock units; GO = Gross output - €; OH = Overhead costs - €
Data-points with common subscripts are significantly different within year and system ($P < 0.05$)

Scale efficiency

Chavas *et al.* (2005) defined a scale efficient farm as one for which output or earnings could not be improved by increasing or decreasing the size of the input/output mix. Bias corrected scale efficiency score (SES) was calculated for each DMU in the dataset using the calculation of Fried *et al.* (2008) and substituting BCES for efficiency score:

$$SES\ DMU_i = BCES_{CRS}\ DMU_i / BCES_{VRS}\ DMU_i \qquad (2)$$

Where $BCES_{CRS}$ is the constant returns to scale bias-corrected efficiency score and $BCES_{VRS}$ is the variable returns to scale efficiency score.

Scale efficient farms have a scale efficiency score of unity, meaning that these farms are equally efficient under models assuming constant and variable returns to scale (farm F in Figure 1). Such farms may be said to be operating at optimal scale and productivity cannot be increased on these farms by changing scale. Scale inefficient farms were then classified as operating at either 'increasing returns to scale' (IRS) or 'decreasing returns to scale' (DRS). IRS farms could increase income efficiency by increasing scale while income efficiency would decline on DRS farms if scale increased. Farms were subsequently classified into evenly sized terciles ranked on bias-corrected scale efficiency score. Characteristics of each scale efficiency tercile were compared to determine management or demographic factors associated with scale efficiency.

3. Results

Income efficiency scores

The mean deterministic income efficiency scores ranged from 0.76 (CO 2010) to 0.86 (CR 2009). The proportion of farms exhibiting a deterministic income efficiency score of unity ranged from 17 to 21% (CO 2010 and CO 2009 respectively) (Table 2). Input slacks for each input variable are presented in Table 3. These input slacks are quantified using an input oriented model and are presented to indicate the inherent sources of input inefficiency within each beef production system. The mean input slack is the extent of over-supply of a given input on the average farm relative to farms on the efficiency frontier. The slack of 5 ha for CR 2009 indicates that the average farm in that sample would need to reduce area farmed by 5 ha to achieve income efficiency under an input minimising model. A ratio of input slack to input variable mean is shown as an indicator of the relative importance of that input to efficiency. Variables exhibiting high slack to input mean ratios indicate that that particular input is of greater importance in determining farm level income efficiency, therefore direct payments, a relatively fixed input, exhibits the lowest slack. Conversely, the slack results indicate that reducing overhead costs and

Table 2: Sample mean income efficiency scores and bootstrapping results under assumptions of both variable and constant returns to scale for two beef farm systems for 2009 and 2010

	Cattle Rearing		Cattle Other	
	2009	2010	2009	2010
Variable returns to scale				
Deterministic mean efficiency score	0.86	0.81	0.78	0.76
Proportion of sample efficient [1]	0.19	0.21	0.21	0.17
Bias corrected mean efficiency score	0.80	0.71	0.66	0.64
Bias [2]	0.06	0.10	0.12	0.12
5% confidence interval	0.76	0.68	0.64	0.63
95% confidence interval	0.85	0.80	0.78	0.75
Constant returns to scale				
Deterministic mean efficiency score	0.58	0.60	0.50	0.45
Proportion of sample efficient	0.10	0.11	0.13	0.11
Bias corrected mean efficiency score	0.45	0.45	0.39	0.35
Bias	0.14	0.15	0.11	0.10
5% confidence interval	0.46	0.47	0.36	0.32
95% confidence interval	0.57	0.59	0.59	0.43

[1]Proportion of sample with efficiency score equal to one in the deterministic income efficiency model
[2]Bias and confidence intervals calculated from 10,000 bootstrap replications (Simar and Wilson, 1998)

concentrate feed costs provide the greatest potential to achieve increased efficiency. Greater slacks were also observed on the CO farms than on the CR farms, highlighting greater potential for cattle finishing farms to improve their income efficiency.

Explanatory variable differences

Table 4 shows differences in size, system, intensity, environmental and demographic variables between the top and bottom thirds ranked on income efficiency score. Six key variables were further analysed to identify their effect on BCES. These variables were ranked in quintiles and plotted against BCES in Figure 2.

Size

The top and bottom thirds ranked on income efficiency were of similar size in terms of livestock units and hectares. However, the top third of CR farms had significantly less hectares in 2009 and significantly less livestock units in 2010. The top third of farms tended to have greater farm gross output than the bottom third. However differences were slight and non-significant. Figure 2 shows a peak efficiency score for CR farms at 22 LU and at 28 and 41 LU for CO farms in 2009 and 2010, respectively. In LU terms, both larger and smaller CO farms were less efficient than those with intermediate cattle numbers. For CR farms, although intermediate size farms were most efficient, smaller farms tended to be more efficient than the largest quintile (Figure 2). The top third of CR farms received greater farm direct payments than the bottom third, however any differences within the CO group were non-significant.

System and intensity

There were no significant differences in labour input, or AI usage between high and low efficiency groups. There was generally no significant effect of stocking rate on efficiency except for a slight positive effect for CO 2010. Concentrate expenditure had a significantly negative impact for the CR farms and was much less negative for the CO farms, indicating a return to concentrate feeding on some CO farms but not on CR farms. Gross output value/LU was strongly positive for cattle rearing farms and somewhat less so for CO farms. Market gross output/LU (i.e. output value excluding subsidies) appeared to reach an optimum at about €400 for CR and €580 for CO farms in 2010 (Figure 2). Increased market gross output above those levels in that year were achieved at the expense of declining income efficiency. There was a tendency towards a lower proportion of land rented for the top third of farms, although only significant in CR 2009. The more efficient CO farms were less specialised in terms of LU species. Overhead costs per LU had a significantly negative effect on BCES in all systems and years, as did depreciation and interest repayments.

While not significant, there was a repeated tendency for the higher income efficiency CR farms to market cattle as weanlings and for the low income efficiency CR farms to market cattle directly for slaughter. Direct payments/LU were significantly greater for the higher income efficiency CR farms, but there was no significant difference in this measure between high and low income efficiency CO farms. High income efficiency farms had greater labour input, but not significantly greater for CR farms. Investment in machinery, buildings and livestock exhibited varying degrees of significance across systems and years but the tendency was for a negative effect of investment on income efficiency score.

Demographic variables

There was no significant difference in farmer age, proportion of family labour, soil type, off-farm employment or income or participation in an environmental stewardship programme (Rural Environmental Protection Scheme; REPS) between the top and bottom BCES thirds. Fragmentation had a negative effect on income efficiency but only significantly so in CR 2010 (Table 4). Although not generally significant, there was a tendency for the least income efficient farms to be situated in the eastern region of Ireland; Meath, Kildare, Wicklow, Dublin, and the most income efficient farms to be situated in the west, mid-west or south-west.

Table 3: Slacks for model input variables under an input oriented efficiency model

		Model Input	Land area	Labour	Fertiliser	Concen-trates	Livestock units	Other variable costs	Overhead costs	Direct payments
		Units	*Ha*	*Labour units*	€	€	*LU*	€	€	€
Cattle Rearing	2009	Slack	5	0.10	733	1,295	6	1,808	6,000	427
		Slack/mean	0.12	0.09	0.31	0.40	0.14	0.31	0.46	0.02
	2010	Slack	3	0.12	1,011	1,373	5	1,634	4,543	577
		Slack/mean	0.08	0.12	0.38	0.38	0.13	0.27	0.30	0.03
Cattle Other	2009	Slack	11	0.20	1,175	1,865	15	1,603	7,703	1,433
		Slack/mean	0.26	0.19	0.33	0.31	0.26	0.22	0.48	0.06
	2010	Slack	7	0.34	551	3,033	12	1,882	6,158	848
		Slack/mean	0.16	0.32	0.16	0.47	0.23	0.23	0.34	0.04
CR mean slack/input mean			0.10	0.10	0.34	0.39	0.14	0.29	0.38	0.03
CO mean slack/input mean			0.21	0.25	0.24	0.39	0.24	0.22	0.41	0.05
Cross system mean slack/input mean			**0.15**	**0.18**	**0.29**	**0.39**	**0.19**	**0.25**	**0.39**	**0.04**

Scale efficiency

Table 5 shows mean scale efficiency scores and the number of farms exhibiting IRS, DRS and scale efficient. Farms with an SES of one lay on the production frontier and were efficient whether CRS or VRS was assumed in DEA efficiency calculation. 7% of all sample farms were scale efficient in 2009 and 2010. Of the remaining farms, just 1% and 4% of the CR farms exhibited increasing returns to scale in 2009 and 2010 respectively. No CO farms exhibited increasing returns to scale in either year. The top third SES farms were smaller, less intensive and retained more of their direct payments as income than the bottom third (Tables 6 and 7). The top third CO farms also rented proportionally less land, employed less non-family labour and held less fragmented farms. These traits were either weaker or not observed for CR farms. Overheads/LU were not significantly different for high and low scale efficiency farms, except for CO 2010 where overheads/LU were greater on the high scale efficient farms. High SES farms were significantly more specialised. While the larger, low SES farms were more intensive (LU/ha) (Table 7), market net margin and FFI per hectare were not significantly different to the smaller, low SES farms. No economies of scale with respect to fixed costs were observed, i.e. no advantage in terms of lower overhead costs/LU for the larger, lower SES farms (the exception being CO 2010).

4. Discussion

Scale and intensity

Non-linear relationships between scale and efficiency have been previously reported by Latruffe *et al.* (2005) in a study of Polish livestock farms and Hansson (2008) in a study of Swedish dairy farms. However the relationships reported in those studies were 'u' shaped (intermediate scale farms exhibiting lower efficiency than smaller and larger farms), rather than the 'n' shaped curves evident in Figure 2. In terms of both intensity and size, intermediate farms were more efficient, indicating an optimal scale and intensity close to the mean. Therefore only a small minority (<4%) of cattle rearing farms can increase efficiency by increasing scale (Table 5). There was little potential identified for cattle other farms to increase efficiency by increasing scale.

Furthermore, stocking rate appears to be a lesser determinant of income efficiency than either scale or market gross output per livestock unit. Similar to the scale effect, stocking rate exhibited a 'n' shaped relationship with efficiency (Figure 2iv). This is indicative of an optimal stocking rate close to the sample mean, between 1.0 and 1.5 LU/ha. This contrasts with an almost linear positive relationship of stocking rate with gross margin reported in a study of Irish suckler systems in 2010 (Teagasc Specialist Service, 2011). However, that analysis was partial rather than whole-farm in that farm fixed costs were allocated on an LU basis to the suckler enterprise. It appears that increasing stocking rates above optimal levels may reduce profitability due to increased expenditure on buildings and purchased concentrates. Therefore in order to improve income efficiency, increased stocking rates must be associated with increased utilisation of low cost grazed pasture rather than an

Table 4: Mann-Whitney test results for differences in explanatory variable means for beef farms ranked in income efficiency groups of top and bottom 1/3

System	Cattle Rearing						Cattle Other					
Year	2009			2010			2009			2010		
Income efficiency tercile	Top 1/3	Bottom 1/3		Top 1/3	Bottom 1/3		Top 1/3	Bottom 1/3		Top 1/3	Bottom 1/3	
Size variables												
Income efficiency score	0.89	0.69	***	0.84	0.57	***	0.82	0.50	***	0.79	0.47	***
Scale efficiency score	0.58	0.51	***	0.65	0.58	***	0.56	0.59	NS	0.50	0.57	NS
Total livestock units - LU	44	46	NS	43	46	**	52	54	NS	56	52	NS
Land area - ha	42	45	*	47	44	NS	42	44	NS	46	47	NS
Farm gross output - €	40,600	35,129	NS	41,745	38,508	NS	48,263	42,041	NS	54,545	41,712	NS
Farm direct payments - €	21,057	18,565	***	21,224	18,230	***	21,754	20,366	NS	22,943	18,774	NS
System and intensity variables												
Stocking rate - LU/ha	1.24	1.21	NS	1.11	1.23	NS	1.34	1.33	NS	1.35	1.23	*
LU/labour unit	32	29	NS	28	30	NS	33	31	NS	35	27	NS
Gross output - €/LU	978	772	***	1,058	864	***	918	790	**	992	976	*
Direct payments - €/LU	548	433	***	595	440	***	447	421	NS	443	496	NS
Concentrate costs - €/LU	74	123	***	82	125	***	103	123	*	143	181	NS
Fertiliser costs - €/LU	60	68	NS	58	69	***	57	63	NS	63	62	NS
Depreciation - €/LU	69	121	***	94	119	**	60	100	***	78	133	***
Interest payments - €/LU	18	24	***	11	15	**	9	18	**	9	15	NS
Other variable costs - €/LU	146	176	***	144	168	***	123	159	***	124	163	***
Overhead costs- €/LU	285	438	***	329	430	***	275	337	***	296	454	***
Machinery investment - €/LU	365	616	***	413	505	NS	400	510	NS	400	654	*
Buildings investment - €/LU	601	952	***	679	824	NS	432	741	***	476	857	***
Livestock investment - €/LU	910	938	NS	896	956	**	898	964	*	836	1,000	***
AI - € per cow[1]	8	7	NS	6	8	NS	–	–	–	–	–	–
Rented land[2]	0.10	0.17	**	0.14	0.14	NS	0.13	0.17	NS	0.14	0.12	NS
Specialisation[3]	0.97	0.96	NS	0.96	0.94	NS	0.95	0.96	NS	0.92	0.97	***
Environmental and demographic variables												
Age of holder - years	54	53	NS	54	52	NS	59	59	NS	59	59	NS
Family labour[4]	0.99	0.98	NS	0.99	0.97	NS	0.98	0.98	NS	0.99	0.97	NS
Fragmentation[5]	3.1	3.2	NS	2.9	3.4	*	2.9	3.2	NS	3.2	3.3	NS
Off-farm income[6]	–	–	NA	973	928	NS	–	–	NA	681	860	NS
Soil[7]	2	4	NS	5	3	NS	5	1	NS	5	3	NS
REPS participation[8]	54	59	NS	66	56	NS	55	45	NS	46	41	NS
Off-farm employed[9]	78	76	NS	82	71	NS	71	77	NS	69	76	NS

[1]Artificial insemination expenditure per cow or breeding heifer
[2]Rented land area as a proportion of total area farmed
[3]Cattle LU as a proportion of total LU
[4]Family labour employed as a proportion of total labour employed
[5]Number of land parcels
[6]Monthly off-farm income; not recorded in 2009
[7]Soil qualitatively classified from 1 to 6 on potential agricultural use; soils classified 1 have broadest use, soils classified 6 have limited use
[8]Rural Environmental Protection Scheme – percentage of farms participating
[9]Percentage of farms with holder or spouse in off-farm employment
Significance levels: *** $P<0.01$; *** $P<0.05$; * $P<0.10$; NS = Not significant

Table 5. Mean income and scale efficiency scores and number of farms exhibiting increasing, constant or decreasing returns to scale

System	Year	IRS[1]	CRS[2]	DRS[3]	IES[4]	Bias	SES[5]
Cattle Rearing	2009	3	5	220	0.80	0.06	0.56
	2010	9	5	204	0.71	0.10	0.63
Cattle Other	2009	0	24	163	0.66	0.12	0.55
	2010	0	29	220	0.64	0.12	0.52

[1]Increasing returns to scale
[2]Constant returns to scale; these farms are fully scale efficient (IES = 1)
[3]Decreasing returns to scale
[4]Income efficiency score (under variable returns to scale model)
[5]Scale efficiency score

increase in purchased inputs (Finneran *et al.*, 2012). The observed positive relationship of market gross output per livestock unit (Figure 2iii) with efficiency observed has been previously highlighted by Helfand and Levine (2004) in a study of Brazilian farms. It is indicative of either improved genetic merit of livestock sold or an improved marketing strategy relative to the mean.

Although the bottom third farms ranked on SES were 1.8 to 4 times the scale of the bottom third in LU terms, overhead costs and FFI were not significantly different. This suggests that these larger farms were not taking advantage of economies of scale. This is because overhead costs and depreciation were rising almost linearly with rising livestock numbers. Thus, it appears that the more intensive (higher stocking rates) production systems employed by these larger farms are associated with increased fragmentation, land rental and machinery and livestock investment. The negative effects of fragmentation and associated travel between dispersed land parcels have been identified previously by O'Neill and Matthews (2001) and Del Corral *et al.* (2011).

Market net margin was negative across systems and years and not significantly different between low and high scale efficiency farms (Table 6). Therefore, the larger (low SES) farms suffered more negative farm market net margins, but earned significantly greater farm direct payments than the smaller, more scale efficient farms (Table 7). These larger farms received lower direct payments/LU, indicating a greater diversion of subsidies towards livestock and capital investment than on the smaller farms.

Therefore, it appears that there are two principal divergent strategies for maximising household income on cattle farms. Despite negative market net margins, larger farms appear to utilise the direct payments as a subsidy for increased scale and intensity of production, and a source of investment finance (supported by greater borrowings – Table 7), in addition to an income support. This tendency to use subsidies to support unprofitable production – despite the primary subsidy (the single farm payment) being fully decoupled from production – has been previously identified by Howley *et al.* (2012). Smaller farmers in contrast retain a greater proportion of the direct payments as FFI and supplement this with greater monthly off-farm income. Smaller farms thereby maintain a low scale, low intensity production strategy and consequently achieve greater farm scale efficiency.

Management, environmental and demographic effects

High concentrate feeding on cattle rearing farms was a significant impediment to income efficiency. This relationship has been identified and explored previously by Kelly (2000) and Crosson *et al.* (2007), with increased utilisation of grazed grass and home produced forages a recommended solution to this constraint (Finneran *et al.*, 2012). Achieving increased grass utilisation while minimising capital and labour investment is a considerable challenge on low profit beef farms. However, given that the greatest input slacks were observed for concentrate feed and overhead expenditure (Table 3), reducing these inputs while maintaining or increasing output would appear to provide the greatest potential for efficiency increases.

Surprisingly, soil type was found to have no effect on income efficiency, however farms in the western regions of the country typically exhibited greater efficiency scores. This may be because soil and climate is more suited to dairy and cereal production in the east of the country and therefore the more profit oriented farmers are most likely to choose these more profitable enterprises over beef production in the east (Boyle, 2002).

The lack of any effect of labour input on income efficiency is striking. Greater labour input/LU was associated with greater scale efficiency (although not significant on CR farms). It is clear that the higher proportions of (generally unpaid) family labour utilised on smaller farms is a key component of the greater scale efficiency of these farms. This finding accords closely with the results presented by Latruffe *et al.* (2005).

Similar to the results of Carroll *et al.* (2007), Lien *et al.* (2010) and Kelly *et al.* (2012), off-farm employment had no effect on-farm income efficiency. This is likely due to smaller, part-time farmers implementing farm production strategies which permit most efficient allocation of resources between off and on-farm employment (Chavas *et al.*, 2005; Lien *et al.*, 2010).

Greater capital investment in a low profit enterprise such as beef production was associated with lower farm income efficiency in the short run. Longer term productivity analysis such as Malmquist Index modelling would be required to determine the long term effect of such investment. Such a model should ideally take account of increasing fixed asset values by including net worth change as a model output in addition to annual farm income.

Table 6: Mann-Whitney test results for differences in farm financial measures for beef farms ranked in scale efficiency groups of top and bottom 1/3

System	Cattle Rearing						Cattle Other					
Year	2009			2010			2009			2010		
Scale efficiency tercile	Top 1/3	Bottom 1/3		Top 1/3	Bottom 1/3		Top 1/3	Bottom 1/3		Top 1/3	Bottom 1/3	
Scale efficiency score	0.74	0.40	***	0.81	0.46	***	0.85	0.33	***	0.82	0.29	***
Gross margin - €/ha	542	529	NS	571	567	NS	577	680	**	694	713	NS
Market net margin - €/ha	−234	−216	NS	−197	−201	NS	−221	−185	NS	−182	−180	NS
Family farm income - €/ha	230	194	NS	232	205	NS	265	290	NS	338	278	NS
Off-farm income[1]	–	–	NA	1,168	915	NS	–	–	NA	1,053	720	**

[1]Monthly off-farm income; not recorded in 2009
Significance levels: *** $P<0.01$; *** $P<0.05$; * $P<0.10$; NS = Not significant

5. Conclusions

The highly heterogeneous nature of physical output from Irish beef farms, and the prevalence and diversity of complementary enterprises create impediments to efficiency modelling. Development of a whole-farm income efficiency DEA model has partially overcome these constraints, as well as providing more holistic solutions than could be derived from comparative analysis using partial measures of profit such as gross margin analysis. By including direct payment subsidies as both inputs and outputs (as a component of FFI) the model took consideration of the efficiency with which the farmer retained these direct payments as an income support or employed them as a production subsidy. While this whole-farm approach may provide a richer picture of efficiency drivers than partial analysis approaches, further studies including off-farm income and non-economic factors could provide even greater insights. Given that social and environmental factors can play as great a role as economic factors in farm decision-making (Macken-Walsh, 2010) they should be considered in any truly holistic family farm model.

Little opportunities exist to increase beef farm efficiency by way of increased scale, although this may be possible for a minority of the smaller, less intensive cattle rearing farms. Smaller, more scale efficient beef farms retained more direct payments as income and supplemented this with greater off-farm income. Larger, less scale efficient farms utilised direct payments to subsidise increased investment in rented land and additional livestock. These larger, more fragmented farms are not achieving economies of scale because overhead costs and investment are increasing linearly with livestock unit increases. This may be associated with greater stocking rates requiring greater machinery and building investment. Substituting capital inputs and paid labour for unpaid family labour is also contributing to reduced scale efficiency on larger farms.

Smaller farms with off-farm incomes are classified as ''sustainable'' by Hennessey *et al.* (2012), however, their existence is dependent on the continued availability of off-farm employment in rural areas. That the regions with the smallest farm size, (border and west) are also the regions experiencing the greatest unemployment rates nationally (Central Statistics Office, 2012b) is of concern. At the other end of the size scale, larger farms are more dependent on the continuity of direct payment subsidies. Prospects of increasing beef output by means of scale expansion are therefore negative in an external environment of declining subsidies and off-farm employment in rural areas.

Increased output from Irish beef farms must therefore come primarily from farm system structural changes rather than scale changes, otherwise farm income efficiency will decline. High overhead costs per livestock unit and high concentrate feeding on cattle rearing farms were identified as significant constraints to income efficiency. Maximising output from grazed forage on owned land is likely to result in the greatest income efficiency.

Prescriptive advice from a farm comparative analysis study may provide greater insight when conducted over a longer time period than two years. Long run farm efficiency analysis should include non-income benefits of the farming system such as accumulation of net worth. A

Table 7: Mann-Whitney test results for differences in explanatory variable means for beef farms ranked in scale efficiency groups of top and bottom 1/3

System	Cattle Rearing						Cattle Other					
Year	2009			2010			2009			2010		
Scale efficiency tercile	Top 1/3	Bottom 1/3		Top 1/3	Bottom 1/3		Top 1/3	Bottom 1/3		Top 1/3	Bottom 1/3	
Size variables												
Scale efficiency score	0.74	0.40	***	0.81	0.46	***	0.85	0.33	***	0.82	0.29	***
Income efficiency score	0.83	0.77	***	0.74	0.67	***	0.68	0.64	NS	0.64	0.62	NS
Total livestock units - LU	24	49	***	29	52	***	26	97	***	24	97	***
Land area - ha	30	49	***	38	48	***	27	68	***	29	75	***
Farm gross output - €	22,178	40,209	***	29,087	44,453	***	22,899	76,550	***	28,597	82,850	***
Farm direct payments - €	13,312	20,095	***	15,222	21,534	***	12,735	33,187	***	12,831	33,900	***
System and intensity variables												
Stocking rate - LU/ha	1.00	1.23	***	0.99	1.21	***	1.18	1.54	***	1.08	1.56	***
LU/labour unit	23	30	NS	26	28	NS	26	55	***	20	60	***
Gross output - €/LU	953	854	**	1059	889	**	858	807	NS	1173	863	***
Direct payments - €/LU	586	455	***	602	463	***	503	349	***	642	353	***
Concentrate costs - €/LU	108	98	NS	123	91	NS	80	127	***	164	143	NS
Fertiliser costs - €/LU	59	64	NS	61	64	NS	56	63	NS	62	68	*
Depreciation - €/LU	87	92	NS	128	95	**	67	73	NS	112	91	NS
Interest payments - €/LU	16	20	***	13	16	NS	5	16	***	7	18	***
Other variable costs - €/LU	167	158	NS	179	146	***	149	124	*	162	141	NS
Overhead costs- €/LU	377	342	NS	433	365	NS	292	285	NS	409	319	*
Machinery investment - €/LU	405	481	*	604	428	NS	434	398	NS	547	439	NS
Buildings investment - €/LU	734	706	NS	803	656	NS	528	562	NS	703	610	NS
Livestock investment - €/LU	890	912	NS	894	901	NS	876	910	NS	892	960	**
AI - € per cow[1]	11	8	NS	10	7	NS	–	–		–	–	
Rented land[2]	0.14	0.15	NS	0.15	0.14	NS	0.09	0.15	**	0.07	0.16	***
Specialisation[3]	0.97	0.96	**	0.96	0.95	**	0.97	0.92	***	0.97	0.92	***
Environmental and demographic variables												
Age of holder - years	53	54	NS	53	55	NS	59	57	NS	60	56	*
Family labour[4]	0.99	0.98	*	0.98	0.96	NS	1.00	0.95	***	1.00	0.96	***
Fragmentation[5]	3.1	2.9	NS	3.4	3.1	NS	2.5	3.5	***	2.7	3.9	***
Off-farm income[6]	0	0		1168	915	NS	0	0		1053	720	**
Soil[7]	3	2	**	5	2	NS	5	1	NS	3	1	NS
REPS participation[8]	42	61	***	63	51	NS	44	56	NS	36	40	***
Off-farm employed[9]	83	74	NS	84	73	NS	74	76	NS	76	70	NS

[1]Artificial insemination expenditure per cow or breeding heifer
[2]Rented land area as a proportion of total area farmed
[3]Cattle LU as a proportion of total LU
[4]Family labour employed as a proportion of total labour employed
[5]Number of land parcels
[6]Monthly off-farm income; not recorded in 2009
[7]Soil qualitatively classified from 1 to 6 on potential agricultural use; soils classified 1 have broadest use, soils classified 6 have limited use
[8]Rural Environmental Protection Scheme – percentage of farms participating
[9]Percentage of farms with holder or spouse in off-farm employment
Significance levels: *** P<0.01; *** P<0.05; * P<0.10; NS = Not significant

broader, multi-output model could more accurately reflect farmers likely long term behaviour under changing regulatory and macro-economic circumstances.

About the authors

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BOOK REVIEW

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Farm Incomes, Wealth and Agricultural Policy: Filling the CAP's Core Information Gap

Berkeley Hill

4th Edition, published April 2012 by CABI, Oxfordshire (www. http://bookshop.cabi.org). ISBN-13: 978 1 84593 847 5. Hardback, 336 pages. Price £95.00 / $180.00 / €125.00.

Hill's main thesis is introduced to readers on page one - the European Union's agricultural policy is primarily concerned with incomes of farmers, however, much of the data collected and analysed in order to examine the effectiveness of the policy, or determine its future constitution, relates to the economic performance of agricultural production rather than to farm household incomes. The introduction to the book sets the scene for the chapters that follow and explains the conceptual and contextual issues surrounding the measurement of farm incomes. In Chapter 2 the book takes the reader through some of the economic issues surrounding agriculture, the aims of agricultural policies, an overview of the history of EU and other industrialised agricultural policies and the role of data systems within a policy context.

In Chapter 3 the concept of 'standard of living' is placed in context of defining living standards within and beyond agriculture. Issues of low-income/high-asset wealth, different definitions of income, concepts of welfare as they relate to agriculture, personal income versus household income and disposable income and wealth and status are each deconstructed. Chapter 3 ultimately provides the context for the more data driven chapters that follow. The focus of Chapter 4 is indicators of income from agricultural production–at both the micro and aggregate levels. The historical basis of EU accounting processes and procedures take the reader through the detailed understanding of the link between micro and aggregate indicators of production income. A more detailed coverage of the UK's farm accounts surveys is provided, covering a 75 year history in a only a few pages, and providing a good overview of the differences between the various income measures these research surveys generate. Chapter 4 also includes two case studies of patterns in aggregate accounts in the UK and US, providing graphical and tabular analyses of the changing fortunes of agriculture, before presenting an analysis of the distribution of income across EU member states. Chapter 4 closes by placing income from agriculture into context with the rest of the economy and presenting results of income (in)stability.

Thus far the book has established a conceptual framework, provided historical context and presented analyses of production income returns to agriculture. Chapter 5 arguably presents Hill's main thrust of the book as it explores incomes of agricultural households in contrast to income from agricultural production. Before presenting data from Eurostat's incomes of agricultural household statistics (IAHS), Chapter 5 takes the reader through the context of incorporating a household income measure into reporting statistics, including some definitional concepts of recording net disposable income and the constitution of a 'household'. Graphical and tabular results of the IAHS in selected member states are presented in conjunction with some intricacies of data sources and collection issues across EU member states; what comes across is the breadth of information sources frequently required to compile household income statistics and the differences that exist in the manner by which different countries collate these data. Additionally, the challenges that the production of IAHS encountered are insightful. Data on household incomes are presented for a selection of EU member states, the USA, Canada and Australia. A selection of the results provides an indication of the depth of Hill's findings: agricultural households across a range of countries are in receipt of substantial amounts of income from outside of agriculture; agricultural household income is considerably more stable than from agriculture alone; and differences in taxation rules between countries can lead to substantial differences in the metrics relating to disposable *cf.* gross household income. Hill's conclusion to Chapter 5 is that one cannot objectively examine the success of the objectives of the CAP without inclusion of agricultural household income as a key metric; it is a strong, well-argued and logical conclusion.

Farmers are frequently defined as 'asset-rich/cash-poor'; Chapter 6 considers the issue of wealth in agriculture, the estimation of net worth and the implication of wealth to farmers' economic status. The chapter presents analyses of UK and US balance sheets over time (graphically) explaining the driving forces that lie behind these temporal changes. Hill's argument with respect to wealth is that such aggregate or farm business level data are however flawed–much in the same way that only measuring income from agricultural production is flawed if we are concerned with income stability. Chapter 6 argues that the net worth of agricultural households should include personal balance sheet aspects–e.g. shares, savings and personal liabilities in the form of loans. Wealth is argued to be of crucial importance as farmers operating their businesses have the ability to take realised profit as income or as an addition to wealth. Once again, these measurement issues lead to data needs, and Hill takes the reader through previous work in this area. In Chapter 7 Hill returns to the main argument of his thesis, that in order to assess the success of agricultural policies in addressing agricultural income stability and well-being, the data and information needs go beyond that of the agricultural production unit. The chapter explores the practical, political and policy issues associated with the collation and analyses of data at the level of the agricultural household, and calls for data on income and wealth to be jointly collected in order to assess agricultural welfare relative to the population more generally.

For those with an interest in agricultural incomes and policies relating to the welfare of farmers in the EU and industrialised countries, this book represents a substantial contribution, bringing together a wealth of information and providing convincing arguments that address the book's main thesis. In style it is comprehensive, inclusive and evidenced-based. In summary, Berkeley Hill's book on farm incomes, wealth and agricultural policy draws upon a wealth of information, knowledge and experience that few could even begin to match.

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