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An appreciation of John Nix

Emeritus Professor John Sydney Nix
1927 - 2018

Professor John Nix, who died on March 15th 2018, had an outstanding career as the leading figure of his generation in the study of farm business management. Through his teaching, research, publications, public speaking and involvement with organisations, such as the Institute for Agricultural Management, his aim was to improve the application of management skills to agricultural businesses at a practical level. He was remarkably successful in that endeavor and in doing so he became a household name amongst the farming community. His influence has been both far reaching and profound in the UK but it has also been significant internationally.

John was brought up in an urban environment on a Council Estate in South London. An academic high achiever from a very early age, he gained a scholarship to read Economics at Exeter University. On graduation he joined the Royal Navy as an Instructor Lieutenant. He had hoped to see something of the world in his new job but sadly this did not extend beyond the confines of HMS Ganges, a shore-based establishment in Suffolk. After three years in the Navy, he decided in 1951 to apply for a post as Senior Research Officer in the School of Agriculture at the University of Cambridge. It was this somewhat unlikely change in direction that started his lifelong passion for agriculture and agricultural economics. His new job involved touring East Anglia visiting farms and collecting data and in doing so he developed an understanding and a fondness for the industry that never left him. Whilst at Cambridge John authored a number of studies into the economics of various farm enterprises in East Anglia and he became involved with the early modelling work on farm systems which was developing at that time.

In 1961 he moved to Wye College (University of London) to join the Economics Department as lecturer and also as Farm Management Liaison Officer whose task it was to provide economic and management support for the NAAS, the state run agricultural advisory service of those days. This latter role meant that, as well as conducting research and teaching within a university environment, he was expected to extend the results of his research directly to individual farmer clients.

This gave him a unique insight into the practical data needs of farm planners and was a stimulus to the production of The Farm Management Pocketbook, the first edition of which came out in 1966. This publication, now titled the 'John Nix Farm Management Pocketbook' and under the editorship of Graham Redman of Anderson's, is currently in its 48th edition. Estimated to have sold a quarter of a million copies by the time John retired in 1989, it became a standard reference for business in UK agriculture.

He always emphasized that the data was for planning purposes only and should *always* be modified if local conditions or knowledge suggested it. He was sometimes frustrated by the way in which figures from the Pocketbook became treated as fixed targets, goals or objectives, rather than as guidance as to what was likely in an average year in a particular situation. He was also on one occasion taken aback when one farmer said that he found the Pocketbook very useful for filling in complicated farm survey questionnaires about yields, labour use and other items (thus completing the data circle!).

John built, over time, a large information exchange network with the industry to source data for the Pocketbook, for mutual benefit. An example of this was the dairy advisory support group Kingshay, which John helped found in 1991, and was then its President until 1996. John updated the Pocketbook on an annual basis. He imposed a strict timetable for himself and during this time he went into purdah. Woe betide anyone who interrupted him over that period!

As an academic, he was known for his analytical approach to farm management problems. The first edition of his textbook *Farm Planning and Control*, jointly authored with C.S. Barnard, came out in 1973, with a second edition in 1979. It was regarded as the best UK treatise on the subject, was used throughout the world and was translated into Spanish. He also authored, together with Paul Hill and Nigel Williams, a second textbook *Land and Estate Management* which appeared in 1987 and ran to three editions during the 90's. There was a third textbook, *Farm Mechanisation for Profit* with Bill Butterworth appearing in 1983.

In 1973, following the expansion of the economics teaching at Wye, John was appointed as Head of the Farm Business Unit. He lost no time in developing a tight unit with a strong focus on teaching and research. He was always supportive of his staff in the development of their own careers and encouraged them to explore whatever avenues they felt might be productive. He was a popular lecturer with a heavy teaching load both at undergraduate and postgraduate levels. His notes were legendary, often consisting of a few ragged foolscap sheets with scribbles added year after year until almost illegible. One of his secretaries even found a discarded sheet and had it framed. He supervised many PhD students and a number of these became good lifelong friends. Shortly after his retirement in 1989, he was appointed Emeritus Professor and in 1995 he was made a Fellow of Wye College.

John's personal success and that of the FBU at Wye led to him being granted a personal chair in Farm Business Management in 1982, the first such chair in the UK. In 1984 he oversaw the introduction of the undergraduate degree in Agricultural Business Management at Wye. This became highly successful and well regarded. Despite his commitments within College, he always maintained a heavy programme of lectures at farmers' meetings, conferences and other gatherings up and down the country. He was in demand as a speaker or advisor to many organisations associated with the industry. At one time he was a regular on local television. His easy style and willingness to explain things in simple language endeared him to his audiences.

John had considerable influence within the Agricultural Economics Society and the Institute of Agricultural Management. He was President of the AES in 1990-91 and in 2011 the Society honoured him with its Award for Excellence in recognition of his outstanding contribution to public policy and the farming industry. He was a founder member of the Farm Management Association which was formed in 1965. He chaired the FMA from 1978 to 1981 and edited the journal *Farm Management* from 1971 to 1995. The organisation was later to become the Centre for Management in Agriculture and is now known as the Institute of Agricultural Management. The Institute honoured him with its first National Award in 1982 and a Fellowship in 1993.

The large number of other awards which John received give some indication of the very high regard in which he was held in the industry as well academia: Companion of the British Institute of Management (1983), Fellow of the Royal Society of Arts (1984), Fellow of the Royal Agricultural Society (1985), Agricultural Communicators Award (first recipient in 1999), The Farmers Club Cup (2005), NFU Lifetime Achievement Award (2006), Honorary Fellow of the Royal Agricultural Society of England (2007) and the Farmers Weekly Lifetime Achievement Award (2014).

John's life was one full of extraordinary achievement and impact within the subject of farm business management and on the agricultural industry. But for those that knew him and worked with him it will be the extraordinary warmth of his personality, enthusiasm and friendship that has left such a huge impression on so many of their lives. His first wife Mavis, by whom he had two daughters and a son, died in 2004. In 2005 he married Sue who survives him.

James V.H. Jones and Paul Webster

REFEREED ARTICLE

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Till death do us part: Exploring the Irish farmer-farm relationship in later life through the lens of 'Insideness'

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ABSTRACT

The senior generation's unwillingness to relinquish managerial duties and retire is a globally recognized characteristic of intergenerational family farm transfer. This is despite the array of financial incentives put in place to stimulate and entice the process. Applying Rowles' concept of 'insideness' as a theoretical framework, this paper brings into focus the suitability and appropriateness of previous and existing farm transfer policy strategies, by presenting an insightful, nuanced analysis of the deeply embedded attachment older farmers have with their farms, and how such a bond can stifle the necessary hand over of the farm business to the next generation. This research employs a multi-method triangulation design, consisting of a self-administered questionnaire and an Irish adaptation of the International FARMTRANSFERS Survey in conjunction with complimentary Problem-Centred Interviews, to generate a comprehensive insight into the intricate, multi-level farmer-farm relationship in later life. The overriding themes to emerge from the content analysis of the empirical research are farmer's inherit desire to stay rooted in place in old age and also to maintain legitimate connectedness within the farming community by remaining active and productive on the farm. Additionally, there is a strong sense of nostalgia attributed to the farm, as it is found to represent a mosaic of the farmer's achievements as well as being a landscape of memories. The paper concludes by suggesting that a greater focus on the farmer-farm relationship has the potential to finally unite farm transfer policy efforts with the mind-set of its targeted audience, after decades of disconnect.

KEYWORDS: family farming; insideness; succession; retirement; generational renewal; rural sustainability

1. Introduction

1.1 Background

The survival, continuity and future prosperity of the agricultural sector, traditional family farm model and broader sustainability of rural society ultimately depends on an age-diverse farming population. With a steady decline in the number of young farm families reported as being key in the demoralization of rural communities in which the farm is located (Ball and Wiley, 2005; Goeller, 2012), and the recent declaration by European Commissioner for Agriculture and Rural Development, Phil Hogan, that a priority for future CAP reforms must focus on generational renewal (European Commission, 2017), it is increasingly clear that a major challenge presents itself in the area of intergenerational family farm transfer. Intergenerational family farm transfer, encompassing three separate yet interrelated processes of succession, retirement and inheritance (Gasson and Errington, 1993), is an integral facet of farm management. While present attempts to confront the global demographic trend of an ageing farming population and a low level of land mobility (Ingram and Kirwan, 2011; Bogue, 2013; Chiswell, 2014; Fischer and Burton, 2014; Zagata and Sutherland, 2015), have added significantly to existing knowledge in this field, there are numerous, intricate emotional facets affecting the older generation's farm transfer decision-making process, which for the most part have been neglected (Conway *et al*., 2016). The outcome; a derailment of the process in many cases (ibid).

This paper, drawing on gerontological geographer, Graham Rowles' (1983a) concept of 'insideness', contextualises the difficulty and reluctance to 'step aside' and retire from farming (Foskey, 2005; Lobley *et al*., 2010; Ingram and Kirwan, 2011; Fasina and Inegbedion, 2014) that continues to be the mainstay in many rural areas globally. The paper probes into the subjective experiences of farmers in the Republic of Ireland in later life and unearths a layer of understanding and attachment, both implicit and explicit, between farmer and farm, that we argue must be central to policies aimed at facilitating family farm intergenerational transfer. Reinforcing the

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urgency, is the realisation that this phenomenon has resulted in significant socio-economic challenges for young people aspiring to embark on a career in farming (Kirkpatrick, 2013), with adverse implications not only on the development trajectory of individual family farms and rural communities, but also on the production efficiency and economic growth of the agri-food sector as a whole (ADAS, 2004; Ingram and Kirwan, 2011; Goeller, 2012). In the Republic of Ireland, young people's entry into farming is particularly inflexible, due to the fact that entry to the sector is predominately by inheritance or purchasing highly inflated farmland (Gillmor, 1999; NESC, 1997; Hennessy and Rehman, 2007); entry via leasing of land or partnership arrangements, common in many countries throughout the world, are not widely practiced (ibid). Such a cultural anomaly requires immediate policy intervention. A recent report on 'Land Mobility and Succession in Ireland' claims the lack of land mobility (i.e. transfer of land from one farmer to another, or from one generation to the next) currently experienced in the Republic of Ireland is stifling agricultural growth by preventing young 'enthusiastic' farmers gaining access to productive assets (Bogue, 2013).

1.2 Policy interventions

In response to rigidity in the agrarian system, the policy environment in the Republic of Ireland has explored various mechanisms of financially stimulating and enticing farm transfer over the past four decades. Little change however, in attitude amongst the older generation towards intergenerational transfer has come about to date, resulting in an on-going resistance or at best ambivalence toward the process (Commins and Kelleher 1973; Ryan, 1995; Gillmor, 1999; Bika, 2007; Bogue, 2013; Leonard *et al.*, 2017; Conway *et al.*, 2017). Conway *et al.* (2016) argue however that such policy measures aimed at facilitating land mobility from one generation to the next were excessively preoccupied with financial incentives and have 'little or no regard' for the older farmer's emotional welfare (p.166). In particular, Conway *et al.*, (ibid) strongly criticised the eligibility requirements for farmers entering the most recent largely unsuccessful Early Retirement Scheme for farmers (ERS 3, June, 2007), which included a clause that stated that 'Persons intending to retire under the scheme shall cease agricultural activity forever' (DAFM, 2007). This type of language and sentiment was completely oblivious to the consciousness of many older farmers. Indeed Conway *et al.* (2016) found that the potential loss of one's lifelong accumulation of symbolic capital, with associated characteristics of identity, status, position and authority, upon transferring managerial control and retiring is a dilemma that farmers find difficult to accept and ultimately resist (ibid).

Equally it could be argued that the lack of any great understanding of a farmer's psyche is also clearly visible in the various attempts to develop 'answers' usually in the form of tax initiatives (Meehan, 2012; Leonard *et al.*, 2017) or unconventional tenures like Joint Farming Ventures (JFVs) for example. While there is merit in such structures, they do not, we would argue, fully grasp the enormity of a farmer's attachment to his/her farm. Specifically, not unlike elsewhere in the world, JFVs, including arrangements such as farm partnerships, contract rearing and share farming (Turner and Hambly, 2005; ADAS, 2007; Ingram and Kirwan, 2011), have recently been promoted within Irish policy discourses as strategies that act as a stepping stone to successful farm transfer (DAFM, 2011; Hennessy, 2014), subsequently helping to alleviate concerns of an ageing farming population and maximize production efficiency. Ingram and Kirwan (2011) note however that while it appears that some older farmers are willing in principle to offer JFV arrangements, when it comes to the reality of 'handing over control (or partial control) of a business that they have been in charge of for perhaps 40 or 50 years' (p.294) they are often reluctant to do so. Indeed, research indicates that the older generation can experience difficulty relinquishing managerial control and ownership of the family farm, even to their own children (Barclay *et al.*, 2012; Price and Conn, 2012; Whitehead *et al.*, 2012; Conway *et al.*, 2017). Kirkpatrick's (2013) study in the USA explains however that 'in many cases the older farmers' sense of place and purpose attached to the family farm' supersedes any fiscal incentives that encourages 'the handing over of the family farm to the next generation' (p.4).

Consequently, if tax relief schemes or JFVs arrangements are unable to progress the desire for generational renewal on the farm, what are the obstructions that continue to frustrate or delay the process and how might these be addressed? It is to this and the concept of farmer-farm attachment that we now consider.

1.3 Farmer-farm attachment

This paper brings into focus the suitability and appropriateness of previous and existing farm transfer policy strategies, by generating a comprehensive insight into the deeply embedded relationship older farmers have with their farms; emulating Shucksmith and Hermann's (2002), contention of the need to examine 'farmers' own ways of seeing the world' (p.39). While Conway *et al.'s* (2016) research into the human side of farm transfer identified the complex psychodynamic and sociodynamic factors that influence the farm transfer decision-making process, existing research in the field has yet to thoroughly describe or explain the level of emotional attachment placed on the family farm and its embodied contents (i.e. land, farmhouse, livestock). These 'embodied contents' are often developed over several generations, and as such the bond created often affects the older farmer's ability to deal with and accept the inevitable challenges and changes brought about by the 'twin process' of succession and retirement. Price and Conn (2012) previously argued that 'allowing for succession is an emotional rather than rational process (p.101), resulting in decisions on whether to implement the process or not, being based more on 'heart than head' (Taylor *et al.*, 1998, p.568). It is therefore argued here that an in-depth understanding and knowledge of farmer-farm attachment is necessary and will aid in the modification of existing policies and/or the development of novel strategies that sensitively deal with problematic issues surrounding intergenerational farm transfer. Perhaps most importantly of all is the contention of this research that in fully understanding the farmer-farm connection and allowing this to inform the type of decisions being made, this will not only enable greater intergenerational transfers to take place but more significantly will help secure the well-being of farmers as they age.

Furthermore, given that succession planning is a relatively uncommon practice within the farming community

(Kimhi and Lopez, 1999; Burton and Fischer 2015), and there seems to be a cultural expectation that 'farmers don't retire' (Conway *et al.*, 2016, p.172), this paper has global relevance and will be of particular interest to countries throughout the European Union where the high age profile of the farming community and the low rate of succession and retirement have been matters of concern and unease for decades (Commins and Kelleher 1973; Gasson and Errington, 1993; Bika, 2007; Hennessy and Rehman, 2007; Zagata and Sutherland, 2015). European demographic trends reveal an inversion of the age pyramid with those aged 65 years and over constituting the fastest growing sector of the farming community (Zagata and Sutherland, 2015). Preliminary results from Eurostat's most recent Farm Structure Survey indicate that 6% of farmers were aged 35 and under in 2013, while over 55% were aged 55 and older (European Commission, 2013; European Commission, 2015). Furthermore, Eurostat's Farm Structure Survey highlights that for each farmer younger than 35 years of age, there were 9 farmers older than 55 years (European Commission, 2012; European Commission, 2015). The situation in the Republic of Ireland is closely analogous to that of its European counterparts; in 2010, only 6.2% of Irish landowners were under 35 years of age whilst 51.4% were over 55 years old (CSO, 2012). Between 2000 and 2010, those over 65 years increased by 31%, while those within the 55 to 65 age bracket increased by 26%, with a 52.8% reduction in the amount of farmers aged less than 35 years recorded (ibid).

The next section presents the theoretical framework adopted, followed by a description of the methodological approach employed, while thereafter the empirical evidence is used to explore the 'farmers' own ways of seeing the world' (Shucksmith and Hermann's 2002, p.39). The latter part of the paper expands on this evidence and examines potential pathways that we argue should inform those policy makers and key stakeholders who have the means and ability to deliver interventions and programmes for older farmers. The directions for future research are also discussed.

2. Theoretical approach

This study is driven by a theoretical gap in the understanding of farmer-farm relationship in later life. A growing body of work has pointed out that personal experience gives meaning to places and contributes to self-identity (Chaudhury, 2008). Arguably, a formative work in the area of place attachment and identity amongst rural elderly persons in old age is Rowles's (1983a) concept of 'insideness' (after Relph, 1976). In considering the geographies of later life, Rowles (1990) explains that insideness involves 'an intimate involvement with a place that is grounded in personal history and qualitatively differentiates this place from space outside' (p.107). Rowles' (1983a) three-year, in-depth ethnographic research on elderly people living in a rural Appalachian community in the U.S.A. conceptualized three key dimensions of place attachment: physical, social and autobiographical insideness. Although direct application of these concepts will be discussed in the results sections, it is instructive to define each here. Physical insideness is characterized by 'familiarity and habitual routines of habitation within the home setting' (Oswald and Wahl, 2005, p.29), resulting in the sense that an individual is able to 'wear the setting like a glove' (Rowles, 1983b, p.114). This 'body awareness' of space (Rowles and Ravdal, 2002; Rowles, 1993), results from an intimacy with one's 'physical configuration stemming from the rhythm and routine of using the space over many years' (Rowles, 1984, p.146). Physical insideness is also considered to significantly contribute to general satisfaction and well-being in old age (Rowles, 2006). Rowles (1983a) suggests that the intimacy of physical insideness is supplemented by a sense of social insideness, or immersion. Social insideness is fostered and developed through 'everyday social interaction and the performance of particular social roles in a neighbourhood' (Riley, 2012, p.763). Furthermore, social insideness is considered to be particularly significant in old age, as one may need to draw on these long-term relationships in accommodating declining physical capabilities and health in later life (Rowles, 2008; Riley, 2012). Finally, the third sense of insideness in later life is 'autobiographical insideness'. Autobiographical insideness extends beyond the physical setting or social milieu to create an environment that has 'a temporal depth of meaning' (Rowles, 1983a, p. 303). Peace *et al.* (2005) add that autobiographical insideness is 'based on time and space, a historical legacy of life lived within a particular environment' (p.194). Autobiographical insideness has been suggested to be the most relevant to describe older people's attachment to place because it is embedded in memories of significant experiences, relationships and events over one's lifetime (Rowles, 1993; Dixon and Durrheim, 2000; Burns *et al.*, 2012). According to Rowles (1983b) this provides 'a sense of identity and an ever-present source of reinforcement for a biography interpreted from the retrospective vista of a life review' (p.114). Older people with strong ties to place may feel more mastery as well as a greater sense of security and belonging (Burns *et al.*, 2012; Lecovich, 2014).

The three senses of insideness, expressing different, yet inextricably intertwined aspects of the rural elderly populations' affinity with their home environment, have been extensively drawn upon by rural geographers, gerontological experts and occupational therapists investigating the importance of space and place-identity in old age (Dixon and Durrheim, 2000; Seamon, 2014; Degnen, 2016). In a farming context, Riley (2012) previously employed the concept of insideness to explore the challenges and issues surrounding the occupational cessation and retirement relocation of retired farming couples in the United Kingdom, however there have been no studies carried out to date which have explicitly explored Rowles's three interrelated constructs of place attachment in later life amongst older, active and productive members of the farming community. While it is acknowledged that the concept of insideness does not cover every facet dictating the farm transfer decision-making process, it does contribute to identifying current needs and priorities within policy and research by providing insight into the subjective experience of farmers growing old on the farm, rather than relying solely on aggregate data. This aids in the interpretation of existing quantitative results in the field and thereby increases policy relevance.

3. Methodology

This research employs a multi-method triangulation design used by Conway *et al.*, (2016), in conjunction with a preliminary exploration of data obtained from an Irish adaptation of the International FARMTRANSFERS Survey in an attempt to obtain a complete picture of the intricate, multi-level farmer-farm attachment in later life and the suitability of previous farm transfer policy strategies. A detailed survey was initially undertaken with 324 farmers aged 55 and over in attendance at a series of 'Transferring the Family Farm' clinics (TFFC) hosted by Teagasc (the Agriculture and Food Development Authority in Ireland) to investigate the attitudes and behavioural intentions of the farming community towards succession and retirement. The reasoning for specifically focussing on farmers aged 55 and over is that one of the terms and conditions for farmers intending to retire under the 2007 Early Retirement Scheme (ERS 3) was that participants must have been 'between his/her 55th and 66th birthday' to be eligible (DAFM, 2007). Over 2,800 farmers attended these clinics held at 11 different locations throughout the Republic of Ireland in September and October 2014. Sixty percent (n=194) of questionnaire respondents also gave their consent to be interviewed in more depth at a later date.

In order to validate, strengthen reliability and build on the data gathered at the TFFC, the second phase of data collection involved a list of copyright questions derived from the International FARMTRANSFERS Survey, refined for Irish conditions, being included in the 2014 Land Use/Mobility Farm Survey conducted by Teagasc (see footnote 1). Lobley and Baker (2012) explain that the FARMTRANSFERS project is an international collaborative effort around a common research instrument that 'yields a range of (largely quantitative) data relating to the pattern, process and speed of succession and retirement which provides a firm base for future inquiries utilising different methodologies' (p.15). To date, the survey, based on an original design developed by the late Professor Andrew Errington of the University of Plymouth in in 1991 (Errington and Tranter, 1991), has been replicated in 10 countries and 8 states in the U.S.A. and completed by over 15,600 farmers throughout the world (Lobley and Baker, 2012).

The FARMTRANSFERS data collected from a stratified random sample of 309 farmers aged 51 and over included in the 2014 Land Use/Mobility Farm Survey and Choice Experiment analysis, representing over 80,000 farms nationally, combined with the 43,000 invitations sent out by Teagasc to each of their farmer clients to attend the TFFC, provides a thoroughly comprehensive nationally representative sample of the Irish farming population across a broad spectrum of farming operations, typologies, geographical location and scale. Such an expansive sample of Irish farmers is important due to the fact that different farming regions exist around the country, where boundaries span unevenly across county perimeters. The largest concentration of small sized farms occurs in the Western and Border regions for example, with the largest farms in the South-East, Mid-East and Dublin areas (Lafferty *et al.*, 1999).

The next phase of data collection involved a Problem-Centred Interview (PCI) approach, to peel back the layers and broaden the two farmer survey responses and in doing so, inform possible new policies. Witzel (2000) explains that PCI can be combined with questionnaires in order to 'solve the problems arising in connection with samples and to relate the results generated by different procedures' (p.3). Following frequency distribution and cross-tabulation analysis of aggregate data obtained at the TFFC and the FARMTRANSFERS survey on the Statistical Packages for Social Sciences (SPSS) programme, in conjunction with an additional review of relevant literature in the field, it was possible to drawn up a specific PCI guideline containing preformulated questions on the issues that were identified to be subjectively significant to the sample farming population. A 10% (n=19) sample of farmers recruited at the TFFC for the interview phase of data collection were sourced using a systematic sampling technique (see Table 1) and subsequently interviewed from May until August 2015.

Given the personal nature of the issues under investigation the use of individual face-to-face interviews in the homes of the respondents was deemed the most appropriate means of obtaining information. The interviews lasted up to 2.5 hours and were recorded, transcribed verbatim and assigned pseudonyms to protect participant's privacy. Content analysis (Mayring, 2000) was used to analyse the

Table 1: Interviewees' Details

Pseudo Name	Gender	Age	Farming Enterprise	Regional Location	Considered Retirement	Succession Plan in Place
Frank	Male	57	Mixed livestock	West	Yes	Yes
Luke	Male	69	Mixed Livestock	West	Maybe	No
Dominic	Male	77	Mixed Livestock	West	Maybe	No
Rory	Male	66	Sheep	West	No	No
Andrew	Male	64	Beef	West	Maybe	No
David	Male	70	Beef	North West	Maybe	No
Thomas	Male	80	Sheep and Tillage	North West	Yes	No
Sean	Male	75	Dairy and Poultry	North East	No	No
Mark	Male	61	Dairy	East	No	Yes
Claire	Female	82	Mixed Livestock and Tillage	East	No	No
Josh	Male	70	Tillage (Crop Production)	South East	Yes	No
Jack	Male	72	Dairy	South East	No	No
Ian	Male	67	Dairy	South	No	No
John	Male	70	Mixed Livestock	South	No	No
Colm	Male	71	Mixed Livestock	South West	No	Yes
Eimear	Female	65	Beef	South West	No	No
Brian	Male	85	Dairy	Midlands	Yes	No
Richard	Male	67	Beef	Midlands	Yes	No
Aoife	Female	68	Mixed Livestock	Midlands	No	No

data collected and identify categories and themes. Relevant quotes from the interviews were then integrated into the various themes in order to support particular findings.

4. Results and Discussion

The presented findings are the result of a triangulation of quantitative survey data and complimentary qualitative Problem-Centred Interviews maintaining the same foci. Findings from both the TFFC and FARMTRANSFERS survey reveal that there is a significant cohort of farmers in the Republic of Ireland that do not plan to retire from farming in the future (see Table 2). Of those who are open to the idea, Conway *et al*. (2016) previously identified the 'divergence of opinion and uncertainty between retirement expectations and retirement realisations, resulting in the decision to retire being difficult to execute and follow through' (p.170). This finding is consistent with psychological research, showing that attitudes are not necessarily related to behaviours (e.g., Ajzen, 1991).

Correlating survey findings also illustrate that there is a substantial percentage of farmers who have identified a successor (see Table 3), signifying a resurgence in demand from young people for a career in farming, resulting in an anticipated renaissance in agriculture (Chiswell, 2014) and, by extension, a rejuvenation of rural life (Teagasc, 2011; Goeller, 2012; Marcus, 2013).

Interviews identified however that farmers are ill prepared for succession with 84% of participants not having a succession plan in place (see Table 1). This finding is analogous with results obtained from the nationally representative sample of farmers surveyed in the FARMTRANSFERS survey which found that 67% do not have a succession plan in place. Moreover, 40% of FARMTRANSFERS respondents were found to not even have a will in place. Kimhi and Lopez (1999) previously highlighted that succession planning is unpopular within the farming community and therefore rarely occurs while the older generation is still alive, resulting in significant difficulties for the successor in waiting to integrate and evolve into a more formidable role in family farm business (Ingram and Kirwan, 2011). Gasson and Errington (1993) argue that the older farmers must be aware of the needs of the next generation and relinquish ownership rights of the farm to ensure continued involvement and interest in the family farm business. If this is not the case, the farmer runs the risk of not having a successor at all because the younger generation may go in search of alternative employment elsewhere in order to achieve their career ambitions and personal development (Kimhi and Lopez, 1999; Kirkpatrick, 2013) resulting in potentially good young farmers being lost to the agricultural sector (Nuthall and Old, 2017). Such a potentially detrimental phenomenon, requires urgent attention. Taking into account the senior generation's opinions and feelings towards farm transfer policy strategies however, 88% of TFFC questionnaire respondents agree that 'policy makers and practitioners need to have a better understanding of the world as farmers see it'.

Table 2: Retirement Plans

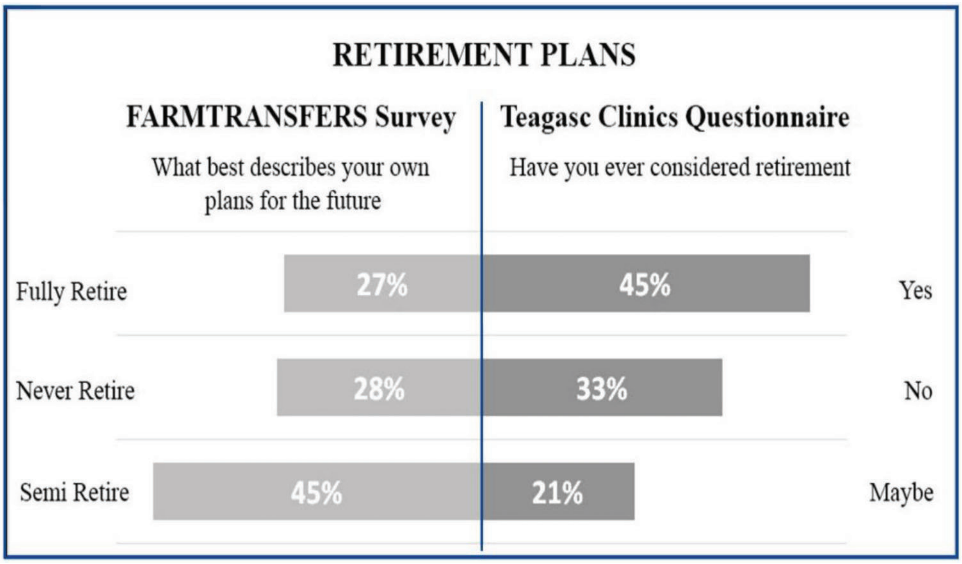
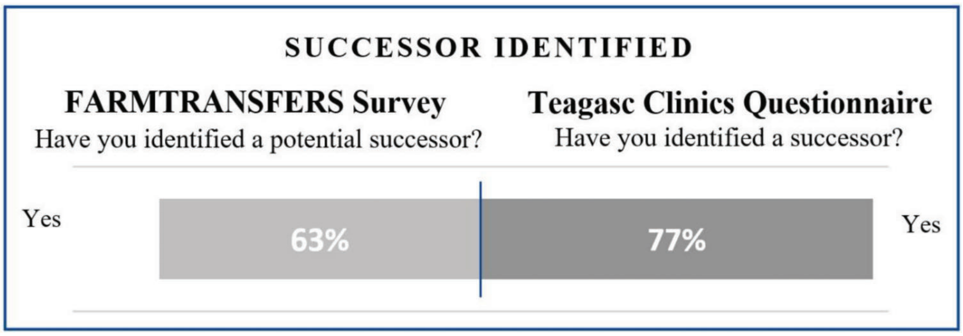


Table 3: Successor Identified



Winter (1997) previously highlighted that 'for too long the policy debate has been conducted with little reference to farmers or to their view of the world' (p.377). Furthermore, 88% of farmers surveyed at the TTFC who have not considered retiring from farming in the future agree that 'the lifestyle quality from being a farmer is far greater than any financial incentive to leave farming.' When asked more specifically about the suitability of the terms and conditions of the 2007 ERS 3, interviews reveal that there exists a clear disconnect between such policy measures and the mind-set of respondents:

'Ceasing all farming activity was a ridiculous rule. It was almost as if you couldn't even own a pair of wellingtons anymore and that is crazy. A lot of the rules and regulations brought into farming here in Ireland tend to be half baked'. (Josh, aged 70)

'Asking farmers to stop farming forever was very much a very backward step, because I think it would end up creating depression amongst farmers. Cutting a farmer adrift from their farm at that stage of their life would leave them in a very lonely place'. (Frank, aged 57)

'I thought that last retirement scheme was a disaster. I mean requesting that we couldn't do bits and pieces around our farms, it was bureaucracy gone mad. It was a no brainer that it wouldn't work and whoever came up with that scheme hadn'*t a clue about farming. We are talking about a way of life here, how could we be expected to cease agricultural activity forever?'. (Colm, aged 71)*

As such, while certain processes of contemporary rural restructuring may have impacted on the economic and social landscape of farming in the Republic of Ireland (Kinsella *et al*., 2000; Ní Laoire, 2005), empirical research findings indicate that there still exists an overwhelming significance of 'intrinsic' farming values over profit maximisation in Irish agriculture (Price and Conn, 2012; Duesberg *et al*., 2013; Conway *et al*., 2016; Duesberg *et al*., 2017). It is therefore imperative that existing and future policies and programmes encouraging intergenerational farm transfer take into account the emotional value attached to the farm and farming occupation 'beyond the economic' (Pile, 1990, p.147).

The overriding themes of farmer-farm attachment to emerge from the content analysis of the empirical research were (i) rooted in place (ii) legitimate connectedness and (iii) sense of nostalgia. These themes will now be discussed in the next sections, to provide a detailed insight into the level of insideness that the older generation of the farming community attach to their farm. Interestingly, despite the patriarchal prominence of farming highlighted in previous research (Gasson and Errington, 1993, Brandth, 2002; Price and Evans, 2006), empirical findings in this study did not uncover any great variation between male and female farmer-farm relationships. This may be explained by Bourdieu's concept of habitus (Bourdieu, 1977). Through regular practice in a social setting (such as the farm in the context of this research), Bourdieu explains that individuals develop habitus, 'the set of dispositions or learned behaviours which provides individuals with a sense of how to act and respond in the course of their daily lives' (Blackledge, 2001, p.349). Habitus thus functions as an 'internal compass', orientating and guiding one's social behaviour and practices of everyday life (Panagiotopoulos, 1990; Maclean, *et al*., 2010). Research respondents, of both genders, were found to share common deep-seated dispositions towards their farms, having lived there for most, if not all of their lives. We thus seemed unnecessary in this particular research to differentiate whether study participants were male or female. Instead we opted to utilize a gender-neutral 'labelling' approach to identify farmers who participated in this study.

4.1 Rooted in place

Results from the empirical research illustrate the deep-rooted familiarity farmers have with their farms. Exploring the interplay between people and place within agriculture, Gray (1999) previously used the phrase 'being at home on the hills' to capture 'the special, sensual and intimate attachment people feel towards the hills in which they spend so much time, a feeling of being in their proper place' (p.441). Such a close acquaintanceship was evident from the TFFC survey results, with 92% of respondents agreeing that they spend most of their time at home on their farms. The motif of insideness is appropriate here as it suggests that older people develop an intense sense of familiarity and belonging in their home environment late in life, which is notably distinct from the outside world (ibid). When asked what their lives would be like if they no longer lived on the farm, interviewees found it hard to visualise what this might be like or that it might ever happen, for example:

'I can't see myself retiring and heading off to Costa Brava or the likes of for the rest of my life, oh no, I certainly can't. I find that when I go away somewhere on holidays for a few days with my wife, that I'd be anxious to get back to the farm, I'd be really missing it you see. I suppose I am kind of institutionalised on the farm at this stage… I'd be way out of my depth living somewhere else'. (Andrew, aged 64)

'I know the older we get, we might not able to look after ourselves, or the mind might go and then of course you'd have to be shipped off to a nursing home, but while I am alive and well I'm staying put on the farm. You see if it is somewhere where you have been born and lived all your life, it's hard not to be hugely attached to the place, it's part of who I am now, I don't want to be anywhere else'. (David, aged 70)

These findings illustrate that the older generation have become almost 'physiologically melded' into the farm environment over time (Rowles, 1984, p.146). Such rootedness is referred to as physical insideness (Rowles, 1983a). This innate intimacy or 'body awareness' (Rowles and Ravdal, 2002) of the farm space, is also found to equip farmers with an intricate understanding of the environmental conditions and limitations of their land, confirming previous research (Gray, 1998; Burton, 2004; Yarwood and Evans, 2006; Burton *et al*., 2008).

'I know this place like the back of my hand. My father lord rest him taught me all he knew about the farm and my son now looks up to me to teach him all I know. I know all the fields that need an extra bit of slurry in the spring and what fields are best to fatten the bullocks over the summer. No books or computers can teach you

things like that. The point I am trying to make is you cannot underestimate a lifetime of experience on the farm'. (Luke, aged 69)

These findings suggest that the criteria of previous early retirement schemes (ERS 3), which stressed that 'continued participation in farming is not permitted' (DAFM, 2007), may in fact have had negative effects on farm performance by creating critical shortages of experienced personnel who hold an invaluable store of locally specific lay and tacit knowledge developed over years of regularized interaction and experience working on the farm (Conway *et al*., 2016). Interviews also identified that the idiosyncratic 'rhythms, routines, and rituals' (Rowles *et al*., 2003, p.172) of farm life, shaped and internalised by the daily and seasonal labour-intensive demands of working on the farm, fosters a heightened sense of physical insideness for the older generation:

'I'm always working the land. I'd be spreading fertilizer and fixing fences and bringing the cows in and out of the milking parlour twice a day. I hope to spend the rest of my days keeping busy on the farm… at least while I am fit and able to do so'. (Jack, aged 72)

'In a way, you are pretty much married to the farm… because you can't just decide that you are going to take off for six weeks and walk around Borneo or the Himalayas, no, no, there's always work to be done on the farm, 365 days a year'. (Josh, aged 70)

Riley (2011) previously explained that integrating with and tending to the needs of animals plays a central role in organizing and structuring the day-to-day and annual lives of farmers, with many claiming that such tasks are what 'they got out of bed for' (p.23). Glover (2011) add that the farm represents 'who the farmer is' (p.9). The cessation of occupational engagement upon retirement however 'not only left voids in terms of time and empty routine structures, but also the loss of a lens through which they channelled very particular understandings of, and relationships with, specific places and practices' (Riley, 2011, p.23). Riley (2012) also noted that retirees felt 'lost' upon ceasing their 'association with, and everyday routines and actions within', the farm space (p.770). Interviews identified that the familiarity and habitual routines within the farm environment also offers therapeutic benefits to older farmers, in an almost sanctuary-like setting:

'Space is the most wonderful thing in the world to have. If there was something or another bothering me, I find there is nothing better than to just walk up the fields early in the morning or late in the evening, and look back across the land, and watch all my lovely cattle grazing and thriving… your head would be a lot clearer after that'. (Aoife, aged 68)

'I love every inch of this place, it makes me feel good. I love being able to walk through the fields, checking on my crops and just enjoying the nature all around me, it's quite therapeutic for me in fact. As I have lived here my whole life I probably take it for granted sometimes just how special it really is'. (Josh, aged 70)

Rossier (2012) previously noted that keeping active on the farm may 'improve the quality of life, and serve to crate meaning' (p.84), while Price and Conn (2012) add that farmers 'engage with animals and nature in a spatial arena where legacy, culture belonging home and work are intertwined' (p.95). Similarly, from an Australian perspective, Guillifer and Thomson (2006) explain that the emotional bond that farmers have developed with their land over their lifetime, acts as a source of 'identity, refuge and comfort' in old age (p.91).

The general satisfaction and well-being that elderly farmers attribute to the 'physical insideness' of the farm space and associated routines (Riley, 2012), offers potential for understanding why many are unwilling to recognize or accept their physical limitations on the farm (Peters *et al*., 2008) and instead, continue to traverse spaces that would appear to be beyond their level of physiological competence (Ponzetti, 2003), with subsequent risks to their health and safety. Such a phenomenon requires immediate policy intervention, as almost half of all farm fatalities in Ireland and many other European Union member states involve farmers aged 65 and over (HSA, 2013).

4.2 Legitimate connectedness

Research findings also reveal that the farm provides the farmer with a sense of legitimate social connectedness within the farming community. Seventy-eight percent of questionnaire respondents at the TTFC agree that farming provides them with a sense of belonging and a position in society. Riley (2012) explains that 'just as the boundaries of work, home and leisure are often indivisible on the farm, so too are the nature of social interactions taking place there', as they are woven into the everyday activities and routines of the farm (p.770). Furthermore, 71% of TFFC questionnaire respondents also agree with the notion that farming is not only their job, but also their lifestyle, pastime and social outlet. Interviews reveal the manner in which the farm and its practices provides a fulcrum around which social interactions can take place:

'I became more and more involved in various farming organisations and activities in the area when my husband, lord have mercy on him, passed away. The farm ties me in with these groups you see, we are all farmers there, we have a common ground. I find that it's great to mix with like-minded people on an on-going basis… it has helped me cope with his loss in a way'. (Eimear, aged 65)

'I don't do anything else only farm and go to the local mart once or twice a week. Even if I'm not selling or buying sheep I'd still go to the mart, I enjoy the social aspect of it you see. I always go into the canteen when I'm at the mart and sit down and have a chat with the lads about farming and the weather…. things like that'. (Rory, aged 66)

'I have been actively involved in breeding Texel sheep on the farm for the last 30 years. I love the buzz out of breeding, finding the next big thing at the pedigree sales, meeting and competing with the other breeders for prizes… ah it's a great pastime to have as well as everything else'. (Frank, aged 57)

Rowles's (1983a) concept of 'social insideness', which is fostered and developed through 'everyday social exchanges and relationships' and 'a sense of being well known and knowing others' (Burns *et al*., 2012, p.3) is evident here. Social Insideness provides farmers with a sense of belonging by allowing them to integrate and become a part of the 'social fabric of the community' (Rowles, 1983a, p.302), thus enhancing their emotive attachment to the farm in old age. Social insideness is considered to be particularly significant in later life, as one may need to draw on these long-term relationships for help and social support if they happen to experience age related physical impairments and disabilities (Ponzetti, 2003; Riley, 2012). Sutherland and Burton (2011) previously noted that farmers feel that they can 'count on the neighbour in an emergency' (p.246). Research findings also illustrate the considerable social significance attributed to being approved and recognised as a 'good farmer' in a community of like-minded farmers, reiterating previous research (Burton; 2004; Burton *et al*., 2008). Seventy-one percent of respondents at the TFFC agreed that it was important to be viewed as an active and productive farmer amongst their peers to maintain their status in the farming community with Glover (2011) pointing to the fact that a 'farmer's status is measured in the size and production levels of the farm' (p.7). The perceived loss of social insideness and the subsequent distancing and/or hiatus from previously familiar social networks brought about by retirement is brought to light in the following interview extracts:

> *'It would certainly be a shock to the system not to be dairy farming anymore. It would be hard not to see the milk lorry driving into the yard in the mornings… and if I was no longer able to talk the same talk with other dairy farmers about milk yields, butterfat and protein and all that. I'd hate to be out of the loop so that's why I need to stay in touch and continue dairying with my son'. (Brian, aged 85)*
>
> *'I feel very much part of the farming community here… ah there really is a great group of farmers in our area. We are also involved in a few Teagasc discussion groups around here. I think they are a great idea to thrash out ideas with farmers similar to yourself and also for the social aspect too of course. That's why it is important to stay actively involved in farming, otherwise you'd be cut adrift from these sorta things'. (John, aged 70)*

These findings illustrate that it is almost impossible to untangle a farmer's everyday social interactions from everyday practices on the farm. Riley (2012) previously explained that the 'indivisibility of social and occupational spaces' within the farming community however, leaves farmers feeling isolated or like 'an outsider' within previously 'familiar and comfortable spaces' following retirement (p.769). The perceived loss of legitimate social insideness brought about by retirement, is reported to be even more pronounced for those who are unable to draw on successors in connecting to these spaces (ibid). More specifically, Riley (2011) found that the commonality of owning and tending to animals are essential requirements to be a 'proper' part of livestock-related gatherings, such as auctions and agricultural shows. The lack of active and corporeal engagement with livestock upon 'stepping aside' from the farm however, irrevocably changes the nature of these pre-existing settings of social inclusion (ibid). Conway *et al*. (2016) also noted that many older famers believed that they would be seen or perceived differently by other farmers if they became a 'retired farmer'. The farm thus provides an arena in which the older generation can preserve their legitimacy as an active and productive farmer in society in later life.

4.3 Sense of nostalgia

A farmer's relationship with their farm extends beyond the physical setting and social milieu to represent a space and environment that has 'a temporal depth of meaning' (Rowles, 1983a, p.303). Eighty-two percent of farmers surveyed at the TFFC could trace their family's occupancy of the farm back two generations or more, a finding previously identified by Potter and Lobley (1996) who noted that farming tends to be 'the most hereditary of professions' (p.286). Furthermore, findings from the TFFC found that 87% of farmers surveyed think that 'it is important that their farm stays in their family's ownership in the future'. The temporal aspect of the farmer-farm based relationship is reflected in Rowles's (1983a) notion of autobiographical insideness. Often unspoken and taken for granted, autobiographical insideness is developed through acquisition of place-associated memories of significant life experiences, relationships and events in one's personal history (Rowles, 1993) which offers 'a sense of familiarity, connection and self-identity' in old age (Riley, 2012, p.764). Interviews reveal that the ancestral lineage of the farm, passed down through generations, provide farmers with an ingrained sense of autobiographical insideness as custodians of their family's land in its present history:

> *'I inherited the place here from my father, just like he did from his father before. You are tied into a long family history when you are brought up on a farm you see. But I am only a spoke in the wheel of this farm's story, I am only a caretaker, so I hope to hand it over to my son one day and fingers crossed it stays in the family forever more after that'. (David, aged 70)*

Price and Conn (2012) explain that farmers have 'a desire to maintain the farm in the family as a result of feelings of responsibility to past generations' (p.100). The farm therefore is not just a piece of land or a workplace (Burton, 2004), but rather 'the physical manifestation of generations of knowledge; knowledge developed and used over time' (Gill, 2013, p.79) by both the farmer themselves and by those who have lived and worked there before (Glover, 2011). The inherent desire not to keep the farm in the family is evident in findings from the FARMTRANSFERS survey which found that only 4% of respondent's 'desired succession and inheritance outcome' was to 'sell the farm to divide assets equally'. Irish farmer's profound historical connection to their land is aptly illustrated in the following extract taken from world-renowned author and playwright John B. Keane's play in 1965 entitled 'The Field': 'I watched this field for forty years and my father before me watched it for forty more. I know every rib of grass and every thistle and every whitethorn bush that bounds it'.

This captivating portrait of the deeply embedded attachment to farmland in rural Ireland in the mid-20th century, remains relevant to this day (Banovic, *et al.*, 2015), with less than 1% of the total land area in the Republic of Ireland put on the open market annually (Hennessy, 2006; Irish Farmers Journal, 2012). Findings from the TFFC questionnaire confirm such a bond, with 88% respondents agreeing that they 'have an emotional/sentimental attachment to their land and animals'. More specifically, interview conversations reveal the nature of such intricate relationships:

'You form an attachment to the animals in the sense that you know how to live with every single one of them, they all have their own temperament and personality you see. I know the one's that will come to the gate first when they see me coming and I'd be able to tell straight away if any of them were sick or off form... so you see I need to check on my stock every day, every single day without exception. I'd be lost without them and they wouldn't survive without me, it's as simple as that'. (Luke, aged 69)

'I can still remember the dairy cows that we had when I was 6 or 7 years of age... I can remember them all dripping milk as they walked into the old parlour we had on the farm.… We had a couple of Kerrys, a few Shorthorns, three Ayrshires, oh and a couple of Jerseys for the butter fat, so there was a good mix of breeds there. I remember them all, fond memories indeed… those very cows are the foundation of the fantastic wee herd we have on our farm today'. (Brian, aged 85)

The level of emotional attachment that farmers place on their farm and animals was previously brought to light by Glover (2010) who highlighted the extremely distressing experiences of farmers who had lost their entire dairy herds in the 2001 Foot and Mouth Disease crisis. Riley (2011) explains that a dairy herd not only acts 'as biographical markers through which farmers may narrate not only their own life' (p.25) but it also represents an embodiment of the farm history, 'with the efforts and achievements of several generations inscribed upon them' (p.21). Similarly, Gray (1998) pointed to how sheep farmers in the Scottish Borders invested considerable time establishing flocks whose 'characteristics embody the natural qualities of the ground on which they graze' (p.351) through decades of selective breeding on their farm. Consequently, such distinctive breeding skills and practices define the personhood and lifetime's work of the farmer (ibid), which in turn, adds further to their personal accumulation of symbolic capital (Conway *et al.*, 2016). Eighty-seven percent of questionnaire respondents at the TFFC agree that the farm represents years of hard work and what they have managed to achieve over their lifetime. Interviews reveal that the farm is a central site of autobiographical insideness as it represents a mosaic of the farmer's achievements as well as being a landscape of memories:

'Myself and my wife have been farming here for the last 34 years. We came from very humble beginnings and we make a lot of strides here through the years. We take pride in the fact that we have built slatted sheds, reclaimed land, picked stones, moved ditches, put in fences, dug out roadways and established a good herd of cows. We have left our mark on the farm, just like my own father and mother did'. (Ian, aged 67)

Riley (2012) previously noted the 'emotional challenge of 'ending the line there' (p.774). This is especially the case when a successor is not in situ to take over the farm (ibid). Research findings indicate that the deep-seated sense of autobiographical attachment older farmers have with their farms can override and stifle various collaborative farming policy efforts aiming to facilitate land mobility from one generation to the next. This reluctance to 'let go' and/or alter the status quo of the farm is explained by Ingram and Kirwan (2011) who explain that the older generation are 'clearly attached to their farms, having put a lot of effort and investment over the years into building up the business' (p.295) and are therefore reluctant to 'let go' and/or alter the status quo of the farm:

'Unfortunately, we have no one to take over from us though so we will be looking to lease out some of the land soon. But I would hate for someone to come in and mess it all up. Oh that would be a huge disappointment, so we will be having a damn good look at the way the person who wants to lease our land looks after their farm first before we'd even consider leasing it to them'. (Ian, aged 67)

Ambivalence towards the succession process is also evident in the U.S.A., with programmes encouraging farm transfer reporting that they have 'approximately 20 beginning farmers for every existing farmer' (Whitehead *et al.*, 2012, p.216). Price and Conn (2012) explain however that there is 'something about growing up on the farm that leads farmers to often imbue a sense of pride of being born to farm, a sense of destiny, of it being in their blood and this is clearly hard to pull away from' (p.105).

5. Conclusion

This paper provides an in-depth, nuanced understanding of the complex farmer-farm relationships in later life. As the average age of the farming population is increasing worldwide, this investigation is very timely. The significant contribution of this paper to current needs and priorities within policy and research lies in its empirical insights, which demonstrate the appropriateness of utilizing the three dimensions of Rowles's (1983a) concept of insideness; physical, social and autobiographical, in bringing into focus the level of attachment older farmers place on their farms, and how such a bond can stifle the necessary hand over of the farm business to the next generation.

The prominent themes of rooted in place, legitimate connectedness and a sense of nostalgia, that emerge from the triangulation of quantitative and qualitative data, illustrate that farming is more than an economic activity. The so-called 'soft issues' i.e. the emotional issues, identified in this research, are the issues that distort and dominate the older generation's decisions on the future trajectory of the farm. Such issues have resulted in intractable challenges for succession and retirement policy over the past forty years. These really are the 'hard issues'. As every farmer and farm is somewhat unique, this study acknowledges that there are no uniform or easily prescribed solutions to resolving this complex conundrum. However, we do advocate that family farm policy makers and practitioners re-examine their dominant focus on economic-based incentives and become more aware and knowledgeable of the intrinsic farmer-farm relationship identified in this study. This we argue will be crucial when reforming and developing future initiatives and strategies that seek to encourage the transfer of farm process by rightly considering interventions that maintain the quality of life of those concerned. Conway *et al.* (2016) previously noted the development of strategies 'concerning the human dynamics of family farm transfer (had) the potential to greatly ease the stresses of the process' (p.174). More fundamentally still, we follow Conway *et al.* (2017) in recommending that a concerted effort is made to provide extension advisory specialists on the ground with supplementary training in 'facilitation/communication' skills, in addition to their current 'technical' orientation. Such an understanding of the intrinsic link to farm attachment in old age will particularly equip these professionals with the necessary credibility, skill and reverence needed to empathise with elderly farmers and their individual needs.

On a related aspect, and while not central to what this particular study has focused on, is the issue of occupational health and safety on the farm. The insight into the senior generation's deeply-embedded sense of insideness towards their respective farms developed during this research suggests that there is much to be learned from the farmer-farm relationship that would benefit this very significant contemporary challenge. Farming is reported to be one of the most hazardous occupations in terms of the incidence and seriousness of accidental injuries (Glasscock, *et al.*, 2007). Moreover, agriculture exhibits disproportionately high fatality rates, when compared to other sectors (ibid). The general satisfaction and well-being that the older generation of the farming community attribute to the labour-intensive demands of working on the farm in later life, appears to be part of the farming psyche. An insight into the intrinsic link to farm attachment in old age and the importance attributed to the habitual routines within the farm setting, will provide the Health and Safety Authority (HSA) and member organisations of the HSA Farm Safety Partnership Advisory committee in the Republic of Ireland with an invaluable understanding of the various actions taken by (or should be taken by) older farmers to handle age-related physical limitations and barriers on their farms. This knowledge will aid in the development of an effective health and safety service tailored specifically to the needs of older farmers.

More fundamentally, this study recommends is the establishment of a national voluntary organisation that specifically represents the needs of the senior generation of the farming community in rural areas, equivalent to that of younger people in rural Ireland i.e. Macra na Feirme (see footnote 2). There are no such bodies or services currently in existence in the Republic of Ireland. Suited to the older generation's own interests and needs identified in this research, (and by Conway *et al.*, 2016), such a voluntary organisation, funded annually by the Government and through membership, would provide the older generation with a fulcrum around which they can remain embedded 'inside' their farms and social circles in later life. A significant obstacle to the intergenerational farm transfer process is the rigid inflexibility of the occupational role, where older farmers wish to remain 'rooted in place' on the farm and in many cases, have developed few interests outside of farming, due to the 'dense intertwining of occupational and social spaces' within the farming community (Riley, 2012, p.769). A nationwide voluntary organisation, with a network of clubs in every county across the country, would allow older farmers to integrate within the social fabric of a local age peer group, whilst also providing them with opportunities to develop a pattern of farming activities suited to advancing age. This would contribute to their overall sense of insideness, and, therefore, sense of self-worth, amidst the gradual diminishment of their physical capacities on the farm in later life. Collaborating with their younger counterparts in Macra na Feirme on various campaigns and activities would also allow the senior generation to retain a sense of purpose and value in old age. Similar to Macra na Feirme, this body for older farmers, with their added wealth of experience, would act as a social partner farm organisation together with the Irish Farmers Association (IFA) for example, that would allow this generation to have regular access to government ministers and senior civil servants, thus providing them with a voice to raise issues of concern. Indeed, such a group could be invaluable with regard to the development of future farm transfer strategies that would truly be cognisant of the human side of the process of intergenerational renewal. An established organisation for older farmers would also allow this sector of society to have a representative on important committees such as the Board of Teagasc, similar to their younger counterparts.

Finally, although this study is limited to the Republic of Ireland, and findings may be dependent on the cultural and institutional milieu that govern Irish farm transfers, its association with the International FARMTRANSFERS project, provides a solid database upon which future research can begin to build, and general conclusions can be based. Indeed, such is the complexity of the farmer and farming traditions that a multi-layered picture comparing farmer's succession and retirement plans, with patterns obtained from other participating countries and states in the U.S.A. would be invaluable. As Hofstede (1984) points out 'culture determines the identity of a human group in the same way as personality determines the identity of an individual' (p.22). Difficulties around intergenerational family farm transfer and an ageing farming population are not unique to any one country but are recognised at all levels, national, European Union and beyond. Consequently, this study, while reflecting the Irish experience, will begin a much broader international conversation on farmers, their place, view, concerns and challenges in the context of the future prosperity of the agricultural sector and ultimately the future sustainability of rural families, communities and environments on which we all depend. Further involvement in the International FARMTRANSFERS project will also ensure the internationalisation of research findings to key stakeholders outside of academia. In summation, a greater focus on the farmer-farm relationship has the potential to finally unite farm transfer policy efforts with the mind-set of its targeted audience, after decades of disconnect.

Footnote

1. The survey was undertaken within a memorandum of understanding between Dr Shane Francis Conway, Postdoctoral Researcher at NUI Galway, Anne Kinsella, Senior Research Officer at the Teagasc Agricultural Economics and Farms Surveys Department and the International FARMTRANSFERS project's Co-Directors, Professor Matt Lobley, at the Centre for Rural Policy Research, University of Exeter, United Kingdom and John R. Baker, Attorney at Law at the Beginning Farmer Centre, Iowa State University, U.S.A.

2. Macra na Feirme is a voluntary, rural youth organisation in the Republic of Ireland for people between the ages of 17 and 35. Founded in 1944, the organisation now has approximately 200 clubs in 31 regions around the country. One of the organisation's main aims is to help young farmers get established in farming and assist them through learning and skills development.

Ethical approval

Ethical approval for this research was obtained from the Research Ethics Committee at the National University of Ireland, Galway.

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REFEREED ARTICLE

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Identifying and prioritizing opportunities for improving efficiency on the farm: holistic metrics and benchmarking with Data Envelopment Analysis

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ABSTRACT

Efficiency benchmarking is a well-established way of measuring and improving farm performance. An increasingly popular efficiency benchmarking tool within agricultural research is Data Envelopment Analysis (DEA). However, the literature currently lacks sufficient demonstration of how DEA could be tuned to the needs of the farm advisor/extension officer, rather than of the researcher. Also, the literature is flooded with DEA terminology that may discourage the non-academic practitioner from adopting DEA. This paper aims at making DEA more accessible to farm consultants/extension officers by explaining the method step-by-step, visually and with minimal use of specialised terminology and mathematics. Then, DEA's potential for identifying cost-reducing and profit-making opportunities for farmers is demonstrated with a series of examples drawn from commercial UK dairy farm data. Finally, three DEA methods for studying efficiency change and trends over time are also presented. Main challenges are discussed (e.g. data availability), as well as ideas for extending DEA's applicability in the agricultural industry, such as the use of carbon footprints and other farm sustainability indicators in DEA analyses.

KEYWORDS: commercial dairy farms; farm management; efficiency; benchmarking; Data Envelopment Analysis

1. Introduction

A commonly used measure of efficiency is stated in the ratio of output to input (Cooper *et al.*, 2007) and is widely used in benchmarking procedures to identify best-practice management for a given farming system (Fraser and Cordina, 1999). Such procedures, henceforth referred to as 'efficiency benchmarking', are instrumental for guiding farmers on how to reduce costs and resource use, increase profitability and minimize environmental impacts of production (Fraser and Cordina, 1999). This paper demonstrates how an efficiency benchmarking tool that is well-established in agricultural research may be used to solve actual problems facing (dairy) farm managers.

Limitations of conventional efficiency benchmarking

In the farming industry, benchmarking is typically effected by reporting average values (e.g. of input use, production, costs and prices, input-output ratios) from a group of farms with similar characteristics, so that farmers from that group may compare these values to their own performance (AHDB Dairy, 2014; Kingshay, 2017). This type of more 'conventional' benchmarking is myopic and performance indicators such as simple single ratios may mislead when performance and profitability are determined by interrelated multifactorial processes (Cooper *et al.*, 2007). For example, good feed efficiency may be achieved at the expense of inefficient use of labour and nitrogen fertilizer, and at higher replacement rates, resulting in higher costs/lower profits and higher environmental impacts. Moreover, some of these multifactorial processes have public good dimensions, which consumers and society increasingly expect farmers to account for, and they may even reward their delivery if objective metrics can be found that prove contribution while ensuring that the farmer is not left at a disadvantage (Foresight, 2011). Although the agricultural industry is increasingly responding to these demands with novel tools accounting for carbon foot-printing data (Alltech E-CO2, 2017; SAC Consulting, 2017) or other environmental, social and

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economic indicators (BASF, 2012), developing holistic indicators of farm efficiency performance is mainly confined to academic research, where significant developments have been made with the efficiency benchmarking method Data Envelopment Analysis (DEA; Cooper *et al.*, 2007)[1].

Efficiency benchmarking with Data Envelopment Analysis

DEA is becoming extremely popular in agricultural science (Emrouznejad and Yang, 2018), owing to its numerous virtues. DEA gives a more meaningful index of comparative performance that is likely to identify worthwhile opportunities for improvement. Indeed, DEA replaces multiple efficiency ratios by a single weighted sum of outputs over the weighted sum of inputs or by a single 'profit function' (i.e. the weighted sum of outputs *minus* the weighted sum of inputs), with the weights being calculated by the model itself, so that no subjective weighting choices or input and output pricing are necessary (Cooper *et al.*, 2007). Therefore, DEA simplifies the analysis by reducing the need to take into account a range of performance indicators (e.g. input-output ratios) and reduces the danger of improving one performance indicator to the detriment of another (which may not even be monitored; Bowlin *et al.*, 1984; Fraser and Cordina, 1999).

Another advantage of DEA is that it obviates the need to resort to 'average' values that many of the aforementioned industry tools rely on for benchmarking farm performance. Instead, DEA identifies benchmark farms for *each* farm in the sample and indicates the adjustments that this farm should make to its inputs and outputs to become as efficient as its benchmarks (Cooper *et al.*, 2007).

Scope for using DEA as a (dairy) farm management tool

Despite DEA's attractive features and, as shown later, its relative simplicity, it is an ongoing challenge to move the method from the academic to the practitioners' world (Paradi and Sherman, 2014). Paradi and Sherman (2014) identified key reasons why managers are reluctant to adopting DEA, including (i) excessive DEA jargon; (ii) ineffective/insufficient communication/explanation of DEA to managers so that they stop viewing it as a 'black box'; (iii) data availability; and (iv) limited emphasis on managerial applications.

Indeed, the more than 40 peer-reviewed DEA studies of the dairy sector (with which this study is concerned; see Appendix A in Emrouznejad and Yang, 2018; and Appendix I in Soteriades, 2016) mainly explore research questions that *do* inform policy and managerial decision-making, yet *do not* demonstrate how DEA could be tuned to the needs of the farm advisor/extension officer, rather than of the researcher. In our view, two major elements generally missing from DEA dairy studies are the economic (rather than e.g. technical and environmental) insights attached to the DEA models, and the analysis of efficiency over time. Temporal assessments are particularly useful for monitoring performance month-by-month (Kingshay, 2017). Similarly, economic insights are indispensable for decision-making and, unless they are accounted for, a mathematical model (such as DEA) may mean little to a manager (McKinsey & Company, 2017). DEA can help farmers improve economic performance by indicating them how to make best use of their resources, on the one hand, yet, on the other hand, it can be used to guide other priorities such as the improvement of environmental performance (Soteriades *et al.*, 2015). This makes DEA a flexible and holistic tool to suit particular objectives for the benefit of both business management and the public good.

Objective

In this study, we demonstrate how DEA can be used to benchmark individual (dairy) farm efficiency performance, as well as indicate the inputs and outputs in which the largest inefficiencies occur. Then, by attaching prices to the inefficiencies, we show how DEA can help guide management actions through a variety of prioritised cost-saving and/or profit-making options for each farm. This deals with point (iv) above. Points (i) and (ii) are addressed by explaining DEA step-by-step and visually, with minimal use of DEA jargon. Formal mathematical formulas describing the DEA model are placed in appendices. Point (iii) is dealt with by using an abundant dairy farm dataset by Kingshay Farming and Conservation Ltd, which also allowed us to demonstrate several temporal DEA approaches of potential interest to farm consultants. We believe that this study provides sufficient insight into how DEA can help identify areas for improvement in (dairy) farm efficiency and so add considerable value to any benchmarking service.

2. Understanding DEA

Numerous DEA models exist with different functions so it is important to choose one that fits the requirements of the problem at hand (Bogetoft and Otto, 2011; Cooper *et al.*, 2007). However, most DEA models share two strong advantages: (i) they produce standardized scores between 0 and 1, with unity indicating 100% efficiency and a score less than 1 indicating inefficiency; and (ii) the score is not affected by different measurement units (e.g. milk in L, feed in kg) because DEA uses the data themselves to weight the input and output variables. This study employed a so-called 'additive' model (Cooper *et al.*, 2007), which is explained later[2].

The concept of DEA can be more clearly understood when compared with that of linear regression. The latter measures 'central tendency' (expressed by the regression line) and so we can determine how 'far' observations (dairy farms) are from the 'average' (Cooper *et al.*, 2007). Contrariwise, DEA constructs an *efficient frontier* (which we will refer to as the *best-practice frontier*) consisting of the best performers in the sample and all other farms are benchmarked against this frontier. Consider, for instance, seven farms A, B, C, D, E, F and G producing a single output (e.g. grain yield) using a single input (e.g. land; Figure 1). Farms A, B, C, D, E and F form the frontier, i.e. they do not have to further reduce their input and further increase their output to become relatively efficient- they are the best performers.

[1] For an introduction to DEA, see also the excellent textbook by Bogetoft and Otto (2011).

[2] We have chosen not to present and discuss alternative DEA models here to avoid the danger of making our presentation too 'academic' for the 'intelligent lay' non-academic reader. As with any DEA model, the additive model has pros and cons that we believe are irrelevant to the objective of our study.

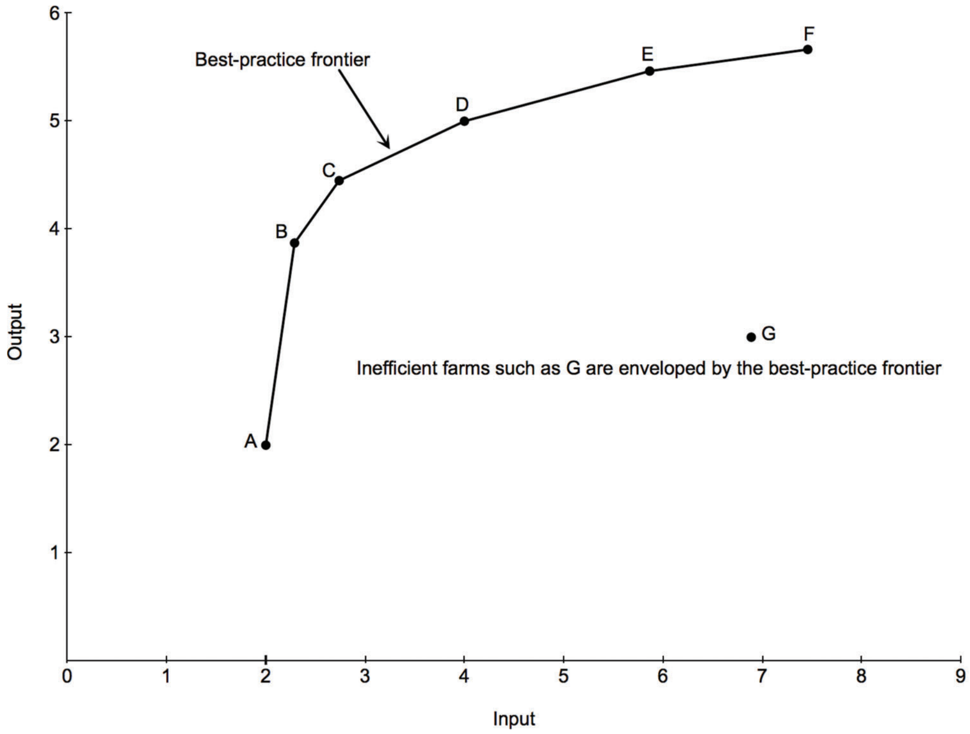

Figure 1: A DEA best-practice frontier ABCDEF and an inefficient farm G in the single-input single-output case

By contrast, farm G is relatively inefficient as it could be producing more output and using less input relative to one or more efficient farms[3,4]. To become relatively efficient, farm G will have to reduce its input and increase its output until it reaches a point on the frontier. DEA measures the efficiency of farm G by detecting the magnitudes of the inefficiencies that this farm exhibits in its input and output. Consequently, DEA will produce an efficiency score for farm G whose magnitude indicates by ‘how much’ this farm is inefficient in its input and output. This score is *farm-specific* and thus differs from regression that can only indicate by how much farms deviate from the ‘average’. Also, with DEA the single-input single-output case can be easily extended to multiple inputs and outputs, contrary to regression, which, in its simplest and most widely-adopted form, cannot handle more than one dependent variable at a time (Bowlin *et al.*, 1984, p.127).

Which efficient farms serve as benchmarks for farm G?

The answer to this question reveals one of DEA’s key properties: it can extrapolate from the given dataset by creating ‘virtual’ or ‘synthetic’ benchmarks that lie at any point on the frontier ABCDEF (Figure 1; Bogetoft and Otto, 2011). On the one hand, farm G could be benchmarked against, say, efficient farm C or D. On the other hand, it could be benchmarked against a virtual farm represented by a point lying on, say, segment CD. In any case, the benchmark farm’s input can be represented by a linear combination of the inputs of farms C and D (see Appendix A).

The above provides an explanation of the idea behind DEA, especially in relation to the construction of the best-practice frontier and the identification of benchmark farms for the farm under evaluation. The additive model is outlined below.

How does the additive model calculate efficiency?

The reason why a farm such as G is inefficient is because it exhibits excess in its input and shortfall in its output relative to its benchmark(s). The excess in inputs and shortfall in outputs represent the *inefficiencies* that G exhibits in its inputs and outputs. These inefficiencies are called *slacks* in the DEA terminology (Cooper *et al.*, 2007), but the terms *input inefficiency* and *output inefficiency* will be used in this paper.

The additive model finds the optimal values for the inefficiencies maximizing the total (sum) of input and output inefficiencies and projects farm G onto point C on the frontier. See Figure 2 for a visual representation as well as the Appendices B and C for the mathematical description of the additive model.

Before turning to the application with the sample data, it might be more reasonable to consider some of the DEA inputs and outputs as fixed. In this case, the DEA model will not seek to increase/decrease them, yet these inputs and outputs still play a role in shaping the best-practice frontier. This concerns variables that a farmer may not be looking to increase/decrease on the short-term but rather in longer time-horizons. For instance, it might be more appropriate to model cows in herd, forage area and milk yield as fixed, for the following reasons.

[3] Note that the input-output frontier lies on the northwest of the dataset, enveloping inefficient farms such as G, hence the term data ‘envelopment’ analysis. This is by contrast with a regression line, which would be passing *between* the points, leaving some above it and some below it.

[4] Also note that the frontier displayed in Figure 1 is piece-wise linear. This is because we have assumed that farms operate under *variable returns to scale*, under which inefficient farms are only compared to efficient farms of a similar size (Fraser and Cordina, 1999). Alternatively, the frontier can be represented by a single straight line. However, this would imply that an increase in a farm’s input would result in a proportional increase in its output (Bogetoft and Otto, 2011; Cooper *et al.*, 2007). This assumption is known as *constant returns to scale* and was considered unreasonable in our case. See also Appendix A.

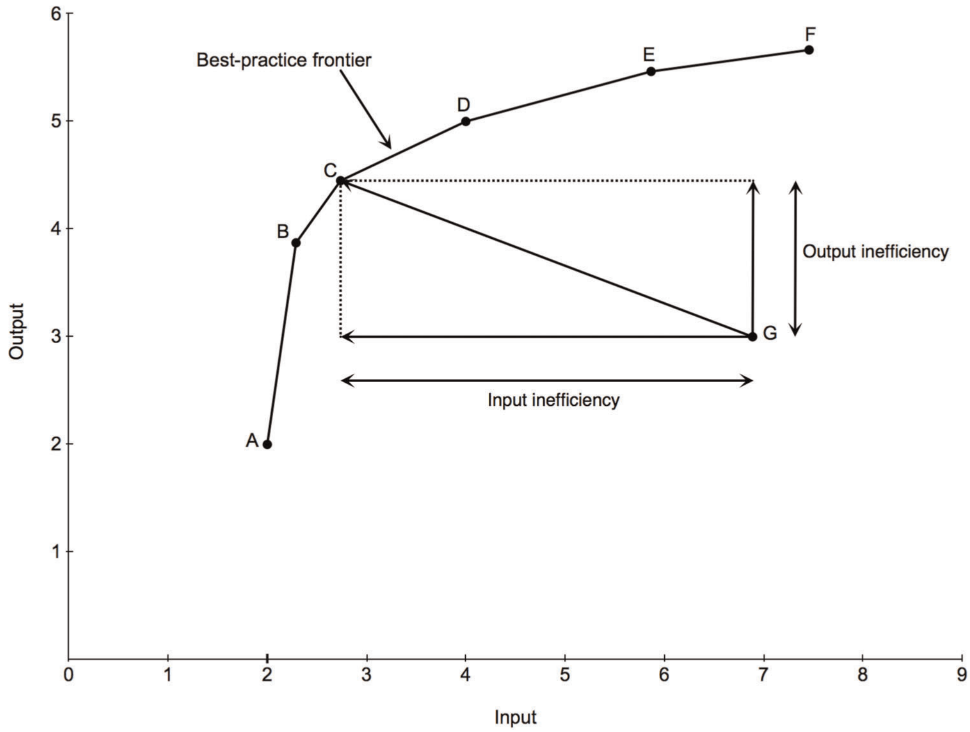

Figure 2: Visual representation of the additive model run for farm G

Table 1: Statistics of the DEA variables

Variables	Min	Mean	Max	SD
Inputs				
Cows in herd (numbers)	14	186	1,257	114
Forage area (ha)	17	99	621	58
Replacements (numbers)	2	54	375	42
Purchased feed (kg DM[1])	13,293	558,187	6,253,623	481,680
SCC[2] ('000s/mL)	64	165	368	48
BC[3] ('000s/mL)	7	26	144	13
Outputs				
Milk yield (L)	79,628	1,532,009	14,031,479	1,103,397
Butterfat yield (kg)	3,203	60,763	531,894	42,526
Protein yield (kg)	2,692	50,278	448,481	36,034

[1]Dry matter. [2]Somatic cell count. [3]Bacterial count.

First, a farmer would for example maintain their herd size fixed and seek to reduce the number of replacements in response to improved output efficiency, rather than reduce the number of cows in the herd. Second, in the short run, it would seem unreasonable to expect that a farmer would reduce their land area. Third, given a low milk price, a farmer would rather increase butterfat and protein rather than milk yield. To illuminate the idea of fixed variables, had the input of farm G (Figure 2) been fixed, this farm would have to move vertically towards the frontier to a point on segment EF. Similarly, had the output of farm G been fixed, this farm would have to move horizontally towards the frontier to a point on segment AB. See Appendix D.

3. Application

Data

Data from 675 UK dairy farms were selected, covering the year 2014–2015. Six inputs and three outputs were considered for aggregation into a single DEA efficiency score per farm (Table 1). The six inputs were cows in herd (numbers); forage area (ha); replacements (numbers); purchased feed (kg dry matter [DM]); somatic cell count (SCC; '000s/mL); and bacterial count (BC; '000s/mL). Cows in herd and forage area were considered as fixed (see previous section). Variables SCC and BC do not represent 'typical' physical farm inputs. However, including them in the model allowed us to estimate the inefficiencies that these two inputs exhibited in each farm, thus offering a way of demonstrating the financial benefits (better milk price) that a farm would gain by reducing them to the levels of their benchmarks (i.e. by eliminating these inefficiencies). Other inputs of interest, such as labour and fertiliser, were absent from the data-set and thus were not included in the model.

The three outputs were milk yield (L); butterfat yield (kg); and protein yield (kg). Milk yield was considered as fixed. As with SCC and BC, setting the DEA model to increase butterfat and protein yield allowed us to estimate the milk price benefits of eliminating the inefficiencies in these two outputs.

Figure 3: DEA efficiency scores (y-axis) plotted against: margin over purchased feed per cow; feed efficiency; milk yield per cow; and concentrate use per cow

In summary, by setting the DEA model to increase butterfat and protein; and to reduce SCC and BC for the given milk yield, we obtained a 'new' milk price for the farm under evaluation. The difference between the actual and 'new' prices can be seen as the reward for producing more efficiently.

Finally, we have added a bound to the inefficiencies of butterfat and protein to avoid getting unreasonably large inefficiency values for these two outputs[5]. Specifically, we demanded that the optimal values for butterfat and protein constrain the percentages in butterfat and protein below the maximal percentages in these two outputs observed in the dataset[6]. These bounds can be set extrinsically by the manager. See Appendix E.

Software

We ran the exercise in programming language R (R Core Team, 2017) using the R package 'additiveDEA' (Soteriades, 2017), that is specifically designed to run additive DEA models. Visualizations were also produced with R.

Results

The additive model (formulas (9a)–(9i) and (11a)–(11b) in the Appendices) indicated that the DEA best-practice frontier consisted of 82 farms out of 675, i.e. 12% of the farms in the sample were efficient. The remaining 593 farms were benchmarked against these 82 farms.

In what follows, we provide four examples to demonstrate DEA's potential as a tool that can help guide farm management. In Example 1 we demonstrate that the DEA scores can disagree with widely-used dairy farm efficiency indicators, because the latter are not comprehensive. In the same example, we compare the technical characteristics of DEA's benchmark farms with the top 25% farms in terms of margin over purchased feed (MOPF) per L of milk[7] (from now on referred to as 'Top 25% Farms'). In Examples 2–4 we choose specific farms exhibiting high inefficiencies in their inputs and outputs and show that these farms could be earning/saving substantial amounts of money by producing more efficiently.

Example 1: comparison of DEA efficiency with widely-used dairy farm efficiency indicators

In this example, we compare the DEA efficiency scores with four widely-used indicators of dairy farm efficiency: MOPF per cow (£[8]); feed efficiency (FE) defined as kg of energy-corrected milk per kg DM of purchased feed; milk yield per cow (L); and concentrate use per cow defined as kg DM of purchased feed per cow. The DEA scores are plotted against each of these indicators in Figure 3. It is shown that high DEA efficiency can be achieved at varying- and sometimes low- levels of MOPF per cow, FE, milk yield per cow and concentrate use per cow. This demonstrates that, contrary to DEA, partial efficiency ratios fail to provide a measure of overall farm efficiency.

The difference between the way that ratios and DEA measure efficiency can also be seen by comparing the Top 25% Farms (169 farms) with the 82 farms that served as benchmarks in the DEA exercise (Table 2). There are some notable differences between the two groups in milk yield per cow, purchased feed per cow, MOPF per cow and per litre of milk and FE. What is interesting is that DEA benchmark farms are much more inefficient, on average, than the Top 25% Farms for FE and MOPF per cow and per litre of milk. However, this seemingly superior performance of the Top 25% Farms came at the cost of lower yields per cow (Table 2) and per forage hectare (Top 25% Farms: 15,343 L/ha; DEA benchmarks: 18,819 L/ha) and greater numbers, on average, of SCC (Top 25% Farms: 104,688 cells/mL; DEA benchmarks: 100,691 cells/mL) and BC (Top 25% Farms: 24,247 cells/mL; DEA benchmarks: 19,285 cells/mL) than for the DEA benchmarks. This stresses (i) that good performance in some ratios could be achieved at the cost of high inefficiencies in other farm inputs and outputs. For instance, despite the lower MOPF per cow and per litre of milk of DEA benchmarks compared to the Top 25% Farms, the milk price for the latter would be more severely influenced by the higher SCC and BC; and (ii) that DEA offers a more holistic way of measuring efficiency. Finally, it is noteworthy that with DEA the number of 'top farms' is defined by the model itself: 'top farms' are the benchmark farms. This is more subjective than arbitrarily defining the percentage of farms that should be considered as 'top farms' (e.g. 25% as in our example).

[5] We noted the need for imposing bounds to the inefficiencies of these two outputs after running preliminary exercises without the bounds, where the DEA model unreasonably indicated that some farms had to increase their butterfat content to as much as 12% to reach the best-practice frontier.

[6] Although the bounds can help calculate more reasonable butterfat and protein inefficiencies, it may be argued that they can still be a source of concern because they allow the butterfat and protein inefficiencies of any dairy farming system to become as large as the bounds. This may not be a sensible expectation for e.g. a system based on a by-products diet that may never give high butterfat for biological reasons. This can be dealt with by running DEA within groups of farming systems. We did not do this here, however, for simplicity.

[7] We got the idea from the *Milkbench+ Evidence Report* (AHDB Dairy, 2014). The report uses net margin/L rather than MOPF/L to identify the top 25% farms. However, net margin was not available in the sample dataset, hence our choice of MOPF/L.

[8] In mid-June 2017 £GBP1 was approximately equivalent to €1.15 and $US1.28. £GBP1 equals 100 pence.

Table 2: Comparison of top 25% farms (in terms of MOPF[1]/L) with the 82 DEA[2] benchmark farms in terms of farm characteristics (averaged)

Farm characteristics	Top 25% Farms[7]	DEA benchmarks	Difference
Cows in herd	200	212	-12
Replacement rate (%)	28	25	3
Milk yield/cow (L)	7,590	8,595	-1,005
Purchased feed/cow (kg DM[3])	2,320	2,955	-635
Purchased feed/litre (kg DM[3]/L)	0.30	0.33	-0.03
Butterfat (%)	4.1	4.0	0.1
Protein (%)	3.3	3.3	0
MOPF[1]/cow (£)	1,908	1,878	30
MOPF[1]/litre (ppL[4])	25	22	3
FE[5] (kg ECM[6]/kg DM[3])	3.69	3.54	0.15

[1]MOPF: margin over purchased feed. [2]DEA: data envelopment analysis. [3]DM: dry matter. [4]ppL: pence per L. [5]FE: feed efficiency. [6]ECM: energy-corrected milk. [7]In terms of MOPF/L of milk.

Example 2: increasing MOPF per cow by reducing inefficiency in purchased feed

This example demonstrates how insights from DEA and widely-used partial performance indicators can be coupled to identify profit-making opportunities for farmers. For each farm, we first calculated MOPF per cow:

$$\textit{milk income} - \textit{price of purchased feed per kg} \times \textit{purchased feed}$$

Then, we calculated the 'optimal' MOPF per cow that each farm would get by reducing its inefficiencies in purchased feed:

$$\textit{milk income} - \textit{price of purchased feed per kg} \times (\textit{purchased feed} - \textit{inefficiency in purchased feed})$$

At the final step, we calculated the difference between the actual and 'optimal' MOPF per cow. The largest difference occurred for a farm with actual and 'optimal' MOPF per cow values of £1,595 and £2,319 respectively, i.e. this farm could be improving MOPF per cow by an additional (£2,319 – £1,594) = £725 pounds per year just by using purchased feed more efficiently.

Example 3: increasing milk price by reducing SCC and BC

Another farm exhibited the largest inefficiency in SCC relative to its actual SCC (79%). It also exhibited a high inefficiency in BC relatively to its actual bacterial count (78%). This farm could greatly increase the price it gets for milk by reducing SCC from 339,750 cells/mL to (SCC – inefficiency in SCC) = 71,235 cells/mL and its bacterial count from 66,583 cells/mL to (BC – inefficiency in BC) = 14,619 cells/mL. In more detail, we used AHDB Dairy's Milk Price Calculator (AHDB Dairy, 2017) so as to get milk prices for actual and efficient SCC and bacterial counts[9]. This farm could be earning an additional 9ppL (pence per L) as the price for milk would have been improved from 20.43ppL to 29.43ppL[10]. It may achieve this increase in the price of milk by better managing its herd, e.g. by culling cows with the highest SCC and/or improving cow health management. Obviously, there would be costs incurred to improve SCC but the benefits of an extra 9ppL would not be lost on the farmer and would focus the mind on this most important source of inefficiency in this case.

Example 4: increasing milk price by reducing SCC and BC and by increasing butterfat and protein

The farm studied in Example 3 could be getting an even better price by also eliminating its inefficiencies in butterfat and protein. This farm's butterfat and protein percentages were, respectively, 26,784/638,168 = 4.2% and 21,782/638,168 = 3.4%, while its efficient levels of butterfat and protein were, respectively, (26,784 + 4,995)/638,168 = 5.0% and (21,782 + 4,589)/638,168 = 4.1%. This farm could be earning an additional 9.55ppL as the price for milk would have been improved from 20.43ppL to 29.55ppL. Again, DEA can help focus the mind of the farmer and farm manager on how best to deal with the greatest challenge to efficiency in a given case. The level of efficiency achievable in practice may be less important than the prioritisation of management effort that DEA highlights.

Further applications

Efficiency analysis over time

All previous example applications were based on the rolling data reported in Table 1. Such applications are useful for monitoring farm performance based on annual data. Yet, monitoring efficiency across time is often more appropriate for decision-making, as it can help detect trends that develop slowly, potentially going unnoticed by the manager (Brockett *et al.*, 1999).

There are several methods for the analysis of efficiency change over time with DEA, each designed to fit particular purposes (interested readers may refer to Asmild *et al.*, 2004; Bogetoft and Otto, 2011; Brockett *et al.*, 1999; Cooper *et al.*, 2007). We discuss three methods that may be of special interest to farm managers: (i) intertemporal analysis (Asmild *et al.*, 2004; Brockett *et al.*, 1999); (ii) a method by Tsutsui and Goto (2009), which we will refer to as 'cumulative temporal analysis'; and (iii) window analysis (Asmild *et al.*, 2004; Cooper *et al.*, 2007).

Intertemporal analysis is the simplest form of efficiency analysis over time: all data from different time periods are pooled and evaluated with a single DEA run. Thus, a farm 'FARM A' is considered as a 'different' farm in each period, i.e. FARM A_1, …, FARM A_T, so the single DEA run involves $T \times n$ farms, where T is the number of periods and n is the number of farms.

[9] One referee rightly commented that, in practice, milk price is dependent on SCC and BC *thresholds* rather than *levels*. This, however, does not affect the analysis: reducing SCC and BC to the levels of benchmark farms will increase the milk price only if efficient levels of SCC and BC are below the thresholds assumed in the Milk Price Calculator.

[10] Prices are annual prices for Arla Foods-Sainsburys. We used the calculator's standard settings. Monthly milk yields for this farm were available in the sample data.

For example, measuring efficiency trends for the period March 2014–March 2015 requires pooling data for all farms from all 13 months and running a single DEA exercise, where all farms are benchmarked against a single best-practice frontier. Doing so allows the farm manager to compare efficiency progress (or deterioration) of individual or groups of farms across all 13 months. Figure 4 illustrates an inter-temporal DEA analysis for the period March 2014–March 2015, with a total of 6,030 'different' farms. The median results are summarized by the six UK regions used in Kingshay's Dairy Manager reports (Kingshay, 2017). In this figure, notable fluctuations in (median) efficiency are observed for Scotland and the Southeast, with the former having the lowest scores for six out of 13 months. By contrast, the Midlands exhibit neither high nor low median efficiency, and these scores are relatively stable throughout the year (between approximately 0.55 and 0.63). Despite the simplicity of inter-temporal analysis, its disadvantage is that it may be unreasonable to compare farms over long periods (e.g. years) if large technological changes have occurred meanwhile.

In cumulative temporal analysis, a farm in a specified period is benchmarked against a best-practice frontier consisting of farms up to that period. For example, a farm in May 2014 is compared to farms in March, April and May 2014. This allows the manager to assess efficiency in each period based on the farms' 'cumulative' performance in inputs and outputs up to that period. As in Figure 4, Figure 5 demonstrates a deep fall in efficiency for Scotland and the Southeast, with Scotland performing at the lowest levels in six out of 13 months. However, all groups have much higher (median) efficiencies than in Figure 4 for up to May 2014. This trend is generally observed for the whole study period, although from June 2014 scores in Figures 4 and 5 tend to get closer for each group. This is intuitive, because in later periods more farms are included in the analysis (note that the DEA run for March 2015 contains all 6,030 farms, hence the resulting scores for this month are identical to those of the inter-temporal analysis).

Window analysis resembles the well-known method of 'moving averages' in statistical time-series. Its advantage lies in the fact that it can be used for studying both trends over time as well as the stability of DEA scores within and between time 'windows' specified by the manager. For instance, for a manager interested in evaluating efficiency every four months (four-month 'window') for the period March 2014–March 2015, window analysis first involves a DEA run for all farms in window March 2014–June 2014. Then, March 2014 is dropped and a second DEA run involves all farms in window April 2014–July 2014. The exercise is replicated up to window December 2014–March 2015. The results are reported in such a manner that allows detection of trends and stability. This is illustrated in Table 3, where results are reported for Scotland (median scores). Looking at the results row-by-row (i.e. window-by-window), we generally

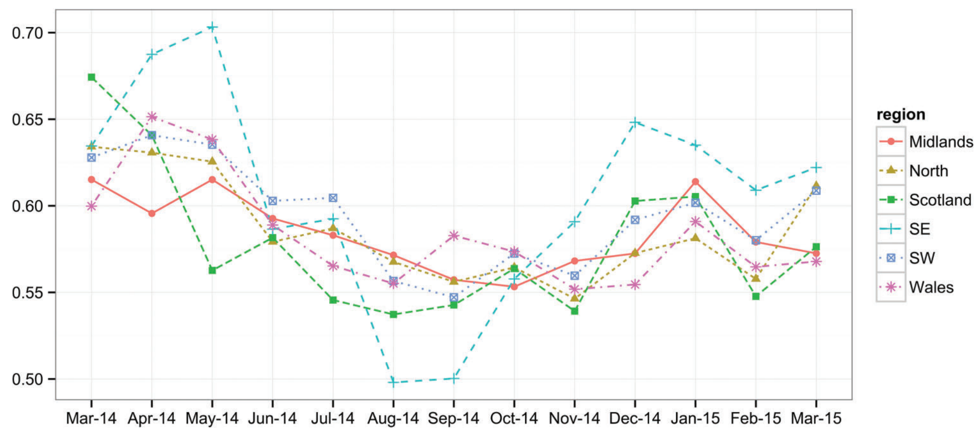

Figure 4: Intertemporal DEA analysis summarized by UK region (median efficiency scores reported). SW: Southwest; SE: Southeast

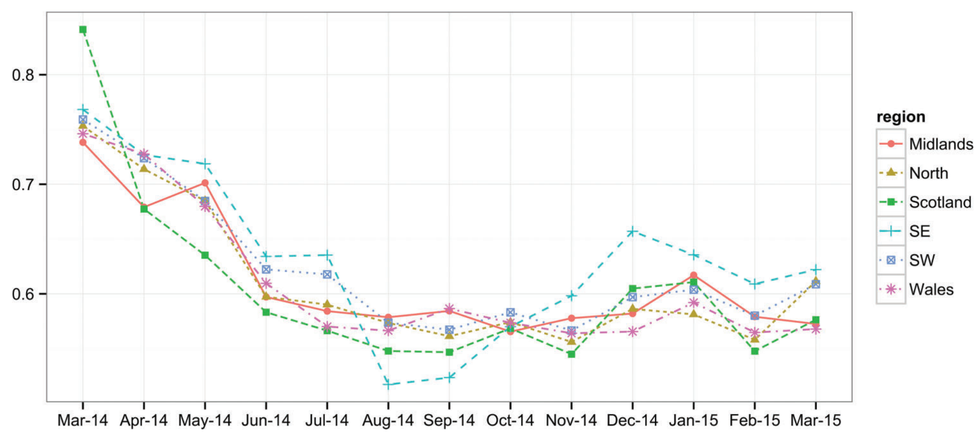

Figure 5: Cumulative temporal DEA analysis summarized by UK region (median efficiency scores reported). SW: Southwest; SE: Southeast

Table 3: DEA window analysis for Scotland (median efficiency scores), Mar 14–Mar 15

Window	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
W1	0.72	0.65	0.56	0.58									
W2		0.65	0.56	0.58	0.57								
W3			0.57	0.58	0.58	0.55							
W4				0.62	0.59	0.56	0.57						
W5					0.62	0.59	0.60	0.63					
W6						0.65	0.65	0.69	0.67				
W7							0.62	0.65	0.65	0.68			
W8								0.65	0.65	0.65	0.69		
W9									0.65	0.65	0.69	0.65	
W10										0.64	0.67	0.64	0.63

observe a decline in efficiency within each row up to window W4. From window W5 efficiency is gradually improving, while results are slightly more mixed within windows W9 and W10. The stability of these findings is confirmed by looking at the scores within each column. In more detail, within each column, scores are generally close, with a few exceptions (e.g. August 2014 where the minimum and maximum scores differ by 0.10), reinforcing the previously mentioned finding that performance deteriorates up to window W4 and then improves (also evident in Figures 4 and 5).

Comparing herds managed under different growing conditions

In the DEA runs of the previous examples, an implicit assumption was made that all farms operated under similar growing conditions and thus could be directly compared. The large variation in variables such as growing conditions, regional characteristics, management practices *etc*. may raise concerns about the direct comparison of different types of dairy farms (Soteriades *et al*., 2016). For instance, Kingshay's Dairy Manager (2017) groups herds by their 'site class', that is, the growing conditions under which these herds are managed (defined by altitude, soil type and rainfall), and compares farms within each group. Similarly with DEA it also possible to compare farms from different groups with a method by Charnes *et al*. (1981), which is also known as 'corrective methodology' (Soteriades *et al*., 2016) or the 'meta-frontier' approach (Fogarasi and Latruffe, 2009).

The concept of the 'corrective methodology' or 'meta-frontier' approach is based on the observation that inefficiencies may be attributed to either management or different operating conditions: when both inefficiency sources are amalgamated, there is a risk of granting some 'bad' managers (farmers) good efficiency scores when they are only benefiting from operating under more favourable conditions (Soteriades *et al*., 2016). Hence, within-group managerial inefficiencies need to be eliminated before comparing groups. This can be done as follows. First, a DEA run is effected within each group to compare 'like with like'. The inefficiencies that inefficient farms exhibit within each group are attributed solely to management. Second, inputs and outputs are adjusted to their efficient levels by eliminating these managerial inefficiencies. For inputs, this means subtracting the inefficiency from the actual input used, for example:

$$\text{'adjusted' purchased feed} = \text{purchased feed} - \text{inefficiency in purchased feed}$$

For outputs, it means adding the inefficiency to the actual output produced, for example:

$$\text{'adjusted' milk production} = \text{milk production} + \text{inefficiency in milk production}$$

This is done for all inputs and outputs to eliminate all managerial inefficiencies within each group. Third, farms from all groups are pooled and a single DEA run is effected. Now, all inefficiencies are attributed to differences in operating conditions between groups and so we can determine which groups are more efficient, as well as which of their inputs and outputs exhibit the largest inefficiencies in each group or individual farm.

This methodology (which was not adopted in our study for simplicity and brevity) can be applied to compare any groups of farms that the practitioner feels cannot be directly compared, because of differences in e.g. breed, accumulated T-sums, manure management technology, system (e.g. conventional *versus* organic or pasture-based *versus* housed all year round) etc.

4. Discussion

DEA in agricultural consulting, extension and teaching

As DEA's numerous advantages have made it a well-established method in agricultural and dairy research (see introduction), this article is mainly intended to reach a wider agricultural audience, specifically farm consultants, extension officers, Knowledge Exchange officers and lecturers in farm management. We hope that our examples provide our target audience with sufficient evidence of DEA's potential for farm efficiency assessments, and that they will encourage them to consider using the method. For instance, similar exercises could be used by lecturers to complement teaching based on standard farm management textbooks that focus heavily on partial indicators (Boehlje and Eidman, 1984; Castle and Watkins, 1979; Jack, 2009). Similarly, extension officers and farm consultants could use DEA to get a wider picture of farm performance before discussing with farmers the managerial strategies for improving efficiency. The DEA findings of such exercises could also be presented in online newsletters and reports by farm consultancies and agricultural levy boards (AHDB Dairy, 2014; Kingshay, 2017) to indicate where cost-saving or profit-making opportunities might lie for the farmer (as this study has intended to do). Knowledge Exchange could be achieved through workshops aiming at presenting findings from novel farm management tools and methods to industry stakeholders (SIP Platform, 2017, p.5).

Challenges

A main question is to what extent the indicators that analysts currently use can help them access the insights provided in our examples. However, as demonstrated in our examples, an attractive feature of DEA is that potentially 'already-known' information is summarized into a single score allowing holistic monitoring, while nothing is lost, because the score can be disaggregated into input and output inefficiencies. Moreover, there is great mileage for extending the DEA exercise by linking the scores with other attributes which are not always so well-known, for example casein content and cheese yield. DEA scores may also be linked with data for animal health and welfare, farm management strategies, regional characteristics and other external variables influencing farm efficiency (Barnes *et al*., 2011; Soteriades *et al*., 2016), which otherwise tend to be looked at in isolation. Data on the environmental footprints of farms can also be considered as DEA variables to add a sustainability dimension to farm benchmarking (Soteriades *et al*., 2016).

Missing and incorrect data, as well as unbalanced panel (monthly) data was a challenge that we faced when designing the DEA exercise. We had to remove farms with missing or negative entries in any of the inputs and outputs that we fed to the DEA model. This reduced the size of the available dataset. Similarly, the monthly entries of some farms were not recorded for all months of the 13-month study period, rendering impossible the study of DEA efficiency of individual farms (rather than our regional groups) over all 13 months. Fortunately, developments with precision farming increasingly offer access to precise, well-informed data (Agri-EPI Centre, 2017). Equally important are financial incentives motivating farmers to gather and share their data, such as Scottish Government's Beef Efficiency Scheme (2017). To be sure, Kingshay Farming and Conservation Ltd. and other recording companies provide the means, yet efforts should be made to eliminate variation between farmers in their accuracy of recording- or even their definitions of a record (Jack, 2009). In any case, the analyst can benchmark the farms for which they hold data against farms from the Farm Business Survey data (FBS, 2017), a comprehensive source of information on managerial, socio-economic and physical characteristics of UK farms. The FBS data are used in this manner in a recently developed benchmarking tool for UK farms (Wilson, 2017).

From a methodological viewpoint, this study makes several assumptions and simplifications, so the examples and results should be viewed with the appropriate understanding that they are for illustration purposes. First, we did not correct the data for errors. Second, we ignored outliers. The issue of outliers is debated in the DEA literature, as extreme observations can greatly alter the shape of the best-practice frontier. However, we considered extreme farms as part of what is currently observed in UK dairy farming systems, and it could be argued that '[such farms] reflect the first introduction of new technology into a production process or an innovation in management practice from which [other farms] would want to learn' (Bogetoft and Otto, 2011, p.147). Third, changing the set of DEA variables and/or adding or removing farms from the data will alter the shape of the frontier, consequently changing the set of efficient farms and the efficiency scores. We therefore recommend that DEA results should be seen as a rough proxy of the efficiency gains that may be achieved for the variables of interest in a given dataset. Variable choice is therefore up to the practitioner, and it may expand DEA's usability. This was demonstrated in our examples, with the use of SCC, BC, and butterfat and protein yields to compare current and 'optimal' milk prices.

Towards a DEA-based decision-support tool for farm management

There is currently no DEA-based decision-support tool specifically tailored to the needs of the (dairy) farming industry. Although DEA models can be easily run with standard software that the analyst may be familiar with, such as spreadsheets, all available DEA software (spreadsheet-based or not) we are aware of (Table 4) suffer from excessive use of DEA jargon. As discussed earlier, this is a main factor discouraging analysts from using DEA. Moreover, DEA software tend to be complicated in that they strive to incorporate as many DEA models and techniques as possible. This is a natural consequence, because DEA is founded on the fields of management, economics and operational research, where alternative theories and approaches are continually developed and debated, thus giving birth to alternative DEA

Table 4: List of available DEA software

Software	URL
additiveDEA	https://CRAN.R-project.org/package=additiveDEA
Benchmarking	https://CRAN.R-project.org/package=Benchmarking
DEA-Excel	https://nb.vse.cz/~jablon/dea.htm
DEAFrontier	http://www.deafrontier.net/deasoftware.html
DEAS	https://sourceforge.net/projects/deas/?source=navbar
DEA Solver Pro	http://www.saitech-inc.com/Products/Prod-DSP.asp
DEAP	http://www.uq.edu.au/economics/cepa/deap.php
EMS	http://www.holger-scheel.de/ems/
Frontier Analyst	https://banxia.com/frontier/
InverseDEA	http://maxdea.com/InverseDEA.htm
MaxDEA	http://maxdea.com/MaxDEA.htm
nonparaeff	https://CRAN.R-project.org/package=nonparaeff
Open Source DEA	http://opensourcedea.org/
PIM-DEA	http://deazone.com/en/software

models and methodologies to satisfy different needs (Bogetoft and Otto, 2011; Cooper *et al.*, 2007). To be sure, this may be of little concern to the farm analyst, who would rather focus their mind on specific objectives that could be dealt with specific DEA models and methods.

That said, it would be bold to assume that the farm analyst would benchmark farms using DEA themselves. As discussed earlier, we are well-aware that our study is a premature and simplified introduction to DEA for farm benchmarking and that many issues were not addressed in our examples. We envisage that this study will evolve to the development of a DEA-based decision-support tool for farm management, following the guidelines in two recent and particularly inspiring papers on the design of decision-support systems for agriculture (Rose *et al*, 2016, 2018).

5. Conclusion

DEA can help identify inefficient producers as well as indicate the inputs and outputs in which the largest inefficiencies occur for each farm. That way DEA can help guide management actions through a variety of cost-saving and/or profit-making options for each farm. We showed that detection- and elimination- of input and output inefficiencies can notably increase milk price and reduce the costs of concentrate use for inefficient UK dairy farms. We also demonstrated three simple ways of studying efficiency change over time with DEA to help detect trends in the technical performance of different farms or farm groups. Our DEA exercise could be extended to include other important variables such as labour, fertilizer use, greenhouse gas emissions, nitrogen and phosphorous surpluses *etc.* to account for objectives relevant to both business management and the public good. This flexibility characterizing DEA increases its importance in the context of a post- 'Brexit' UK, where a significant challenge will be to improve competitiveness in the world market (BSAS, 2017).

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Competing interests

None.

Ethics statement

We hereby state that have paid due regard to ethical considerations relating to the work reported and the work contains no defamatory or unlawful statements.

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6. Appendices

Appendix A: which efficient farms serve as benchmarks for farm G?

Farm G could be benchmarked against, say, efficient farm C or D (Figure 1). On the other hand, it could be benchmarked against a virtual farm represented by a point lying on, say, segment CD. In any case, the benchmark farm's input can be represented by a linear combination of the inputs of farms C and D. Similarly, the benchmark farm's output can be represented by a linear combination of the outputs of farms C and D. We can express these linear combinations mathematically as follows:

$$x_{Ben} = \lambda_C x_C + \lambda_D x_D \quad (1a)$$

$$y_{Ben} = \lambda_C y_C + \lambda_D y_D \quad (1b)$$

where x_{Ben}, x_C, x_D are the inputs of the benchmark farm, farm C and farm D respectively; y_{Ben}, y_C, y_D are the outputs of the benchmark farm, farm C and farm D respectively; and λ_C, λ_D are semi-positive variables whose values are calculated by the DEA model. The values of these lambda variables provide information on which farms serve as benchmarks for farm G. For example, if $\lambda_C = 1$ and $\lambda_D = 0$, then farm C is the benchmark of farm G. If $\lambda_C = 0$ and $\lambda_D = 1$, then farm D is the benchmark of farm G. However, if $\lambda_C = 0.1$ and $\lambda_D = 0.9$, then the benchmark of farm G is a virtual farm with input $0.1x_C + 0.9x_D$ and output $0.1y_C + 0.9y_D$.

We note that farm D plays a larger role in the formation of the virtual benchmark because its lambda value is much larger than that of farm C. In other words, farm D contributes to the formation of the virtual benchmark more 'intensively' than farm C. Therefore, the lambdas are referred to as *intensity variables* in the DEA literature. In this study, the term *benchmark variables* will be used instead.

Now note that, as mentioned above, the benchmark variables are calculated by the DEA model, hence the model does not 'know' *a priori* which facet of the frontier farm G is benchmarked against. Therefore, formulas (1a) and (1b) are more appropriately expressed as follows:

$$x_{Ben} = \lambda_A x_A + \lambda_B x_B + \lambda_C x_C + \lambda_D x_D + \lambda_E x_E + \lambda_F x_F + \lambda_G x_G \quad (2a)$$

$$y_{Ben} = \lambda_A y_A + \lambda_B y_B + \lambda_C y_C + \lambda_D y_D + \lambda_E y_E + \lambda_F y_F + \lambda_G y_G \quad (2b)$$

where $\lambda_A + \lambda_B + \lambda_C + \lambda_D + \lambda_E + \lambda_F = 1$. In formulas (2a) and (2b), the benchmark farm is indicated by those benchmark variables that have non-zero values. Efficient farms serve as benchmarks of themselves, e.g. for farm B we have that $\lambda_B = 1$ and $\lambda_A = \lambda_C = \lambda_D = \lambda_E = \lambda_F = \lambda_G = 0$. Note that the condition that the sum of lambdas equals 1 safeguards that the DEA model accounts for economies of scale. This is important when both small and large farms are present in the dataset, as was the case with the sample data. This condition is known as *variable returns to scale* specification. Other returns to scale specifications are available when needed, see Cooper *et al.* (2007).

Based on the above insights, we will demonstrate how the DEA model identifies benchmark farms for each farm in the sample. It is obvious that benchmark farms use at the most the same amount of inputs as the farm under evaluation, say farm G. Similarly, they produce at least the same amount of outputs as farm G. Therefore, we demand that

$$x_{Ben} = \lambda_A x_A + \lambda_B x_B + \lambda_C x_C + \lambda_D x_D + \lambda_E x_E + \lambda_F x_F + \lambda_G x_G \leq x_G \quad (3a)$$

$$y_{Ben} = \lambda_A y_A + \lambda_B y_B + \lambda_C y_C + \lambda_D y_D + \lambda_E y_E + \lambda_F y_F + \lambda_G y_G \geq y_G \quad (3b)$$

Formulas (3a) and (3b) simply tell us that the benchmark farm cannot be using more input and be producing less output than G. For instance, we could have that $x_{Ben} = 0x_A + 0x_B + 1x_C + 0x_D + 0x_E + 0x_F + 0x_G = x_C \leq x_G$ and similarly $y_{Ben} = y_C \leq y_G$. In this case, the benchmark for farm G is C. Alternatively, we could have that $x_{Ben} = 0.08x_A + 0x_B + 0.67x_C + 0x_D + 0.25 x_E + 0x_F + 0x_G \leq x_G$ And $y_{Ben} = 0.08y_A + 0y_B + 0.67y_C + 0y_D + 0.25y_E + 0y_F + 0y_G \leq y_G$. In this case, the benchmarks for farm G are farms A, C and E.

Appendix B: how does the additive model calculate efficiency?

Another way to interpret formulas (3a) and (3b) is that an inefficient farm such as G exhibits excess in its input and shortfall in its output relatively to its benchmark. The excess in inputs and shortfall in outputs represent the *inefficiencies* that G exhibits in its inputs and outputs. We denote input and output inefficiency as s_G^- and s_G^+ respectively, with $s_G^-, s_G^+ \geq 0$. These inefficiencies are central to the way that additive DEA models calculate efficiency. Before expanding on this, first note that $s_G^- = x_G - x_{Ben}$ and $s_G^+ = y_{Ben} - y_G$ so formulas (3a) and (3b) can be re-expressed for farm G as follows:

$$x_G = (\lambda_A x_A + \lambda_B x_B + \lambda_C x_C + \lambda_D x_D + \lambda_E x_E + \lambda_F x_F + \lambda_G x_G) + s_G^- \quad (4a)$$

$$y_G = (\lambda_A y_A + \lambda_B y_B + \lambda_C y_C + \lambda_D y_D + \lambda_E y_E + \lambda_F y_F + \lambda_G y_G) - s_o^+ \quad (4b)$$

Using formulas (4a) and (4b) as constraints of a mathematical optimization problem, the additive model seeks the maximal sum of input and output inefficiencies $s_G^- + s_G^+$ that farm G can exhibit (hence the term 'additive'):

$$Maximize\,(s_G^- + s_G^+) \quad (5a)$$

subject to

$$x_G = (\lambda_A x_A + \lambda_B x_B + \lambda_C x_C + \lambda_D x_D + \lambda_E x_E + \lambda_F x_F + \lambda_G x_G) + s_G^- \quad (5b)$$

$$y_G = (\lambda_A y_A + \lambda_B y_B + \lambda_C y_C + \lambda_D y_D + \lambda_E y_E + \lambda_F y_F + \lambda_G y_G) - s_G^+ \quad (5c)$$

$$\lambda_A + \lambda_B + \lambda_C + \lambda_D + \lambda_E + \lambda_F + \lambda_G = 1 \quad (5d)$$

$$\lambda_A, \lambda_B, \lambda_C, \lambda_D, \lambda_E, \lambda_F, \lambda_G, s_G^-, s_G^+ \geq 0 \quad (5e)$$

Problem (5a)-(5e) finds the optimal values for the inefficiencies and benchmark variables maximizing $s_G^- + s_G^+$ and projects farm G onto point C on the frontier (i.e. $\lambda_C = 1$ and all other lambdas are zero). See Figure 2 for a visual representation of problem (5a)-(5e) for farm G.

Now we point out some shortcomings of the additive model and propose adjustments to enhance its applicability in the context of dairy farm efficiency. Note that the optimal sum $s_G^{-*} + s_G^{+*}$ ('*' denotes optimality), i.e. the score of the additive model for farm G, represents the maximal sum of inefficiencies in inputs and outputs that G exhibits. This has three drawbacks: (i) the additive model produces a score of total *inefficiency* rather than *efficiency*; (ii) the inefficiency score is not readily interpretable as it represents a sum of inefficiencies in inputs and outputs potentially measured in different units. For instance, the sum of inefficiency in milk production plus inefficiency in fertilizer use is clearly not intuitive; consequently, (iii) the optimal solution is affected by the different measurement units in which inputs and outputs are measured.

Problems (ii)-(iii) can be easily overcome by replacing the sum in (5a) with

$$\frac{s_G^-}{x_G} + \frac{s_G^+}{y_G} \tag{6}$$

In (6) the different measurement units cancel because the inefficiencies are scaled by the actual input and output. In other words, the sum in (6) is *units invariant* and thus deals with problem (iii). The sum in (6) is interpreted as the proportion in input excess in x_G plus the proportion in output shortfall relatively to y_G. In more detail, a ratio of, say $\frac{s_G^-}{x_G} = 0.60$ means that the input of farm G is in excess by 60%, i.e. it could be using $x_G - s_G^- = x_G - 0.60x_G = 0.40x_G = 40\%$ of its input x_G. On the output side, a ratio of $\frac{s_G^+}{y_G} = 0.60$ means that farm G could be producing $y_G + s_G^+ = y_G + 0.60y_G = 1.60y_G = 160\%$ of its output y_G.

However, we are still faced with problem (i), although this can also be easily dealt with. First note from (5b) that s_G^- cannot exceed x_G, i.e. $\frac{s_G^-}{x_G} \leq 1$. However, we note from (5c) that this is not the case with s_G^+, i.e. we may have that $\frac{s_G^+}{y_G} > 1$. Nevertheless, in real life applications it might be unreasonable to have output slacks larger than the actual output because in such a case the farm under evaluation would have to at least double its output to become efficient- an enormous increase. Hence, we may demand that $s_G^+ \leq b_G$, where is an upper bound defined by the user, with $b_G \leq y_G$ (Cooper *et al.*, 2007, ch.13). By safeguarding that $\frac{s_G^-}{x_G} \leq 1$ And $\frac{s_G^+}{y_G} \leq 1$, we have for the optimal solution to (5a)-(5e) that $0 \leq \frac{1}{2}\left(\frac{s_G^{-*}}{x_G} + \frac{s_G^{+*}}{y_G}\right) \leq 1$ and so

$$0 \leq 1 - \frac{1}{2}\left(\frac{s_G^{-*}}{x_G} + \frac{s_G^{+*}}{y_G}\right) \leq 1 \tag{7}$$

Thus, the *inefficiency* score (6) is converted to an *efficiency* score (7) that is bounded by 0 and 1, with 1 indicating full efficiency (zero input and output inefficiencies) and a score less than 1 indicating inefficiency (non-zero input and output inefficiencies). The adjusted additive model for farm G becomes:

$$Minimize\left[1 - \frac{1}{2}\left(\frac{s_G^-}{x_G} + \frac{s_G^+}{y_G}\right)\right] \tag{8a}$$

subject to

$$x_G = (\lambda_A x_A + \lambda_B x_B + \lambda_C x_C + \lambda_D x_D + \lambda_E x_E + \lambda_F x_F + \lambda_G x_G) + s_G^- \tag{8b}$$

$$y_G = (\lambda_A y_A + \lambda_B y_B + \lambda_C y_C + \lambda_D y_D + \lambda_E y_E + \lambda_F y_F + \lambda_G y_G) - s_G^+ \tag{8c}$$

$$\lambda_A + \lambda_B + \lambda_C + \lambda_D + \lambda_E + \lambda_F + \lambda_G = 1 \tag{8d}$$

$$s_G^+ \leq b_G \tag{8e}$$

$$b_G \leq y_G \tag{8f}$$

$$\lambda_A, \lambda_B, \lambda_C, \lambda_D, \lambda_E, \lambda_F, \lambda_G, s_G^-, s_G^+ \geq 0 \tag{8g}$$

Appendix C: the general case

We consider the general case where there are dairy farms each using inputs to produce outputs, denoted as $x_i (i = 1, \ldots, m)$ and $y_r (r = 1, \ldots, s)$ respectively. The efficiency score for the farm under evaluation, denoted as $\mathrm{FARM_O}$, is given by the following generalization of problem (8a)-(8g):

$$\rho^* = \mathrm{Minimize}_{\lambda_j, s_{io}, s_{ro}}\left[1 - \frac{1}{m+s}\left(\sum_{i=1}^{m} \frac{s_{io}}{x_{io}} + \sum_{r=1}^{s} \frac{s_{ro}}{y_{ro}}\right)\right] \tag{9a}$$

subject to

$$x_{io} = \sum_{j=1}^{n} x_{ij}\lambda_j + s_{io}, i = 1, \ldots, m \tag{9b}$$

$$y_{ro} = \sum_{j=1}^{n} y_{rj}\lambda_j - s_{ro}, r = 1, \ldots, s \tag{9c}$$

$$\sum_{j=1}^{n} \lambda_j = 1 \tag{9d}$$

$$s_{ro} \leq b_{ro}, r = 1, \ldots, s \tag{9e}$$

$$b_{ro} \leq y_{ro}, r = 1, \ldots, s \tag{9f}$$

$$s_{io}, s_{ro}, \lambda_j \geq 0 (i = 1, \ldots, m, r = 1, \ldots, s, j = 1, \ldots, n) \tag{9g}$$

where x_{io} and y_{ro} are the inputs and outputs of $\mathrm{FARM_O}$ respectively; s_{io} and s_{ro} are the input and output inefficiencies of $\mathrm{FARM_O}$ respectively; and b_{ro} is the user-defined upper bound of s_{ro}.

Appendix D: fixed variables

Fixed inputs and outputs can be included in model (9a)-(9g) by adding the following two constraints:

$$x_{ko}^{fixed} \geq \sum_{j=1}^{n} x_{kj}^{fixed}\lambda_j, k = 1, \ldots, \textit{ number of fixed inputs} \tag{9h}$$

$$y_{lo}^{fixed} \leq \sum_{j=1}^{n} y_{lo}^{fixed}\lambda_j, l = 1, \ldots, \textit{ number of fixed outputs} \tag{9i}$$

Appendix E: bounds

The bounds imposed to the slacks of the additive model run in this exercise were the following:

$$\frac{y_o^{butterfat} + s_o^{butterfat}}{y_o^{milk}} \le \max\left(\frac{y_j^{butterfat}}{y_j^{milk}}\right) \tag{10a}$$

$$\frac{y_o^{protein} + s_o^{protein}}{y_o^{milk}} \le \max\left(\frac{y_j^{protein}}{y_j^{milk}}\right), \tag{10b}$$

thus

$$b_o^{butterfat} = \max\left(\frac{y_j^{butterfat}}{y_j^{milk}}\right) y_o^{milk} - y_o^{butterfat} \tag{11a}$$

$$b_o^{protein} = \max\left(\frac{y_j^{protein}}{y_j^{milk}}\right) y_o^{milk} - y_o^{protein} \tag{11b}$$

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Farmers' spending on variable inputs tends to maximise crop yields, not profit

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ABSTRACT

We estimate the marginal returns to spending on Crop Variable Inputs (CVI) (such as fertilizers and crop protection), to explore whether observed spending maximises physical or economic returns to farmers. Data are taken from the Farm Business Survey for 2004-2013, where gross margins and input spending are available, in over 10,300 crops of conventional winter wheat or oilseed rape in England and Wales. Marginal spending on CVIs generate financial returns significantly less than £1 per marginal pound spent. This suggests that expenditure on CVIs exceeds an economic optimum that would maximise profit. However marginal physical products (crop yields) are positive, but small and significantly different from zero. This suggests that, on average, farmers approximately maximise yields. These results hold across a wide range of alternative economic models and two crop species. Similar results have been reported in estimations for Indian grain production and for maize in China. In practice, farmers are making decisions on input use in advance of having information on a variety of factors, including future yield, product quality and price, making it difficult to optimise input levels according to expected profit. Farmers may be consistently optimistic, prefer to avoid risk, or deliberately seek to maximise yields. Some farmers may put on the standard recommended application irrespective of input or expected output price. It is also possible that advice may sometimes aim to maximise yield, influenced by an incentive to encourage greater sales. Excessive input use both reduces private profits and is a cause of environmental damage. There are thus potential private as well as social benefits to be gained from optimising levels of input use.

KEYWORDS: marginal products; marginal profit; farm variable inputs; fertiliser; crop protection; agricultural productivity

1. Introduction

Crop production incurs a mix of fixed and variable costs - such as the costs of seeds, fertilizer and pesticides - the levels of which vary in direct proportion to the level of production. Crop *profitability* critically depends on the costs of these variable inputs (Lawes and Gilbert 1879; Barnard and Nix 1979; Cato, cited in Campbell 2000; Van Alfen 2014), termed the Variable Costs of Production.

Typically, in agricultural production fixed costs account for about 60 per cent of total costs and variable costs about 40 per cent (Lang 2015). While fixed costs are by definition not readily altered from year to year, farmers have control over the levels of variable inputs and hence the level of variable costs. Thus decisions as to what level of variable inputs to apply are a significant determinant of the profitability of crop production. For example, in the 2012 harvest year, in production of (non-organic) winter wheat in England, variable costs (VC) accounted for 41 per cent of crop economic output (CEO). The resulting Gross Margin (GM=CEO-VC) was 59 per cent of crop economic output. After deducting 60 per cent of crop economic output for fixed costs, this results in a negative net profit in wheat production, for this year before taking account of subsidies (Lang 2015).

In classic production economics, profit will be maximised when, for each individual input, the Value of the Marginal Product (VMP) (the revenue gained by the farmer from the sale of the output generated by the last unit of input) is equal to the Marginal Cost (MC) (the cost of the last unit of input). Prior to this point, further units of input will increase profit, beyond this point costs will exceed revenue. In order to maximise profit, then farmers may be expected to follow this rule (Nelson and Ibach 1957; Barnard and Nix 1979; Olson 2004; IFIA 2007; Defra 2010).

In practice, the position is more complex. Farmers have to decide *ex ante* on the levels of inputs to apply, in advance of knowing the conditions under which production will take place or the price at which their product will be sold. In this context, farmers may simply follow a standard recommendation, irrespective of the current or expected circumstances, or they may take a risk averse

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approach and apply higher levels of inputs in order to ensure that they achieve a 'good' yield.

Evidence from other countries suggests that farmers may on average apply higher levels of inputs than maximise financial return. Research in China on current Chinese maize cultivation practices (Xu *et al.*, 2014) estimates that farmers could increase profits, and save US$50/ hectare in variable costs for nitrogen, by applying an average of 67kg/ha (30%) less nitrogen than average farmer practice of 224 kgN/ha maize. This was based on 408 trials over 2010-2012 in the prime maize growing region of the eastern seaboard states. Moreover, Zhang *et al.* (2015) observe marginal losses of Rm0.1-0.55 per marginal Rm spent on pesticides. In Indian grain production, using World Bank (2014) functions, average marginal returns were estimated to be small - with marginal production being circa Rs0.45 of cereals/ per Rs of fertiliser spending (a loss of Rs 0.55 /Rs at the margin[1]).

At a global level, it is estimated that current world cereal production could be achieved, with approximately 50 per cent less nitrogen (Mueller *et al.*, 2014), if application rates were optimised across the world. Under this scenario, Mueller *et al.* (2014) estimate for England that nitrogen applications would decrease by 27%, from an assumed average application across all grains in the year 2000 of 127kgN/ha[2].

But this is not always the case. In Sweden for example, at the peak of post-war technical change in farming and in the context of strong policies to boost production, farmers were estimated to be able to achieve marginal products of $3.5-to-2.1 per marginal $1 of fertiliser expenditure (Heady and Dillon 1961). In less intensive systems, Kenyan farmers were recently estimated to achieve much higher returns, with a ratio for VMP to MC measured at 1.7 (Sheahan *et al.*, 2013).

The level of input use in crop production also has wider social implications. Leaching of chemicals from agricultural production represents a significant external cost due to its impacts on water quality (Carpenter *et al.*, 1998). The standards set under the EU Water Framework Directive are likely to require a reduction in levels of diffuse pollution from agriculture (Sutton 2011). These same arguments apply to the use of pesticides.

This implies that the social cost of input use exceeds the private cost, and hence that the socially optimal level of input use will be lower than the privately optimal level. The social cost includes costs that are not borne by producers but by other actors or society more generally. The private cost is borne by producers only. Thus, some estimates suggest that the Socially Optimal N-Rate is at least 50 kgN/ha less than the Privately Optimal N-Rate (which does not account for social costs or other externalities), determined by the European Nitrogen Assessment (Brink and van Grinsven, 2011), for cereals in Northern Europe[3].

The efficiency of input use is thus an issue of importance, both for the private financial performance on farms as well as for public policy making. Levels of current spending on fertilisers and other variable inputs may not be optimal. It is therefore important to explore the position in the UK as there has been no systematic analysis of farm business data in order to assess these issues. So, the objective of this paper is to quantify the marginal returns to crop variable input spending, drawing on data from the Farm Business Survey, in order to assess the efficiency of input spending rates on crop farms in England.

2. Method

The analysis used the fixed effects econometric analysis to extract deterministic relationships from economic datasets (Mundlak 1961). It is a powerful technique developed in the late 1950s and is now a standard approach in many fields of financial, real estate and economic analysis (Brooks 2014; Angrist and Pischke 2009). Mundlak's (1961) methodology obtains coefficients that are free of management bias by controlling for other sources of unobserved heterogeneity. These potential sources include both those permanent factors specific to an individual farm and farmer, such as soils, farm specific fertility and persistent weed burdens, aspect and location, education and skill, as well as those factors specific to an individual year, such as market and weather conditions. We use the fixed effects estimation because it is expected that some of the variables not considered in the model (and therefore would otherwise appear in the error term) might be correlated with the independent variables (e.g. management, which is not included in the model, and therefore is part of the error term, may affect the use of inputs and make the regression coefficients biased) (Brooks 2014; Angrist and Pischke 2009; Chavas *et al.*, 2010). The remaining variation thus represents the variation within farms, essentially the individual farmers' deviations from their own average spending on variable costs (adjusted for general inflation).

This is illustrated, schematically, in Figure 1. The vertical axis is modelled wheat yield, and the horizontal axis is deviation (from the assumed optimum average application rate). Each curve represents an assumed class of result (farm*year) for an average farm. These are then normalised with fixed effects for individual years and individual farms, so that all of the points are brought to one curve and can then be regressed against deviation from the assumed optimum application rate.

We focus in this paper on how farmers respond by adjusting input application rates, when for example relative prices of fertilisers or grains change. In order to assess how farmers optimise expenditure on variable inputs, we use historic spending on fertilisers, seeds or chemicals - unadjusted except for general changes in inflation.

For the linear case, the within farm variation (in spending on crop-variable-inputs), with fixed effects for farms and years, is given as:

$$\text{Output}_{ti} = a + b_1\mathbf{Ferts} + b_2\mathbf{Sprays} + b_3\mathbf{Seed} +$$

$$b_4\mathbf{Othr} + c_t\text{Year}_t + c_i\text{Farm}_i + e_{it}$$

where the dependant variable is Output per hectare (in year $_t$, on farm $_i$), being either Crop Gross Margin (GM) (£ per hectare), Crop Economic Output (CEO) (£ per hectare), or Crop Yield (Yld) (kilograms per hectare). These variables were regressed on farm deviations from

[1] Author calculations based on averages for the breadbasket areas of 'High Yields - where production was Not Growing'.
[2] This figure seems low given BSFP 2014 recommendations in excess of this level.
[3] Which Brink and van Grinsven (2011) posit could incur a 20 per cent yield penalty. However in England it is estimated that this is likely to incur an aggregate yield penalty of only 5 per cent (ADAS, pers. comm.).

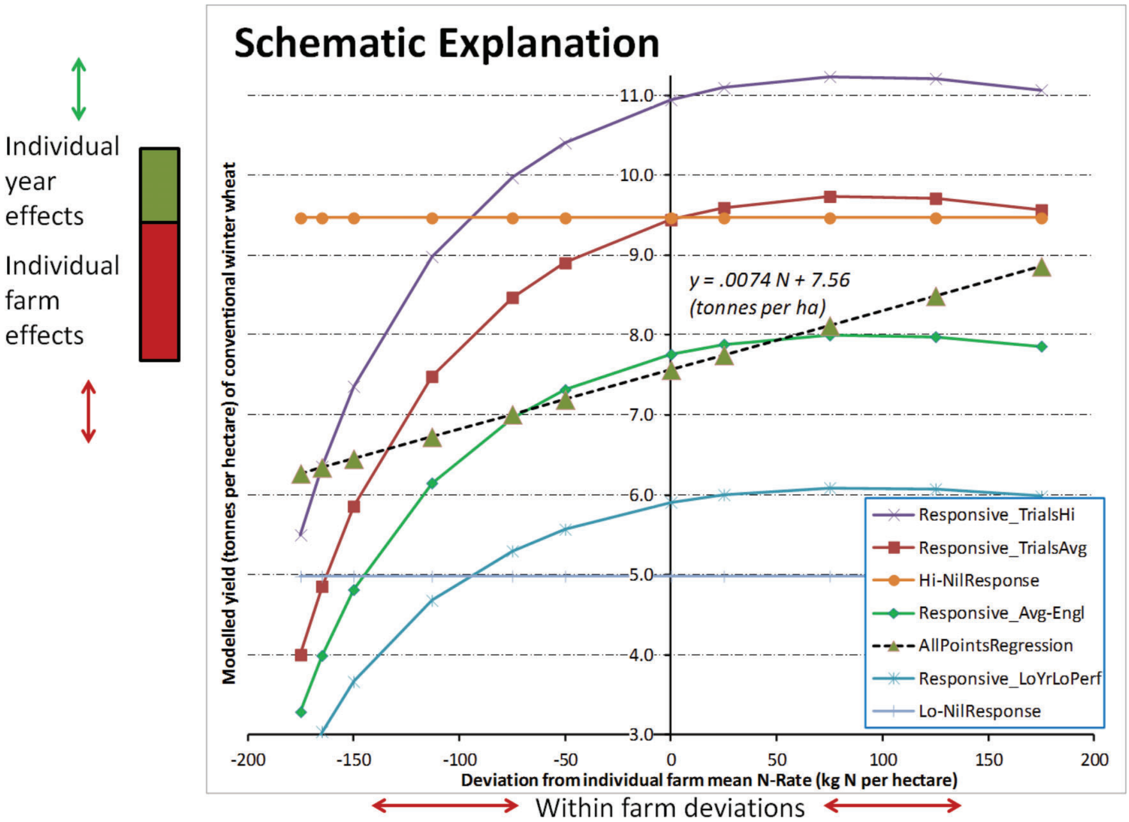

Figure 1: Schematic representation of the analysis - which illustrates the normalisation by "Year" and "Farm" Fixed Effects (vertical constants), and the use of "within farm variation in fertilizer use" (within farm deviations - from the farm optimum) - to normalise horizontally

the mean spending rate of each individual farm: for fertilisers (**Ferts**); all crop protection (**Sprays**); seeds (**Seed**); and other crop variable costs (such as agronomy charges, baling twine or packaging, but excluding heating and drying costs or fuel because spending on fuel for machinery is not allocated to specific crops in the Farm Business Survey) (**Othr**).

Spending variables in the above equation are expressed as individual-farm-deviations from the individual-farm-mean, in £ per hectare. That is to say within farm variation in spending per hectare, e.g. a series of [$Fert_{ti}$ minus $Mean\_Fert_i$]. Year and Farm effects, ($Year_t$ and $Farm_i$), are dummy variables for each respective degree of freedom (t-1 and i-1) (to average out variation between years and between farms). And e_{it} is the residual variation (Farms*Years).

While this is a production function, in the sense that we calculate effects on output of production factors, for unobserved factors of production (the omitted variables), it depends on terms that are specific to each individual farm and to each individual year. The $b_{1 \text{ to } 4}$ coefficients are thus the linear effects, because they represent the return to changes in spending on these inputs at the margin. They are thus the tangents (for limited variation) to the aggregate production function, for GM, CEO or Yld, of an additional one £ per hectare spent on that particular Crop Variable Input beyond the individual farm mean, averaged across years and farms. These coefficients therefore represent 'marginal profit' (Gross Margin), 'marginal economic output' (Crop EO), or 'marginal physical product' (Yield), per marginal cost. Or, put more simply, the effect of the last pound of spending on these variables.

It should be noted that other model specifications that have been adopted in the literature, including translog and quadratic forms (Brooks 2014; Angrist and Pischke 2009; Chavas *et al*., 2010), were also tested. Models were tested too for within year variation between farms with proxies for known variation in farm characteristics (so, in that case, the residual variation was farm). All-inputs-variation for between-farms variation in farm-mean spending was similarly modelled. Results from these alternative models are not presented as no materially different results were observed.

The regressions are generally assumed to be independent of scale effects, because the factors of interest are variable costs which vary in direct proportion to the scale of the enterprise expressed per unit area (hectares) of sown land. This is the dimension that is used in practice, and understood, by farmers. It is also the correct dimension in which to analyse the effect of changing the *rates* of spending on these variable costs. Hence we do not investigate the substitutability of land, labour, machinery and fertilisers (Clark *et al*., 2013).

Regressions were estimated with and without population weights which aggregate on unrelated strata variables (Defra 2015). As may be expected, this weighting increased standard errors, by around 2%, for the coefficients that are of interest.

3. Data

Data were drawn from the Farm Business Survey (Defra 2015), which is a stratified, random unbalanced, panel survey including 1,656 farm businesses in England and Wales that have more than €25,000 standard agricultural

Table 1: FBS sample for gross margins 2004-2013

	Conventional Winter Wheat	Conventional Winter Oilseed Rape
Crops (of one arable "non-organic" crop species, on one farm, in one year)	6,948	3,449
Farms in sample	1,656	895
Years (2004/5-2013/14)	up to 10	up to 10
Farms with at least 4 or more years' observations	789	502

Table 2(a): Ten year average costs and output in the FBS gross margins sample 2004-2013 (£/ha). Performance bands were ranked by gross margin per hectare. (s.e.m. in parenthesis)

£ / hectare sown (in 2013 GBP)	**Winter Oilseed Rape - all**	**Winter Wheat - all**	**Wheat Low 25% Performance**	**Wheat Mid 50% Perf.**	**Wheat High 25% Performance**
Fertilisers (average)	178.5 (1.352)	160.7 (0.909)	166.2 (2.967)	161.4 (1.246)	157.4 (1.437)
Crop protection (average)	151.5 (0.988)	153.9 (0.633)	148.7 (1.881)	154.6 (0.874)	155 (1.044)
Seeds (average)	49.04 (0.482)	59.9 (0.321)	64.47 (1.04)	61.32 (0.429)	55.92 (0.525)
Other Variable Costs (average)	21.58 (0.481)	26.5 (0.504)	28.99 (1.592)	28.64 (0.735)	22.21 (0.71)
Total Variable Costs	400.6	401.0	408.4	406.0	390.5
Crop produced (tonnes/ha)	3.415 (0.0144)	7.811 (0.0193)	7.129 (0.0595)	7.729 (0.0256)	8.203 (0.0312)

Table 2(b): Ten year average costs and output in the FBS gross margins sample 2004-2013 (£ per tonne). Performance bands were ranked by gross margin per hectare

£ / tonne grain (in 2013 GBP)	**WOSR - all**	**Winter Wheat - all**	**Wheat Low 25% Performance**	**Wheat Mid 50% Performance**	**Wheat High 25% Performance**
Fertilisers (average)	52.3	20.6	23.3	20.9	19.2
Crop protection (average)	44.4	19.7	20.9	20.0	18.9
Seeds (average)	14.4	7.7	9.0	7.9	6.8
Other Variable Costs (average)	6.3	3.4	4.1	3.7	2.7
Total Variable Costs	117.3	51.3	57.3	52.5	47.6
Crop Economic Output (average)	298.4	135.2	124.6	133.8	140.8
Gross Margin	181.1	83.9	67.3	81.3	93.2
Number of crops in sample	3,449	6,948	910	3,680	2,358

output and a labour input greater than 0.5 full-time-equivalents. The analysis here uses derived variables and measures of: Gross Margins (GMs), yields, and variable costs of conventional winter wheat and conventional winter oilseed rape over the harvest years 2004 to 2013 inclusive (Table 1).

Winter Wheat: The mean total area of crop sown was 82.9 hectares per farm (all of which were non-organic, or conventional, crops) and mean grain yield per hectare per farm business was 7.8 tonnes per hectare (Table 2 and Appendix I). No one crop on any one farm in any year had zero economic output (and so it was not necessary to exclude any crop so as to be able to fit the Translog model detailed below).

Winter Oilseed Rape: The mean total area per farm was 51.0 hectares and mean yield 3.4 tonnes per hectare per farm business (Appendix II), of which only one crop in one year on one farm had zero economic output. This was excluded from the sample so as to be able to fit the Translog model.

Given a mean total area per farm of 201 hectares, and utilised agricultural area of 194 hectares, this stratified random sample (of up to 8% of all cereals and general cropping farms in England and Wales) closely resembles the typical cropping patterns in English grain production, where cereal farms had in 2012 a mean area of 200 hectares with 75 hectares of winter wheat (Lang 2015).

All financial values were deflated to 2013 pounds sterling (£) using standard GDP deflators from UK HM Treasury.

There do not appear to be systematic biases or consistent trends in relative spending on inputs. For example, Figure 2 shows the distribution of farm deviations from individual farm mean spending in winter wheat on variable inputs, across the time series. As can be seen, the range of deviations within each year is fairly small, indicating that farmers did not typically vary practice greatly.

4. Results

Marginal coefficients for GM, for both winter wheat and winter oilseed rape, of spending an extra unit on Fertilizers, Sprays, Seed and Other inputs beyond the individual farm means are all negative, significantly different from zero (Table 3); and is robust to alternative model specifications (for instance the Wald-Wolfowitz runs test was 173 for GM on ''within-farms-fertiliser-variation'', associated with 1% of the observed variance, and $p < 0.001$).

The marginal GM coefficients thus imply that marginal expenditure is loss making, i.e. the marginal GM is negative because marginal costs exceed marginal returns. Marginal coefficients for Economic Output are positive. Consistently with this, marginal coefficients for physical

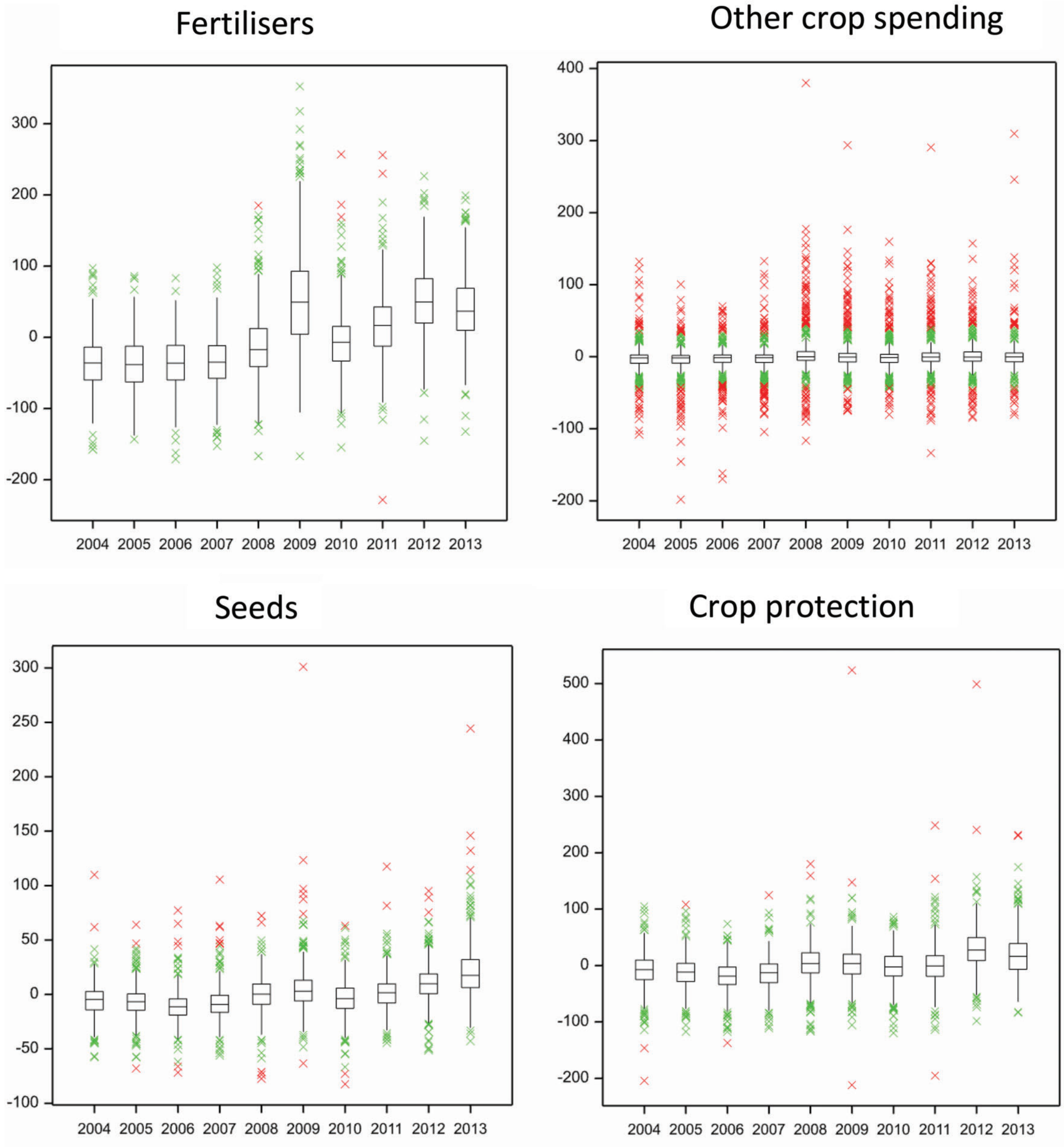

Figure 2: Distribution of farm deviations, from individual farm mean spending in winter wheat on fertilisers, other crop costs, seeds, and crop protection, by years (£ per hectare)

production (yield) are small, but positive, and significantly different from zero (Table 3). This may suggest that the input variables are causally related to yield, but the responses at the margin are small or, in other words, near the peak of the response curve and very close to maximum yield for that input, other things being equal. This indicates that the marginal unit of input increases production but not sufficiently to pay back the cost of the input.

It could be postulated that the effects we observe here are associated with crop rotations, as with a first wheat (after a break crop) less fertiliser could be applied but yields could be higher (because, for example, first wheats after legumes that fix nitrogen require less fertilizer and give higher yields). This was tested by adding an interaction term for peas or beans in a previous year (somewhere on the farm). For fertilizers the coefficient was not significantly different from zero (Table 4), whereas rotations may be expected to lead to a lower response to the application of fertilizers in first wheats, i.e. a lower marginal physical product (MPP). However, most farms will have several fields of wheat (each possibly following a different crop) and so our observations are aggregated across several rotations on each farm in each year and also nitrogen fixing or heavily fertilised crops, such as field-scale vegetables or potatoes, amount to only 15% of the area of cereals in England. So the vast majority of wheat crops will not be following such break crops, making any possible effect of rotations difficult to identify with the available data. We do though, as noted above, identify the same loss-making marginal Gross Margins with near maximum yields for Winter Oilseed Rape which is not subject to this potential rotation effect, supporting the case that the that the results are not a consequence of crop rotation.

Table 3: Marginal returns of variable inputs observed in 10 years of the Farm Business Survey (2004-2013) for conventional crops of Winter Wheat and Winter Oil Seed Rape

Model	Dependent variable*	Ferts†	Sprays†	Seeds†	Other Variable Costs†	Sample	Pseudo r^2	Observation Standard Error
Wheat (within+years+farms)	£GM/ha	*-.85 (.065)*	*-.45 (.089)*	*-1.24 (.164)*	*-.54 (.107)*	5,341	59.3	1,182
Wheat (all / unweighted)	£GM/ha	*-.85 (.061)*	*-.50 (.081)*	*-1.19 (.148)*	*-.58 (.103)*	6,948	58.0	205
Winter Oilseed Rape	£GM/ha	*-.76 (.095)*	*-.26 (.127)*	*-1.48 (.228)*	*-.08 (.231)*	2,927	61.2	232
Economic product (Wheat)	£EO/ha	*.18 (.062)*	*.48 (.085)*	*-.23 (.156)*	*.41 (.102)*	5,341	64.3	125
Translog (Wheat)	£EO/ha	*.22 (.097)*	*.30 (.127)*	*.25 (.219)*	*.19 (.126)*	5,341	66.7	-
Wheat yield (within+years+farms)	kg/ha	*1.51 (034)*	*3.72 (0.47)*	*-0.76 (0.87)*	*1.62 (0.56)*	5,341	51.4	6,231
Wheat yield (all/unweighted)	kg/ha	*1.39 (033)*	*3.42 (0.44)*	*-0.89 (0.80)*	*2.18 (0.55)*	6,948	53.2	1,102
Winter Oilseed Rape	kg/ha	*0.66 (0.27)*	*2.68 (0.36)*	*-1.21 (0.65)*	*2.38 (0.66)*	2,927	37.3	659
Wheat nil PeaBeanPots$_{(t-1)}$	kg/ha	*0.31 (0.53)*	*3.65 (0.75)*	*-0.66 (1.25)*	*1.50 (0.84)*	2,410	49.0	6,679

*£GM/ha is Gross Margin (in £GBP per hectare). £EO/ha is Economic Output (in £GBP per hectare). kg/ha is grain yield per hectare sown. Unless otherwise stated all regressions are for wheat, weighted and only include farms with >=4 observations. Standard errors are in parentheses. Marginal economic outputs, for the Translog, were estimated at mean values.
†deviations from individual farm means (in £GBP per hectare)

5. Discussion

Findings

In our results, yields appear to be nearly maximised. This is reflected in marginal yields (MPP) that are small, positive and significantly greater than zero in both oilseed rape and winter wheat. So farmers appear to be making systematic decisions on spending on crop inputs in England and Wales. This would not be the case if the losses observed at the margin were just an effect of prices. In that case we would expect that the MEOs and MPPs would not be significantly different from zero. Our results do suggest that farmers are consistently applying levels of inputs which, at the margin, cost more than they return in terms of increased financial product.

Limitations of the method

In the available data, prices and quantities of inputs are confounded in the observations and so we are not able to distinguish between contexts where farmers had to pay a higher price for their inputs and contexts in which they applied greater quantities of inputs or inputs of higher quality. However in both economic teaching and in practice (Blagburn 1961; Barnard and Nix 1979; Olson 2004; Warren 1998) farmers are expected to respond to changes in prices. So for example, if fertiliser prices fell (relative to grain) and farmers increased nutrient application rates to maximise returns, we do not adjust for this using separate indexes for prices of farm inputs and outputs because efficiency would in this context appear to decline unrealistically (Langton 2011).

Possible reasons for excessive application levels

We should emphasise that the results do not demonstrate that the application of inputs in total is not profitable. The focus of this analysis is on marginal returns. The results do not represent the average, or industry, profitability of variable input applications. Thus for instance, we calculate that the *average* profit per *kilogram of N* ("UBoN" as defined by Brink and van Grinsven 2011) to be £2.32. The application of N is clearly profitable. By comparison, across Northern Europe the *average* profits from N-application were estimated to be €0.4 to €2.7 per kilogram of N applied (Brink and van Grinsven 2011).

A first point to make is that the results do not appear to simply represent random errors. There is, of course, considerable uncertainty involved in making input decisions without knowledge of the production conditions or of future output prices. But the consistent significance of the estimated coefficients indicates something more systematic. One possible interpretation of this result might be that "*the decision to apply more than average to take advantage of the good years is appropriate since the cost of over-application is low compared to the cost of under-application*" (Rajsic and Weersink, 2008, p56). See also Rajsic, Weersink and Gandorfer (2009). However, in the analysis we find evidence of systematic over-application. If the large gains in a small number of good conditions were greater than the small losses in a larger number of poor conditions, we would expect to find that, overall, mean coefficients on gross margins were positive. This was not the case and so we do not accept this argument here.

Table 4: Marginal physical product (yield) of conventional Winter Wheat, with interaction terms for Peas-or-Beans on-farm in the preceding year

Dependent variable is kg wheat yield per hectare			
Parameter	**estimate**	**s.e.**	**t prob (est)**
w/i Farms Fertilizers (£/ha)	*1.60*	0.41	<.001
w/i Ferts.PYPeaBnGT0	*-0.85*	0.69	0.219
w/i Farms Sprays (£/ha)	*3.00*	0.57	<.001
w/i Sprays.PYPeaBnGT0	*1.96*	1.18	0.097
w/i Farms Seed (£/ha)	*-1.45*	0.93	0.122
w/i Farms Other exp's (£/ha)	*2.44*	0.62	<.001
Constant	*7,543*	546	<.001

The fact that farmers do not operate simply as profit maximisers is well accepted (e.g. Schwarze, *et al*., 2014). Various explanations may be advanced in order to explain why farmers appear to be applying levels of inputs that exceed those that would maximise profits. Sheriff (2005) includes the following possible reasons: i) The perceived limited relevance of recommendations to 'my farm', to 'my county', and to 'this year', be they official, such as in the UK RB209 (Defra 2010), or commercial, such as IFIA (2007), where farmers believe that the recommendation is too conservative or pessimistic; ii) Substitutability of limiting factors (where a farmer might apply extra nutrients where yields are limited by rainfall, and the farmer is optimistic about rain); iii) Opportunity costs; and iv) Uncertainty (especially in the context of large potential losses and small costs).

Following from this, we consider various possible explanations for the apparent over application of inputs in the face of uncertainty, where yield, quality and prices are largely unknown at the time when the inputs are applied (*ex ante*). However, we accept that it is unlikely that any single factor represents a sole cause. Thus we consider: i) The possibility of unobserved costs; ii) The adoption of standard guidance; iii) Optimism; iv) Risk aversion; v) External advice; and vi) Agricultural subsidies.

i) Unobserved cost

It is not possible to observe the full range of costs facing farmers in making decisions about input levels. In this context there are opportunity costs and costs of information. Effort and time spent on increasing the precision of input applications has opportunity costs, such as in terms of work-hours available in autumn when farmers are under pressure to get other work completed. Farmers may save time and other costs by the convenience and low cost of 'with seed' applications of pesticides, or by the ease of application of standard mixes of fertiliser nutrients. To some extent this will depend on the skills and experience of the farmer. In this context then, some farmers may simply to follow standard input packages without reference to their own particular circumstances.

ii) Standard guidance

The standard recommendations for fertiliser applications in England, as provided in RB209 (Defra 2010), may also bias practices towards higher input rates. The recommended N level for England is set at the 98th percentile of the maximum yield on the response curve given in RB209 (because the ratio of grain prices to fertilizer prices is assumed to be 1/6 or 1/10). This corresponds very closely to the 5 year average application rate on winter wheat in Britain of 185 kgN/hectare (BSFP 2014). Given random variation, this means that many applications will be well in excess of the level required for maximum yield. The IFIA (2007) recommends applications at similar levels of the response curves, as do standard texts (e.g. Cooke 1982).

A further factor that may bias industry results towards negative returns from the last unit of input is that no response to varying input rates (e.g. to N) is seen in many site-by-year combinations. For example, 13 out of 30 (45%) site-by-year combinations in trials at 15 sites over 2005-2007 for the 2010 RB209 (Defra) gave no response to N (Sylvester-Bradley *et al*., 2008). In such 'site*years' N-applications will, clearly, incur substantial losses.

iii) Optimism

Farmers may simply make systematic errors in assessing the levels of input to apply, where perhaps they anticipate a better growing season than generally eventuates. Kahneman (2011) has pointed to 'optimistic bias' as potentially the most significant of the cognitive biases. Farmers may apply levels of input that would be beneficial in the event of good growing conditions and prices but outcomes are not as good as anticipated and so the investments are not justified.

iv) Risk aversion

Attitudes to risk may also play an important role in the results that we observe here. Risk aversion may create an incentive for farmers to make prophylactic applications, applying extra inputs to reduce the risk of achieving low yields. A strong preference to avoid a yield-penalty may also be a factor leading to the observation of small marginal products and near maximum yields, perhaps influenced by negative self-image from having 'poor' looking crops or concerns about peer pressures when farmers continue to associate 'good farming' with high yields.

v) External advice

Many farmers rely on external advice on the levels of inputs to apply. We have little evidence on the basis on which this advice is given but these results raise various issues. It is possible that advisors, as we have suggested might be the case with farmers, simply follow the standard recommendations with regard to fertiliser application rates. It could be that with training in agronomy rather than in economics, the emphasis is on yields rather than profits. Further, some advice is tied in with the sale of inputs. This context raises the further possibility that advisors whose incomes rely on the sales of inputs may consciously or unconsciously have an incentive to recommend higher levels of input use than would otherwise be the case. This is an issue that deserves further exploration.

vi) Agricultural subsidies

Direct payments to farmers in Europe are of the order of €230 per hectare, each year, under the EU Common Agricultural Policy (CAP). While input suppliers, and for tenant farmers landlords, may capture some of this support (e.g. O'Neill and Hanrahan, 2016), the increased income may affect farmer behaviour. The guaranteed income might reduce farmers' degree of risk aversion, offsetting the previous effect, or potentially reduce their marginal utility of income. In this context a farmer might opt for a simpler approach, applying standard levels of inputs rather than making the extra effort to maximise net profit. The net effect of CAP subsidies on input levels thus seems uncertain.

Further work is needed in order to assess the relevance and importance of these possible alternative explanations for the observed results.

6. Conclusions

The analysis has provided robust evidence that farmers are systematically applying rates of inputs that exceed the rates that would maximise their profits. In contrast, their decisions appear to enable them to come close to applying levels of inputs that maximise yields. The implication is that farmers could increase profits by applying lower levels of inputs. At the same time, the environmental impacts of input uses indicate that there can also be potential social benefits associated from lower rates of input use through reduced external costs borne by other actors, such as pollution. We have outlined possible explanations for the observed results. Some of these could indicate that the private gains might be hard to achieve, such as where 'over-applications' arise from costs that have not been identified in this analysis. Others could indicate ways in which profitability could be increased, such as if the results are explained by an excessive degree of optimism. Further work is required to sort through these various alternative explanations.

There is also a cautionary implication of the analysis for the adoption of price incentives as a means of shifting farmer decisions closer towards a social optimum. If farmers are not reacting accurately to the prices that they currently face in the market, there can be little expectation that they would react accurately to prices altered in order to promote social or environmental objectives. This is not to say that environmental taxes would not push farm level decisions in a desired direction, rather that we cannot expect such policies to deliver 'optimal' outcomes.

At this stage, we have not attempted to estimate the total losses associated with this apparent over-application of inputs. Aggregate losses, to farmers and to society, should be estimated from the areas under the whole of the production function. It will be interesting to derive the size of industry losses from these effects at the margin. Strip trials and 'field mosaics', which will provide clearer information on the production functions, are being actively explored by NIABTAG, AHDB Cereals and ADAS (ADAS 2017; Sylvester-Bradley 2014). Vast and increasing quantities of data are being generated through precision farming, such as the field mosaics of Tru-Harvest/ ClimateCorp/ AgriData-Deere in the USA. Researchers need to clarify and disseminate the methods and algorithms for farm-level-optimisation using the big-data that is now available.

In conclusion, further analysis is required to understand better the ways in which farmers make decisions and the incentives that they and their advisors face. There are potential private and social benefits to be gained from better farm level decision making and this is an important goal for policy and research.

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Appendix I. Descriptive statistics for the winter wheat

Winter wheat crop variable	Mean	Median	Standard deviation	Standard error of mean	Skewness	Kurtosis
Yield (t/ha)	7.811	7.887	1.611	0.0193	-0.441	0.691
Area	82.92	47.23	118.7	1.424	4.958	42.04
Gross Margin (£/ha)	724	691.5	316.9	3.801	0.451	0.312
Economic output (/ha)	1,056	1,026	324.7	3.896	0.317	-0.169
Bye-products (£/ha)	74.68	51.13	95.38	1.144	4.809	65.11
log10 Economic output (/ha)	3.009	3.02	0.141	0.00191	-0.745	1.562
Fertilizers (£/ha)	160.7	146.1	75.74	0.909	0.927	1.562
Crop protection (£/ha)	153.9	150.6	52.79	0.633	0.767	5.347
Seeds (£/ha)	59.9	55.75	26.79	0.321	3.447	47.9
Other crop costs (£/ha)	26.5	11.36	42.05	0.504	3.051	12.69
Contract costs (£/ha)	89.94	36.13	124.8	1.498	2.407	10.58
log10 Ferts	2.148	2.173	0.353	0.00479	-6.097	51.7
log10 Protects	2.165	2.183	0.211	0.00286	-7.792	110.8
log10 Seeds	1.74	1.747	0.197	0.00267	-2.919	35.39
log10 Other costs	0.774	1.069	1.015	0.0137	-0.748	-0.644
Betw farms: Ferts	160.7	157.9	52.98	0.636	0.351	2.443
Betw: Crop protection	153.9	152	40.43	0.485	0.0291	1.367
Betw farms: Seeds	59.9	57.63	18.94	0.227	6.142	160.1
Betw: Other costs	26.5	14.58	34.3	0.412	2.408	6.554
Betw: Contract costs	89.94	42.38	111.7	1.341	2.106	9.618
w/i farms: Ferts	0	-1.475	54.13	0.649	0.751	2.153
w/i farms: Protects	0	0	33.94	0.407	1.3	17.92
w/i farms: Seeds	0	-0.15	18.95	0.227	1.691	17.06
w/i farms: Other crop costs	0	-0.152	24.31	0.292	2.408	28.81
w/i farms: Contract costs	0	-0.308	55.66	0.668	1.17	18.65
Weight all	32.9	29.38	20.91	0.251	1.771	6.8

Source: Farm Business Survey (Defra 2015) Notes: Production is in tonnes per hectare sown, others in £/hectare (or base 10 logarithms - where specified). n=6,948. Inputs are per hectare figures, for all variation. "Betw" are between farms variation in mean farm spending. "w/i" are individual farms' deviations from individual farm means ("within farm" variation).

Appendix II. Descriptive statistics for the winter oilseed rape (wosr)

Oilseed rape crop variable	Mean	Median	Standard deviation	Standard error of mean	Skewness	Kurtosis
Yield (t/ha)	3.415	3.48	0.847	0.0144	-0.232	1.517
Area	51.05	33.15	55.84	0.951	3.174	14.24
Gross Margin (£/ha)	620.2	570.4	368.1	6.268	0.514	0.626
Economic output (/ha)	1019	965	398.9	6.793	0.536	-0.0902
Bye-products (£/ha)	4.495	0	18.71	0.318	5.607	38.47
Fertilizers (£/ha)	178.5	161.3	79.39	1.352	1.558	8.539
Crop protection (£/ha)	151.5	143.6	58.05	0.988	0.93	2.507
Seeds (£/ha)	49.04	46.29	28.31	0.482	6.585	125
Other crop costs (£/ha)	21.58	13.14	28.23	0.481	4.003	41.32
Betw farms: Ferts	178.4	175.2	54.18	0.922	0.915	4.944
Betw: Crop protection	151.4	146.4	44.15	0.751	0.761	2.12
Betw farms: Seeds	49.03	47.21	20.94	0.356	11.48	368.3
Betw: Other crop costs	21.59	15.75	21.99	0.374	2.234	8.442
w/i farms: Ferts	0.05	-0.773	58.06	0.989	1.45	13.53
w/i farms: Protects	0.0	0	37.72	0.642	0.239	3.123
w/i farms: Seeds	0.0	-0.311	19.06	0.325	3.022	31.29
w/i farms: Other costs	0.0	-0.081	17.67	0.301	2.672	60.81
Weight all	33.15	30.14	19.5	0.351	2.03	8.516

Source: Farm Business Survey (Defra 2015). Notes: Production is in tonnes per hectare sown (t/ha), Area is in hectares (ha), others in £/hectare. n=3,449. Inputs are per hectare figures, for all variation. ''Betw'' are between farms variation in mean farm spending. ''w/i'' are individual farms' deviations from individual farm means (''within farms'' variation).

REFEREED ARTICLE

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Envisaging future New Zealand dairy farm systems: A scenario analysis approach

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ABSTRACT

Designing future farming systems which are resilient in an increasingly volatile and uncertain environment can be challenging. Scenario planning to inform farm systems design can help address this challenge. In the first phase of this wider scenario planning project, three distinct future world scenarios were developed. In this second phase of the scenario planning project, dairy farm systems for these future scenarios were developed over two workshops: a farmer workshop followed by an industry workshop where participants used mental models to conceptualise the future farm systems for each scenario. In general, the farm systems were most diverse under the consumer-driven Consumer is King (CK) scenario, and least diverse under the Government Dictates (GD) scenario (political chaos with trade dictated by governments). There was considerable overlap between farm systems under the CK and the highly regulatory Regulation Rules (RR) scenarios, but very little farm system overlap between the GD scenario and the other two scenarios. These future farm systems descriptions will play an important role in informing the quantitative modelling phase of this project. The approaches used to identify and describe the conceptual future farm systems were considered to be effective.

KEYWORDS: farm management; dairying; New Zealand; scenario analysis; mental models; World Café

1. Introduction

Farm businesses are complex and operate in increasingly volatile business and natural environments. Farm business owners' and managers' goals and objectives, and the resources available to the business, also evolve over time in response to changing business environments and social norms, and the development of new technologies and knowledge. What is certain is that farm systems will be adapted in future, and will differ from those of today. However, it is uncertain what these future farm systems will be.

Predicting or designing future farming systems which are resilient in an increasingly volatile and uncertain environment can be challenging. Farm systems modelling approaches often extrapolate the future from the current situation, however, this approach is relatively simplistic and not necessarily realistic given the uncertainty and volatility inherent in the industry. A scenario analysis approach (Schoemaker, 1993; 1995), which was developed by Shell to help with their strategic planning because of the inherent future uncertainty (Cornelius, Van de Putte and Romani, 2005), is useful where there is considerable volatility and uncertainty. This approach has been used in an agricultural context both overseas (Demeter, *et al.*, 2009; Forum for the Future, 2012; Dairy Australia, 2013) and in New Zealand (Parminter, Nolan and Bodeker, 2003).

The Centre of Excellence in Farm Business Management (CEFBM) used this approach in their Dairy Farm Systems for the Future project to design and evaluate possible future New Zealand dairy farm systems in 2025 to 2030; and in the process informing farmers, industry and researchers; developing a rigorous approach for evaluating farming systems; and building capability and collaboration in farm system design and analysis, all of which are CEFBM goals.

This research had three phases. In the first phase, scenario analysis was used to develop three possible, plausible futures that dairying operated under, plus a base scenario extrapolated from the present dairy farm business environment. Since most of New Zealand's dairy products are exported, a global perspective was taken. The three scenarios arrived at were: 'Consumer is King' (CK) in which a wide range of dairy products are produced in direct response to consumer demand, 'Regulation Rules' (RR) in which there are considerably greater regulatory requirements on dairy farm businesses,

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and 'Government Dictates' (GD) in which commodity dairy products are produced for a World where global chaos exists and trade is dictated by governments and international organisations. While the scenarios developed were extreme in some aspects, future reality is likely to have aspects of all three scenarios. These scenarios are reported in Shadbolt, *et al*. (2015) and shown in Figure 1.

In the second phase of the project, farmer and industry workshops were held in the Canterbury and Manawatu regions of New Zealand to develop conceptual models of possible farm systems for each region, for each of the scenarios. The diverse dairy industry scenarios resulted in a range of possible, plausible future farm systems being developed in this farm systems description phase. The final project phase will extend these conceptual models, then develop quantitative models to explore farm systems performance and resilience, including across scenarios.

This paper comments on the workshop process, and compares and contrasts the Manawatu farm systems for the three futuristic farm systems scenarios that were developed.

2. Method

Two one-day workshops were held at Massey University (in the Manawatu) mid-2015 to develop future farming systems for the futuristic scenarios described above. The farmer workshop was attended by ten experienced dairy farmers with diverse systems, who were well-informed on dairy farm systems and industry dynamics. Farmers were selected to design the initial future farm systems because they are accustomed to thinking systemically and holistically about farm systems in managing their farming businesses.Cognitive mapping and group model building were used to scope up possible farming system(s) for each scenario.

This workshop was followed by an industry workshop attended by twenty-four industry stakeholders and academics from a range of backgrounds with expertise in various aspects of dairy farm systems. A World Café process was employed in this workshop to critique and extend the farm systems, and describe the system interrelationships within the dairy industry. The academics on the research team and some farmers from the farmer workshop attended, enabling group discussions to link back to the thinking at the farmer workshop.

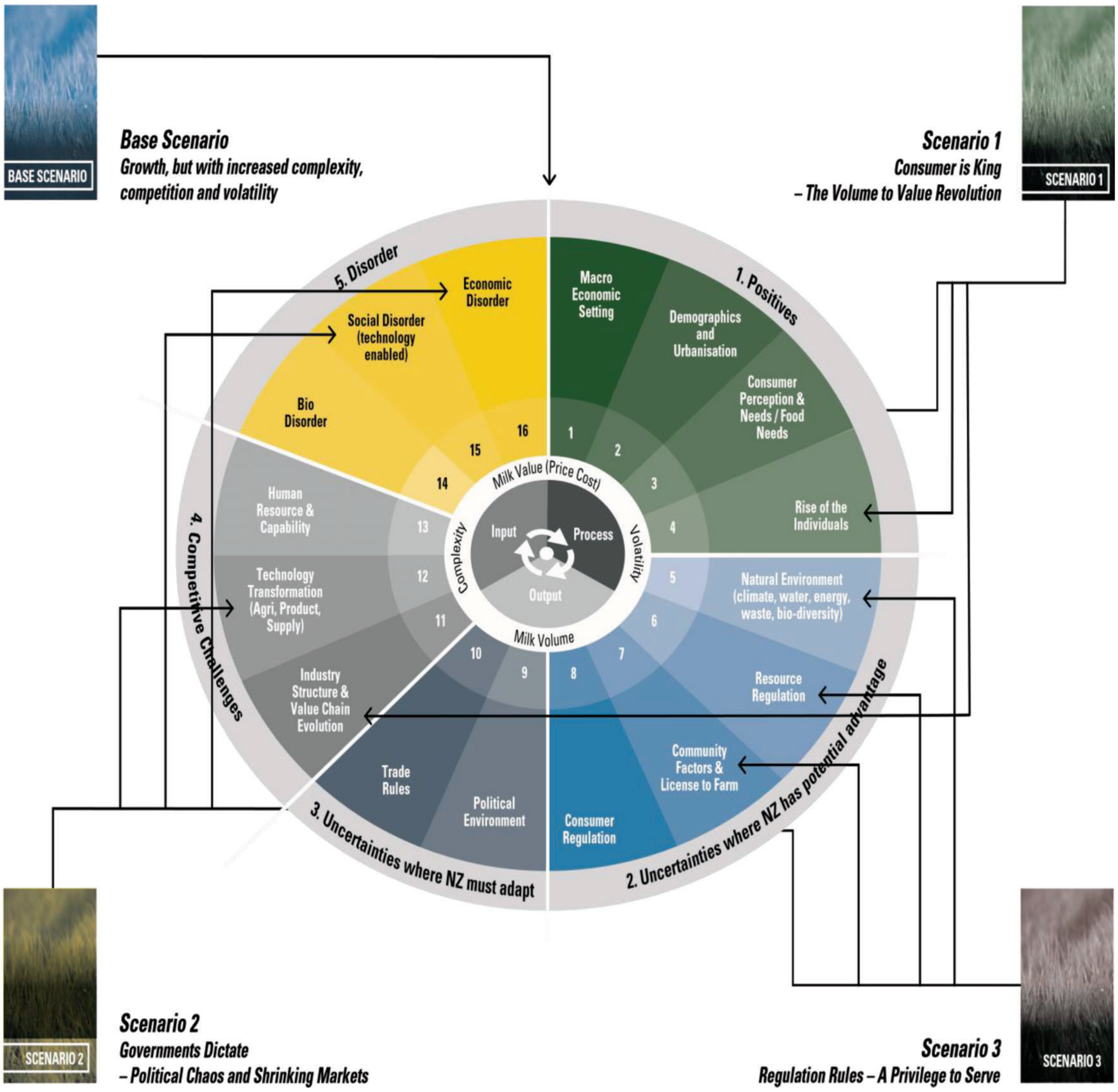

Figure 1: Futuristic dairy industry scenarios developed in the first phase of the project. Adapted from Shadbolt, *et al*. (2015).

Table 1: Massey University Number 1 Dairy Farm description

	Massey Farm	Manawatu Region
System Overview	142.7 ha, 118 ha effective. 2.2 cows/ha (low input farm). 65 paddocks with race access. Farm on bank of Manawatu river. 25% farm irrigated, Flat contour. Free draining alluvial soils, fertile, prone to summer drought. University-owned farm with manager.	141 ha effective. 2.74 cows/ha. 78% dairy farms owner-operated including managed farms, (NZ 70%). 22% farms with sharemilkers. Most farms family owned. Some equity partnerships and corporates.
Animal Production System	256 cows. 70 Friesian (F), 57 Jersey (J), 129 FxJ. Seasonal production, calve in spring (late-July, dry off end of May). 240 days in milk. Once-a-day milking. 2014-2015 season: 90,842 kgMS, 774 kgMS/ha, 354.9 kgMS/cow.	385 cows. 35.4% FxJ, 45.2% Friesian, 11% Jersey, 8.4% other. Just over 50% herds have 100 to 349 cows. 29% have 500+ cows, 12% 750+ cows, 5% 1000+ cows. Majority of NZ farms are seasonal production and twice-a-day milking. 1076 kgMS/ha, 393 kgMS/cow.
Pastures and Feed System	Low input, pasture-based system. Production System 1[3]: self-contained, no purchased supplement. 76 ha ryegrass and clover mix, 10 ha herb-legume mix, 10 ha lucerne, 12 ha summer crop (10T DM/ha). Pasture production 14,146 kg DM/ha (35% spring, 27% summer, 22% autumn, 16% winter).	Most farms run Production Systems 2 to 4 i.e. 4% to 30% purchased feed for milking area and dry cow grazing. Only 5-10% owner-operator farms are System 1.
Technology	24 aside herringbone shed with Westfalia metatrons. 200-cow concrete feed pad. 3-bay calf shed, office, storage room, teaching room. Farm effluent system planned: in 2015 used PN city effluent system.	Predominantly herringbone sheds, with some farms having rotary sheds. Commercial dairy farms have their own farm effluent systems.
People	Employs a manager and a relief milker.	Labour efficiency (peak cows milked per FTE) for NZ is 144. 137 for the North Island, 133 for the lower NI.

The workshops required participants to share their mental models of these future farm systems i.e. cognitive mapping. People use mental models to reflect on their situation, make decisions to behave in certain ways, and consider new experiences and information and store the concepts that are personally salient (Jones, *et al.*, 2011). The process developed for the workshops elicited and consolidated mental models to link peoples' values and management practices to farming outcomes in particular hypothetical situations (Jones, *et al.*, 2011). Individual mental models were submitted to others in small groups and used to build group mental models elicited from the knowledge and experience that the various group members could bring to a situation (Cooke, *et al.*, 2000).[3]

The group model building process used built on the system dynamics approaches pioneered by Vennix (1996), taking individuals' cognitive maps which are not yet well-defined, and consolidating these into substantive interactive systems although these remained qualitative (Forrester, 1975). The group model building process assisted with achieving consensus and aligning mental models so that they can be further applied in problem solving, testing hypotheses and designing simulation software (Andersen, Richardson and Vennix, 1997).

[3] DairyNZ production system category based on level of imported feed for the milking area/ milking herd, including dry cows. System 1 (no imported feed inputs) to System 5 (at last 30% feed imported year around).

Kearney and Kaplan (1997, p. 592) observed that methods for developing cognitive maps from mental models can be constrained by: individual participants' abilities to focus on mental objects and concepts relevant to the presented situation, the concepts contribution to the situation and relationships between concepts; and the efficacy of the group process. To manage these constraints: participants invited were well-informed and expert in their fields; an experienced facilitator helped plan the workshops; techniques suited to eliciting information in a group situation were used; someone in each breakout group understood the rationale and thinking behind the previous project activities and outcomes (i.e. a project team member and/or farmer who attended the farmer workshop); and a World Café process (Brown and Isaacs, 2008) was used in the industry workshop to generate discussion and creativity. This technique is an informal conversational process for groups (Brown and Isaacs, 2008), which Fouche and Light (2010) evaluated and found to be effective for exchanging ideas and information, encouraging creativity through collective discovery and collaborative learning and knowledge creation, and can also be a powerful data collection technique.

Massey University dairy farm description (base farm)

The Massey University No. 1 Dairy Farm was selected to represent a current Manawatu dairy farm as a benchmark in developing scenario farm systems in the workshops.

This farm, which had some atypical attributes, was considered as the base case or status quo farm with respect to its more generic attributes, rather than specifically. Table 1 describes the base farm as at 2015, with some statistics (Massey University, 2015). Information from industry sources for dairy farms in the region at that time (2015) is also provided to provide context (DairyNZ, 2016; LIC and DairyNZ, 2015), particularly where the Massey farm is atypical. Milk price in New Zealand is highly volatile, and in 2014/2015 was low, averaging NZ$4.69[4] per kg milksolids[5] (MS) in 2015 values.

Farmer workshop

The Manawatu farmer workshop was attended by 10 farmers who were pre-allocated to one of three groups, sent information on a futuristic scenario, and asked to consider possible future dairy farm systems for their scenario. A description of the current 'base case' or status quo Massey University dairy farm was provided to farmers (Massey University, 2015), and revisited by the group at the beginning of the workshop to set the scene. Farmers were then asked to work together in their groups to consider their future scenario, and using post-it notes®, to write down the ideas, objects and concepts that could be part of an adapted farm system which could operate viably for their scenario in 2025 to 2030. An academic who had worked on the scenario analysis phase was present with each group to help facilitate, make notes, and explain background as required. The workshop facilitator circulated around the groups. These sessions were recorded.

Farmers were asked for ideas about on-farm production activities, resources, technologies and human capabilities that they expected would be required for their system. Then each group worked together to connect their concepts together into a diagram showing hierarchical dependencies and inter-relationships for their primary system. In addition, they described how the farm system linked to the market and wider industry customers. In doing so, they were asked to consider internal consistency i.e. whether two ideas could co-exist in a system. In the CK and RR groups, farmers could not agree on a single system, so two possible systems differing in size were developed.

At the end of the day, each group presented their dairy farm system and the wider group had the opportunity to provide additional input. This session was video recorded, with the recording later transcribed. The systems for each scenario were written up in table format by theme, and in a narrative form.

Industry workshop

The industry workshop was held a week later and attended by 24 participants (4 dairy farmers from the farmer workshop, 12 academics from different disciplines plus the project team, and 8 dairy industry stakeholders e.g. farm consultants, DairyNZ[6], Landcorp Farming[7] and Fonterra[8] representatives). These participants each had their own strengths: farmers and consultants had a strong understanding of farm systems; academics could offer possibilities particularly in their disciplines, and industry people could identify possibilities from a broader perspective and identify farm and industry interactions required to achieve these. Participants worked in groups of four participants from different backgrounds, with groups moving between the three scenarios. Numbers were sufficient for 6 groups, so two rooms, each with the three scenarios set out were used.

A description of one of each of the farmer-developed farm systems along with some scenario background was provided at each of the three group tables in the room. The system description was in the format of a large table (2xA3 sheets) on flip-chart paper. A narrative of the system and a table summary of all three industry scenarios were available for reference. For each system, groups were asked to provide critical comment, and suggest improvements or new ideas, and supporting services, R&D and technology needed to make this work. Post-it notes® on flip-chart-paper were used to add ideas to the farm system with lines drawn to link ideas. Groups contributed to the systems for all scenarios, spending 40 minutes on each scenario. When moving to the next system, one group member remained behind to link information between groups, sharing and explaining ideas from those who had previously contributed to the system and answering queries (World Café approach).

After lunch, participants had a free hour to consider the systems, adding individual ideas on post-it notes and suggesting new ideas for farm systems. At the workshop conclusion, the last group working with each system scenario presented the final dairy farm system version with research, information, systems and services needed to all participants, followed by group discussion adding further input, ideas and feedback on each dairy farm system. This session was recorded. Results were written up as previously described.

3. Results and Discussion

The farm systems are first compared with an overview of the key points, followed by a description of each of the three systems. The effectiveness of the method is then discussed.

Farm systems comparison

A comparison of the conceptualised farm systems under the three scenarios which integrates farmer and industry feedback is shown in Table 2. There is considerable overlap between the CK and RR systems with respect to the features and attributes of the farm system. In contrast, the GD system features have little commonality with the other two scenario systems. Farm systems are most diverse under the CK scenario, and least diverse under the GD scenario.

There is greater diversity in the animal production system in terms of cow numbers, breed type, production volume and other factors within the CK scenario, followed by the RR scenario. In contrast, the animal production system is largely homogenous under the GD scenario, with a lower milk price driving significant increases in farm size, cow numbers, pasture production (based on GM technology) and milk production, and a

[4] At the time of writing (December 2017), $NZ1 was approximately equivalent to £0.52, €0.59 and $US0.70.

[5] Milksolids (MS) = milkfat plus protein. In NZ, payment is made on these components less a volume charge.

[6] DairyNZ is an industry-good dairy farming R, D and E organisation funded by NZ dairy farmer levies.

[7] Landcorp Farming Ltd is NZ's state-owned farming company and largest farmer with over 141 farms owned and leased. Over 78,000 cows are milked on Landcorp dairy farms.

[8] Fonterra Co-operative Group Ltd, NZ's largest dairy company, is a farmer-owned cooperative supplied by about 85% of NZ dairy farmers.

Table 2: Farm systems description – A comparative view across scenarios

	Consumer is King	Government Dictates	Regulation Rules
System Overview	Farm size polarized, highly flexible and diverse systems, highly automated, diverse ownership structures, significantly increased production costs.	Large farms with high stocking rates, some horizontal integration with beef, high automation, largely corporate-owned or equity partnerships, decreased production costs.	Large farms with low stocking rates in designated dairying areas, highly automated, range of ownership structures, increased production costs.
Animal Production System	May not be seasonal, significant decrease in milk production, focus on milk quality/type, range of cow breeds, close monitoring of animal health and welfare.	Seasonal system, significant increase in milk production, crossbred cows, less importance on animal health and welfare.	Seasonal system, slight decrease in milk production, cows clean and good condition, strong focus on animal health and welfare, no bobby calves, close monitoring.
Pastures and Feed System	Grass-based system (promoted as NZ attribute), may be very specialised feeding systems e.g. feeds to give special attributes to milk, targeted use of nutrients.	Grass-based system with imported grain supplements, high yielding GM pastures, fully irrigated with on-farm water storage, pastures and soils absorb 100% of nutrients applied.	Grass-based system with maize and grain supplements, significant irrigation and drainage investment, water and fertiliser use tightly regulated.
Technology	Significant use of technology and data, complete automation at farm level, technology leasing and IP licencing common.	Increased use of technology and data e.g. drones, robotic milk systems, precision agriculture.	Intensive use of technology and data e.g. drones, robotic milking systems, precision agriculture.
People	Highly educated and trained, technology-savvy staff. Specialist roles on large farms. Public relations function critical to communicate with customers. Good working conditions.	Well trained staff: one highly educated and trained manager, three technology-savvy assistant managers with good farm management skills.	Highly trained, well educated, technology-savvy staff with specialised roles. Specialist administrator for environmental issues, compliance and PR. Staff well treated e.g. 40 hour week.
Auditing for Compliance and Market Guarantees	Significant contractual obligations, strong monitoring and third party auditing for markets and regulation.	Not very important	Strong monitoring systems with tight management control, regular third party audits.

focus on keeping costs low, to increase efficiencies. In contrast, more stringent regulation has resulted in lower cow numbers and stocking rates in the RR scenario. Farm size and cow numbers are variable but tend to be polarised under the CK scenario.

Pasture-based systems are an underlying feature of all three scenarios, but the feed systems and their drivers differ between scenarios: consumer expectations are the drivers for the CK scenario, cost and efficiency the driver for the GD scenario, and regulation the driver for the RR scenario (Table 2). GD and RR systems remain seasonal, however many CK supply chains have changed from seasonal to year-round supply to meet market demand and for greater system flexibility. While milk production per hectare has increased significantly in the GD scenario, this has decreased in the CK and RR scenarios. In the CK scenario, this is primarily due to higher margins and a resulting shift in focus from volume to value. In the RR scenario, greater constraints imposed on the farm systems, specifically around feed supply (water, fertiliser and supplement limits) and cow numbers, restrict production.

Stringent standards and greater compliance needs have caused production costs to increase under the CK and RR scenarios, whereas less regulation and compliance, and a strong focus on keeping costs low because of low milk prices in the GD scenario has meant production costs have decreased. Strong standards imposed by the market (consumers) and regulators (government), and the need to provide credible proof that the standards are being adhered to, mean auditing for compliance and market guarantees is significant in the CK and RR scenarios. A lowering of standards and fewer compliance requirements has meant auditing and compliance are not important features under the GD scenario.

There is increased use of on-farm technology across scenarios, with the use of drones, automatic milking systems, and precision agriculture technologies being common in all scenarios, but highest in the CK scenario where IP licencing and technology leasing occur. Staff are well educated and trained in all the scenarios, but the skills required and levels vary, with demands of both the CK scenario and RR scenario being much higher, requiring more specialist staff, than the GD scenario. CK staff have particular expertise in public relations and communications, and RR staff specialise in managing environmental issues and compliance.

Consumer is King scenario – Volume to value revolution

The defining feature of this system is its flexibility to adapt and deliver to changing international customer needs – or 'dancing with change' as one workshop participant aptly described it. The participants at both workshops agreed that a spectrum of farm system types is likely under this scenario due to the diversity of quite specific products and attributes required to meet customer requirements. Some farms are organised as clusters producing specific milk types for the production of specific milk products, hence farm systems within a cluster are similar. Each cluster is operating in an independent and identity preserved value chain, delivering to a distinct high value niche market. Some farms run split systems, and are part of more than one value chain. There is still a market for non-specific milk in which surplus or non-conforming milk can be supplied, although returns are lower.

Economies of size are less important than previously, since farmers have traded volume for value. Across farm types, productivity in terms of milksolids production per cow and per hectare has decreased or remained constant, with the focus being on milk quality or milk attributes. However, MS returns per kilogram have increased considerably. Average farm size (in terms of hectares and cows) has decreased in many cases, however farm size is variable and tends to be polarised. Small farms with 50 to 100 cows supplying high value milk (e.g. with nutraceutical applications) co-exist with larger farms, some of which produce milk for less specialised products. Smaller farms are predominantly owner-operated, with the owner having a high level of control over milk or product quality which is critical in these supply chains. Larger farms producing specialised milk rely on considerable automation to ensure milk quality and other customer specifications are met, hence economies of scale and size are important here. These larger, highly-automated farms often have multiple owners or are equity partnerships, with highly skilled management and employees.

Greater engagement between farmers and consumers has resulted in contracts between farmers and consumers, resulting in groups of consumers investing in farms. Another feature is other supply chain players (i.e. processors, owners of inputs or product/brand IP) share in the on-farm investment, reducing the capital investment required by farmers. This is frequently in the form of a 'toll-processor' who contracts a cluster of farmers, controls what goes in and out of the farming system and specifies production methods to meet market requirements for specialist products.

Often, specific product attributes desired by the consumer are obtained from cow-specific traits or as a result of specific feeding and management regimes, or a combination thereof. This has made genetics and feeding of cows more complex, with farms operating within a value-chain having similar cow genetics or feeding regimes to produce milk with specific attributes desired by the consumer. In some situations, the unique genetics required means stock replacements are bred on specialist breeding farms and supplied as an input.

Farms are largely pasture-based, with irrigation systems in place. Supplements fed, or nutrients used, can affect milk attributes and are implemented to influence the end product being made. Animal health and welfare are a top priority, and cows are in good condition throughout. Intense quality assurance systems to validate product attributes and system claims, along with robust traceability mechanisms are the norm. With significant shrinking of barriers between consumer and farmer, the farm is more visible and exposed. Farmers are proactive on social media and other platforms to remain relevant to their customers. Consequently, people on farms require good communication and public relations skills, in addition to farming skills.

There is significant uptake and adoption of technology at the farm level and this happens along two dimensions: technologies that improve efficiency in feed, pasture and stock management, and monitoring, information management and communication technologies such as various measurement and surveillance tools, including monitoring devices such as on-farm webcams which customers can access. Almost all farms use drones, robotic milking systems, precision agriculture tools and other technologies still currently under development. Data is a core feature of the farm system and integral to decision making, as well as a tool for monitoring and validation of claims. The greater returns generated compensate for the increased costs e.g. labour, compliance, capital. The big risk that farms face is the increasing fickleness of consumers affecting demand for their specialised milk or milk products.

Government Dictates scenario – Political chaos and shrinking markets

The most likely farm system under this scenario was identified as being a large farm of around 260 hectares, having around 1,200 cows and stocked at a high rate of 4.6 cows/ha. Being efficiency driven and subject to less regulation, both cows and pastures are genetically modified. Pastures produce around 25 tonnes DM/ha, and the resulting milk yield is close to 2,200 kgMS/ha. To support this high level of production, most farms are fully irrigated, and precision agriculture ensures efficient and balanced use of fertiliser and related inputs. This has controlled nitrogen leaching to a large extent, and created a carbon-dioxide sink as well. However, grazing of pasture is not as viable as it was previously due to soil damage risk from high stocking rates, and some farms have adopted a cut and carry model. As a result, cropping science and related technology (e.g. harvesting) have become important.

Farms operate either as independent farms, or as part of a larger collective with individual large farms being nested within a larger structure of farms. Farms are either family owned (some with domestic or international equity partners), or corporate owned. Farms are also more horizontally and vertically integrated than before. There has been horizontal integration into beef operations, i.e. dairy farmers operating a beef operation in parallel to their dairy operation to raise surplus calves from the dairy farms. Vertical integration has been downstream with some very large farm businesses or groups of large farm businesses owning processing assets.

For efficiency on the large dairy farms, farm systems operate to a pre-defined set of rules or a 'recipe', with decisions and problems being solved by staff within the scope of this recipe. Each farm is managed by no more than 4 employees, typically consisting of 1 manager and 3 assistant managers, all of whom are highly qualified, and work no more than 40 hours per week. Staff are good problem solvers and have diverse yet complementary skills such as agriculture, IT and engineering. Although traditional skills such as pasture management and stockmanship are still relevant, much of the focus is on more soft analytical work. Farm consultants are still relevant and possess diverse skills.

There is extensive adoption of on-farm technologies (e.g. drones, satellites, milking systems) and farms are highly automated. Milking systems are largely robotic on a rotary platform, but small mobile automated milking machines are also used. Milking frequency is variable, ranging from once- to thrice-a day. Micro-management of herds is common with cows grouped into smaller herds. The predominant breed is kiwi-cross (Friesian x Jersey), but genetic modification has also led to cows with other genetics producing more concentrated milk resulting in lower transportation costs.

Although regulation is not a constraint, the focus on efficiency has generated positive environmental benefits. On the energy front, farmers are able to meet 100% of their energy needs from on-farm renewable energy systems, and sometimes produce a surplus to requirement which is sold. Finally, the dairy industry has a single large dairy processor which could be a co-operative, private investor-owned firm or a state-owned enterprise.

Regulation Rules scenario – A privilege to serve

Under this scenario, significant regulatory limits have been set which farms need to operate within. This has meant most of the farms struggling to comply and remain viable have exited the industry. Regulation has ensured dairying is restricted to designated dairying areas, and there are limits on stocking rate set at about 2 cows/ha. Due to the stringent guidelines and 'boundaries' to farming practices set by regulation, there is less flexibility on how the farm system can operate.

Due to the need for strong monitoring and control mechanisms, farms are polarised into smaller farms with tighter management control, and larger farms with high automation and/or specialist compliance staff. Typically, farm sizes are about 300 cows at the lower end and 800 cows at the higher end. But in general, most farms are at the larger end due to intensification of capital, increasing costs and constraints from regulation.

There is a decrease is MS production per hectare due to the constraints imposed. In parallel, there is a significant increase in production costs, mainly due to the costs of support services such as certification, science and technology R&D, third party audits, and increased costs of animal welfare, food safety and environmental compliance. Farm ownership is diverse, and includes family ownership, equity partnerships, overseas investment, and joint ventures. However, the need for more capital on farm (with equity as a source of capital) has led to many farms being corporate owned.

Farms are almost entirely pasture-based, but also produce maize silage for 'inside' feeding, mainly to ensure pastures are not damaged by pugging, which is unacceptable. To mitigate any risk of damage to the soil and regional system, limits have been imposed on the amount of cropping that can be done. Feed inputs (quantity and feed types) are also regulated with unsustainable feeds such as palm kernel expeller being banned.

Although most farms are irrigated and nutrient application is permitted, there are extremely stringent limits such as a cap on nutrients, and low specified levels of leaching and water allocation per hectare allowed. All waterways are planted to avoid soil erosion and provide shade for stock. Farms also have to manage air pollution to contain unacceptable farming odours. There is a strong impetus on animal health and welfare. Cows look good, are clean, maintain excellent body condition throughout the season and are very healthy.

There is a decrease in labour and an increase in mechanisation. Farm staff are highly educated, especially in IT and environmental issues. Larger farms employ a specialist administrator to manage technology/data, compliance, PR and marketing, while smaller farms have grouped together forming a cooperative to employ a compliance manager, as well as invest in, and share, resources. It is mandatory to provide good working conditions and a healthy work environment for all staff. Retaining staff is important because of the investment in staff training, and to preserve local communities and contribute to the positive image of farming.

Technology use is intense with: drones to check on pasture, stock, effluent and water; robotic milking systems; and GPS and self-driven tractors. Good data is important as well, and is used for decision making and to support monitoring and compliance functions. This data is stored in the cloud and can be accessed from anywhere, including by third parties for compliance.

Farms are also using scientific techniques and on-farm R&D to inform, validate or disprove the rationale for the increased and changing regulation. A large segment of farms under this scenario are 'triple A' rated. These farms have chosen to deliver a product produced in a system which goes above and beyond regulatory requirements, reflecting a 'privilege to serve' attitude. These farms actively promote their 'triple A' status through professional PR and marketing and are successful in achieving comparatively higher returns as a result. Farms also maintain a high degree of connectivity, with both the community (e.g. 'adopt a cow'-programs, public access days) and with regulatory and political bodies (e.g. via Federated Farmers training on political involvement).

Method Evaluation

With research, there is a trade-off between cost and time required, and the ability to explore the research topic. In this research, we also had a small window of opportunity in terms of farmer availability e.g. while cows were dried off, just prior to next season's calving. Hence this work was completed with only two workshops. A third workshop to develop more system specifics would have been beneficial.

One challenge was to develop futuristic systems for the scenarios that were robust in terms of the systems, but were forward thinking. There can be a tendency for people to largely consider current and developing technologies and capabilities and apply these in a futuristic context, as opposed to re-thinking systems envisioning future technologies and capabilities. There was some tendency for this to occur. However, technologies take time to become commonplace, and the timeframe was such that known technologies currently under development require some time to become commonplace so systems were not unrealistic. External factors were largely predetermined by the scenarios.

To develop robust systems, the first workshop was with farmers accustomed to considering farming systems from a systemic viewpoint. Farmers only worked on one scenario and devoted most of the workshop to this.

Pre-allocating farmers to a scenario enabled information on that scenario to be provided in advance. Most farmers had read the material and some farmers had obviously thought about possible systems e.g. turned up with notes. Unfortunately some farmers were unable to attend at short notice, so one farmer worked on a scenario with no prior information. More time than anticipated was required at the beginning of the workshop for groups to discuss their futuristic scenario, with some challenging the scenarios, but once the scenario was established the farmers turned their attention to possible systems.

Participants invited to both workshops were selected on their forward thinking, knowledge of the industry, and future possibilities. Participants at the industry workshop came from various backgrounds and were allocated to groups to create a mix of knowledge and roles. For both workshops, groups were planned to minimise the influence of dominant personalities i.e. stronger personalities together. Most groups worked well due to the manageable group size and mix, however, there were instances where one or two group members dominated and quieter members did not contribute to the extent they could have. Better knowledge of individuals' strengths and personalities in assigning them to groups would have been helpful, but is not always possible, and excluding people would not be productive since they all had expertise to offer and were willing to attend. A trained facilitator for each group could have helped but accessing expertise and extra cost prohibit this possibility.

The short timeframe between the two workshops meant there was no opportunity to write up the farmer workshop and get the information to participants in advance. Few participants read the reading materials supplied at the workshop. More time between workshops would have allowed some reading material to be provided in advance, but limited the availability of some key participants. The 40 minutes of time allocated for each group to discuss and add to a scenario system at the industry workshop was insufficient for some groups because of the time required to understand the future scenarios and farmer developed farm systems. However, providing a session for extra individual contributions which most participated in, followed by a group session at the end allowed people to provide further ideas, and participate in further discussion and debate. Consequently, the impacts of a significant number of the challenges discussed were addressed in this way.

Ideally, it would have been advantageous to have had accessible on-line sharing and wider farmer feedback post-workshop to further develop the systems for those interested as had been planned: there was interest expressed in this. This may have prompted further development of systems as people responded to others' comments and ideas are reflected on. However, suitable technology for this was not readily available at the time.

4. Conclusions

It was identified that the future farm system would be most diverse under the CK scenario and least diverse under the GD scenario. Moreover, farm systems under the CK and RR scenarios showed a fair degree of overlap, while there was very little overlap between the farm system under the GD scenario and the other two scenarios. From a systems design perspective, this suggests that it would be more feasible to adapt farm systems from CK to RR or vice-versa should the future business environment change, than it would be to adapt farm systems from GD to either of the other two scenarios.

The research demonstrated that a scenario planning process that involves developing team mental models can be a robust method to arrive at conceptual models of future farm systems specific to predetermined future scenarios. The conceptual farm systems models were developed to assist in designing future farm systems by informing the development of quantitative models that are needed to further explore farm systems performance and resilience, including across scenarios. In the next stage of this scenario planning project, it is expected that the commonality between systems, how well systems perform across scenarios, and the flexibility to adapt systems between future scenarios will be explored quantitatively.

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REFEREED ARTICLE

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How current environmental and weather conditions affect time critical decision making on Irish dairy farms

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ABSTRACT

In order to understand how current environmental conditions affect farmer decision making the levels of grass and soil condition are examined in the decision on when to turn cattle out from winter housing to spring grazing on Irish dairy farms. Five years of satellite derived Normalised Difference Vegetation Index MODIS data, as a proxy for grass growth data, were used along with daily rainfall data and turn out dates from 199 dairy farms. Using GIS analysis conditions at the time of turn out were determined at the date and location of the event. A panel analysis shows that farmers respond to early growth but not immediately, gaining three and half days extra grazing for every week that grass growth is early. The inertia in decision making around a preferred date was shown by using the previous year's turn out date in the model. We can accurately predict when turn out occurs with a RMSE of 10 days, compared to average on farm range of dates over the 2008-2012 period of 25 days.

KEYWORDS: NDVI; Remote Sensing; Panel Data; Herd Management; Rainfall

1. Introduction

The decision on when to release cattle from winter housing for daytime spring grazing is a critical one on Irish dairy farms which impacts on the length of time a herd are grazing and grazing season length affects farm profits, with research demonstrating that extending the grazing reduces costs (Kinsella *et al.*, 2010). In a survey of Irish Dairy farmers in 2008 Creighton *et al.* (2011) found the average grazing season length was 245 days and with respect to turn out dates fodder availability and soil condition were the main factors in the timing of the decision. Field trials have shown that early grazing options across a wide range of stocking densities improve animal and sward performance and are to be recommended in dairy systems (O'Donovan *et al.*, 2004). However the situation for specialist beef production in Ireland is not as clear, with work suggesting that the effect on profitability is only marginal and only for some types of beef production system (McGee *et al.*, 2014).

In order to understand why farmers do not engage in the management practices that would allow for a longer season, the issues around adoption of extended grazing have been examined by O'Shea *et al.* (2015) within the context of technical adoption theory. Survey results (207 respondents) were analysed as a binary probit model of adoption/non-adoption of extended grazing (defined relative to regional average). Agricultural education and off-farm employment had the most significant positive relationship with participating in extended grazing and past participation in agri-environment schemes had the strongest negative affect on the choice of extended grazing.

An ordinary least squares (OLS) analysis of one year (2009) of the data set presented in this paper, by Läpple *et al.* (2012), found that geographic region and soil status were strongly associated with length of grazing season but that farm size, stocking density or grazing method had no relationship with grazing season length.

Use of satellite data in observing grassland

Here we use daily satellite observations as proxy for grass growth. Remote Sensing, RS, optical satellite systems record reflected sunlight in different wavelength ranges from the earth's surface. The reflected light is determined by the landcover. In the case of vegetated surfaces, the amounts red and near infra-red light recorded in each pixel of the image are strongly related to the amount of biomass at the earth's surface represented by the pixel. Normalised Difference Vegetation Indices, *NDVI*, is the ratio of red and near infra red,

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NIR, light recorded at a pixel.

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad (1)$$

NDVI ranges from zero over area of no vegetation (bare rock, soil, cement *etc.*) up to one for 100% cover of well growing vegetation, like grass in Ireland in May. NDVI is one of dozens of vegetation indices developed over the last 30 years and their use in biomass monitoring is well developed (see Viña *et al*. (2011) for a current overview).In a managed grassland context in Ireland, NDVI has been used to detect spring time phenology events (O'Connor *et al*., 2012), directly estimate grass biomass levels (Ali *et al*., 2016) and predict stocking density (Green *et al*., 2016).

The use of RS derived data in a panel analysis (with or without a spatial component) is increasing as econometrics begins to draw on a new source of independent data that can, though GIS systems, be incorporated into traditional data models.

Aim of paper

In order to understand how current growth and weather influence the timing of major herd management decisions five years of geocoded farm level data recording when animals are first tuned out from winter housing along with contemporaneous satellite derived measures of fodder availability and local rainfall data (as a proxy for soil condition) are analysed. First the environmental conditions present when animals are turned out are characterised and then through a panel analysis those indicators that are most strongly associated with the decision to turn out are discovered.

This model is developed further as a random effects model with time large to predict when a farmer is likely to have turned out given spring conditions. The implications of the model with respect to farmer decision making are discussed.

2. Data sources

Dependent variable: Turn out date

The Teagasc National Farm Survey, NFS, (Hanrahan *et al*., 2014) is collected as part of the EU Farm Accountancy Data Network. It consists of a detailed set of accounts for approximately 900 farms statistically sampling for farm system. Between 2008 and 2012 specialist dairy farmers in the NFS ($\sim$300 farmers each survey) recorded turn out dates. This gave a total of 1536 recorded turn out events (to avoid issues around an unbalanced panel, we chose to use only farms with five complete years of data in the final analysis leaving us with a sample population of 199 farmers). The turn out date is transformed to Julian day of year, with January 1st as 1 etc. So an early turn out date is a low number and a late turn out date a high number.

The farms are linked to environmental variables via location and to achieve this the NFS was recently geocoded (Green and Donoghue, 2013) using address matching methods. To illustrate the geographic distribution, the average (over the five years) turn out date for the farms in this analysis is mapped in 10km tetrads in figure 1. We can see that farms in the south generally turn out earlier than farms in the north.

All recorded turn out dates, 2008-2012, are plotted to look at day of the week when turn out occurs (figure 2a), the day of the month (2b) and day of the year (2c).

There seems to be little bias in day of the week (figure 2a), perhaps a small drop at the weekend, but dairy farmers run a 7 day week operation, so for there to be no day of the week more likely than another when turn out occurs is unsurprising.

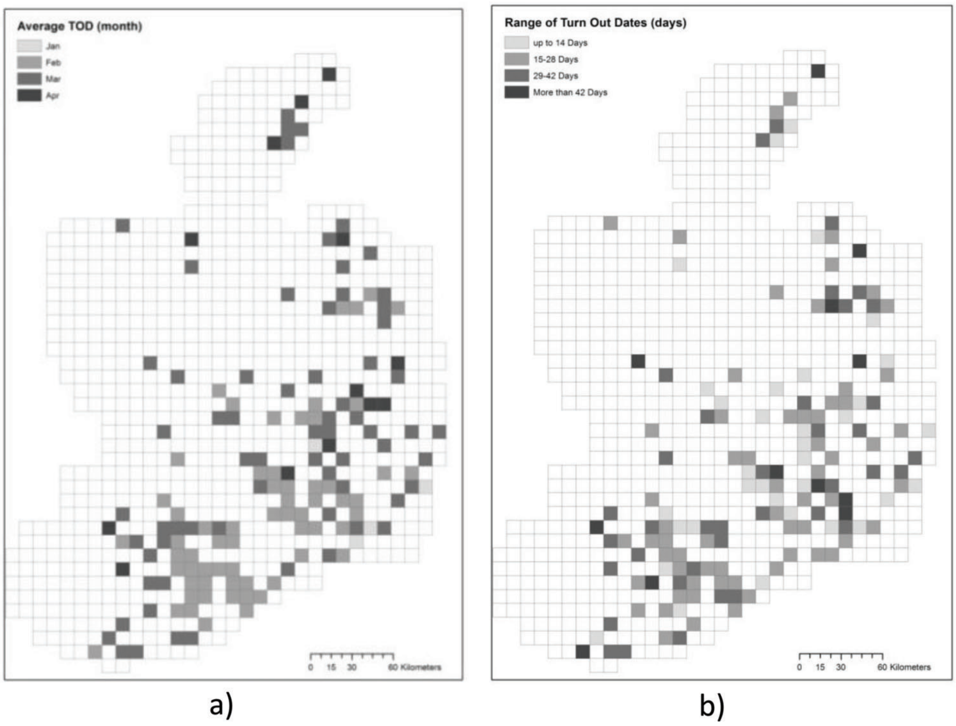

Figure 1: 10km tetrad distribution map of a) average turn out dates (TOD) of the dairy farms in our sample and TOD range over the period 2008-2012

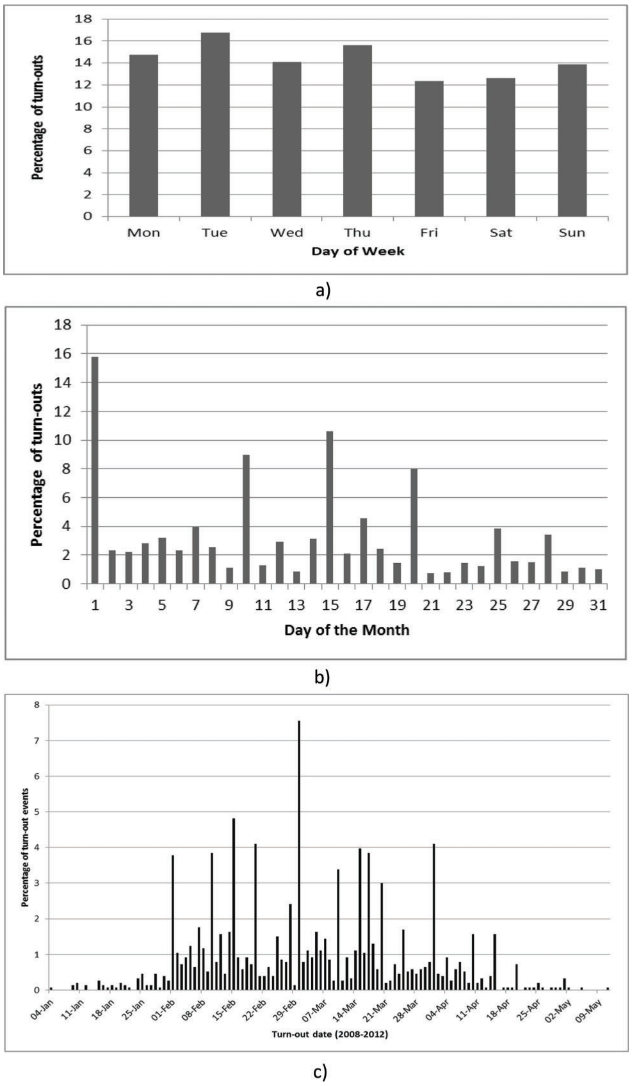

Figure 2: a) day of the week on which turn-out first occurs, b) day of the month on which turn-out first occurs, c) day of the year on which turn-out first occurs, 1536 turn out events, 2008-2012

There is a clear bias toward the 1st of the month when turning out, Figure 2b, this may be farmers responding to advice or defaulting to a habitual day.

Clearly there is no agronomic reason for the start of the month turn out but it must be acknowledged that this decision does not occur in a vacuum and having a fixed date, set in advance, may have personal advantages within a farm household that faces the myriad of competing demands of any other family home.

Figure 2c illustrates that March the 1st is the most favoured turn out day, with February 15th next and then thirdly March 17th, St. Patricks day. It is this apparent tendency for inertia around set calendar days that advice around extending the grazing season seeks to overcome.

Explanatory variables: Satellite observation of grass growth

The satellite data used were 16-day composites of MODIS Normalised Difference Vegetation Index, NDVI, imagery from the MODIS sensor on the Terra satellite (Huete *et al.*, 2002). The selected MOD13Q1 product provided detailed quality flags and Day of Year acquisition stamp for each 250m pixel (García-Mora *et al.*, 2011). Terra satellite records imagery over Ireland every second day, however the majority of these images are contaminated with cloud. In a composite product, the data are examined pixel by pixel across the composite period and the best quality pixel is identified and its value and day of acquisition, DOA, are recorded.

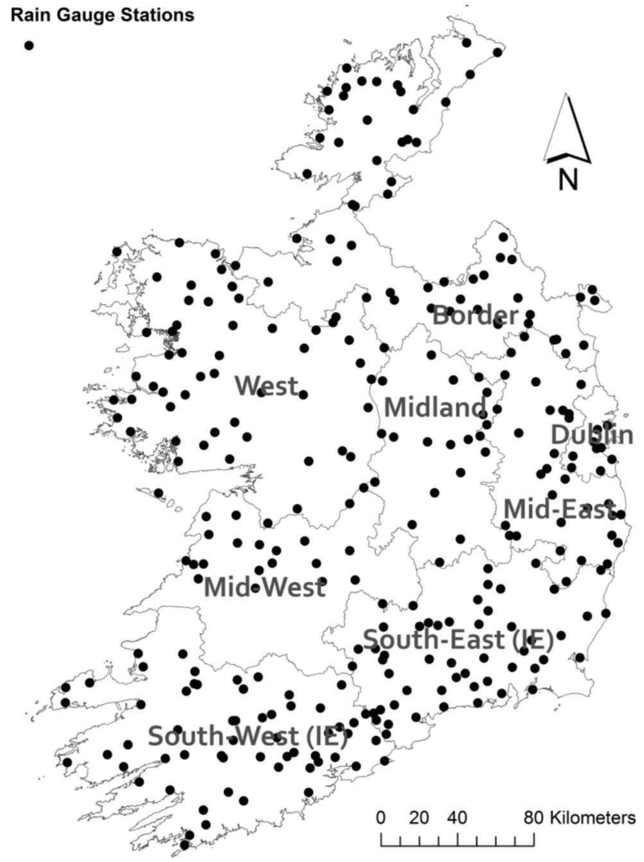

Figure 3: Distribution of rain gauge stations used in analysis

All 16-day composites for the period January 1- May 15 2008-2012 were used. Thus from Jan 1st to May 15th there are 9 Images each year. The farm locations in the study were overlaid on top of the images and the corresponding NDVI score extracted so each farm has 9 NDVI scores each year.

The average NDVI score for each year for each farm and the actual NDVI score at turn out for each farm was also calculated. It is important to note that the NDVI score is uncalibrated, it is related to grass cover amounts but is not a direct estimate of such. A typical NDVI trend for a farm will have NDVI increasing across spring as grass grows from dormancy, with an NDVI of 0.6, to maximum biomass production in mid May with NDVI $>$ 0.8, at the rate of 0.001 per week.

Explanatory data: Rainfall

Daily rainfall data from the national rain gauge network from Met Eireann was used (Walsh, 2012). The exact number of stations in the network varies from year to year but in this analysis (2008-2012) there were 550 stations of which 301 had complete records and were used in this analysis, see figure 3. Each farm in the sample set was ascribed the average of the daily rainfall recorded at the 3 stations closest to it (mean distance, farm to rain gauge, was 7.5km).

Field experiments in Ireland have shown that soil moisture deficit, SMD, is a predictor of soil damage through poaching (Piwowarczyk *et al.*, 2011). SMD is the interaction of weather and soil. As the soil remains the same over time it was assumed that SMD and thus trafficability would be strongly influenced by recent rainfall intensities. Therefor total rainfall (in mm) in the 16 day period before each satellite acquisition and the number of dry days in the period was calculated for each farm as proxies for SMD and trafficability conditions. The total rainfall in spring and the total number of dry days in spring were also calculated each for year for each farm. Table 1 list summarizes the variables used.

3. Methodology

The sample of farms is not a random one and was not designed to model the distribution of farm response to environmental conditions. The repeated measurements are not equivalent to treatments and are not controlled. It's unlikely our sample and variables capture all affects and any omitted covariate will cause a bias in estimating the effects of the covariates we have included. Using a fixed effects model allows us to control for all fixed differences between farms (location, size of farm, farmer education, soil type *etc.*) within the panel.

The fixed model looks at how variation in TOD (around the mean) changes in response to variation in NDVI and rainfall. In the fixed effect model the intercept is allowed to change between farms but the slope of the response is considered the same across each farm and is formulated as:

$$Y_{it} = \alpha_i + \beta_1 X_{it} + U_{it}$$

- Y_{it} is the dependent variable (TOD) where i = farm (i=1….199) and t = time (t=2008…2012)
- α_i is the intercept for each farm
- X_{it} represents one independent variable (NDVI or Rainfall)
- β_1 is the coefficient for that variable
- u_{it} is the error term.

It should be noted that this model assumes there are unobserved factors that influence TOD that are time invariant. A possible source of non-time-invariant factors could be severe weather in an autumn or policy/advice changes nationally – neither are considered to have occurred during 2008 -2012. A fixed effect linear panel analysis of the variation between years of TOD and environmental variables was carried out. The panel of 199 farms with 5 years of observations (995 observations in total) is balanced. The panel ID variable is Farm ID and the time variable is year (2008-2012). When examining the presence of a seasonal effect, then a year dummy is included.

The focus on inter-annual variation in TOD in response to changing environmental variables, as opposed to the causes of variation between farmers, indicated the use of a fixed effect model. This was confirmed by the application of a Hausmann test strongly suggesting the rejection of a random effects model (F test results

Table 1: Summary of variables used in analysis (Number of Observations 995)

Variable	Mean	Std. Dev.	Min	Max	Description
TOD	60.871	21.686	4	121	Turn Out Day
meanvi	0.762	0.059	0.467	0.866	Average NDVI Jan 1-May 8
totrain	358.972	111.772	123.4	880	Total Rain Jan 1-May 8 (mm)
totdry	63.537	16.622	11	119	Total Number of Dry Days Jan 1-May 8
truevi	0.757	0.066	0.440	0.882	Actual NDVI at TOD
trurain	40.962	28.521	0	184.2	Total Rain 16 days prior to TOD (mm)
trudry	6.587	3.399	0	16	Total number of Dry Days 16 days prior to TOD
totr_1	45.966	43.066	0	269.7	Total Rain Jan 1st-Jan 16 (mm)
totr_17	69.835	37.070	0	246.9	Total Rain Jan 17-Feb 1 (mm)
totr_33	43.053	25.347	0	152.1	Total Rain Feb 2-Feb 17 (mm)
totr_49	37.082	29.960	0	170.8	Total Rain Feb 18-Mar 5 (mm)
totr_65	38.850	21.606	0	139	Total Rain Mar 6-Mar 21 (mm)
totr_81	23.681	16.327	0.2	84.3	Total Rain Mar 22-Apr 6 (mm)
totr_97	40.621	35.635	0	168.5	Total Rain Apr 7-Apr 22 (mm)
totr_113	28.035	24.724	0	99.3	Total Rain Apr 23-May 8 (mm)
totr_129	31.850	22.151	0	140.6	Total Rain May 9-May 25 (mm)
ndvi_1	0.731	0.065	0.463	0.864	NDVI Jan 1st-Jan 16
ndvi_17	0.731	0.067	0.448	0.859	NDVI Jan 17-Feb 1
ndvi_33	0.737	0.069	0.440	0.879	NDVI Feb 2-Feb 17
ndvi4_49	0.748	0.069	0.444	0.882	NDVI Feb 18-Mar 5
ndvi_65	0.763	0.067	0.459	0.885	NDVI Mar 6-Mar 21
ndvi_81	0.780	0.062	0.477	0.893	NDVI Mar 22-Apr 6
ndvi_97	0.796	0.056	0.493	0.895	NDVI Apr 7-Apr 22
ndvi_113	0.810	0.049	0.512	0.895	NDVI Apr 23-May 8
ndvi_129	0.755	0.066	0.440	0.879	NDVI May 9-May 25
dry_1	7.006	3.964	0	16	No. Dry Day Jan 1st-Jan 16
dry_17	4.716	3.127	0	16	No. Dry Day Jan 17-Feb 1
dry_33	6.778	3.087	0	16	No. Dry Day Feb 2-Feb 17
dry_49	7.401	3.403	0	16	No. Dry Day Feb 18-Mar 5
dry_65	5.371	3.453	0	15	No. Dry Day Mar 6-Mar 21
dry_81	8.232	3.221	0	15	No. Dry Day Mar 22-Apr 6
dry_97	7.426	3.532	0	14	No. Dry Day Apr 7-Apr 22
dry_113	8.963	4.538	0	16	No. Dry Day Apr 23-May 8
dry_129	7.644	3.990	0	16	No. Dry Day May 9-May 25

strongly indicated fixed effects over pooled approaches). All non-spatial statistical analyses were conducted in the statistical package Stata 11 (StataCorp, 2009).

The relationship to be examined is illustrated in figure 4, where the NDVI in each 16 day period is plotted against the rainfall in the period for each farm for each year (199*9*5= 8955 points) and colour coded for whether the cattle are turned out (no if the period is before the turn out date that year, yes if after). The relationship is complex but in general the black dots (yes) cluster around low rain, high NDVI.

4. Results

Spatial analysis

Table 2 shows the result the fixed effect panel analysis examining how amounts of grass and rainfall across spring relates to the decision of the farmer to turn out. The within variation R^2= 0.387 (199 farms, 5 years a total of 995 observations). The overall fit of the model is good but many of the variables have a low significance. N.B. when interpreting the variables; the TOD variable is a Julian day , with January 1st as 1, January 2nd as 2 etc., so a low value TOD indicates an early turn out

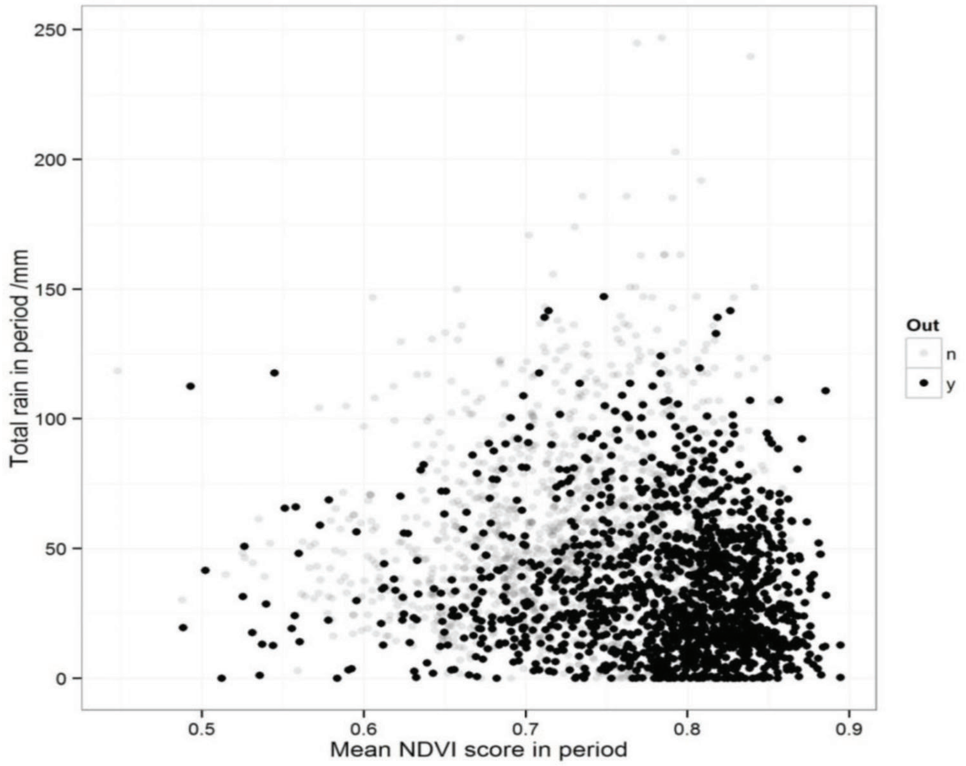

Figure 4: NDVI against rainfall for all observed periods, coded for whether the cattle are turned out (yes or no)

Table 2: Factors associated with turn out date.

Variable associated with TOD	Coefficient (t)	Variable associated with TOD	Coefficient (t)
Total Rain Jan 1st-Jan 16 (mm)	-0.001(0.05)	No. Dry Day Jan 1st-Jan 16	0.238(1.26)
Total Rain Jan 17-Feb 1 (mm)	0.025(1.71)	No. Dry Day Jan 17-Feb 1	0.156(0.60)
Total Rain Feb 2-Feb 17 (mm)	0.008(0.37)	No. Dry Day Feb 2-Feb 17	0.236(1.33)
Total Rain Feb 18-Mar 5 (mm)	-0.019(0.78)	No. Dry Day Feb 18-Mar 5	-0.022(0.10)
Total Rain Mar 6-Mar 21 (mm)	0.009(0.38)	No. Dry Day Mar 6-Mar 21	-0.395(1.88)
Total Rain Mar 22-Apr 6 (mm)	0.109(2.76)**	No. Dry Day Mar 22-Apr 6	0.217(0.87)
Total Rain Apr 7-Apr 22 (mm)	0.023(0.73)	No. Dry Day Apr 7-Apr 22	-0.311(1.37)
Total Rain Apr 23-May 8 (mm)	-0.088(2.64)**	No. Dry Day Apr 23-May 8	-0.279(1.33)
Total Rain May 9-May 25 (mm)	0.015(0.54)	No. Dry Day May 9-May 25	0.045(0.29)
NDVI Jan 1st-Jan 16	-42.132(1.14)	Constant	81.505(5.76)**
NDVI Jan 17-Feb 1	2.005(0.03)		
NDVI Feb 2-Feb 17	-94.435(1.61)		
NDVI Feb 18-Mar 5	-111.586(2.03)*		
NDVI Mar 6-Mar 21	-91.843(1.70)		
NDVI Mar 22-Apr 6	-144.295(1.81)		
NDVI Apr 7-Apr 22	174.002(1.37)		
NDVI Apr 23-May 8	-103.291(1.42)		
NDVI May 9-May 25	380.257(11.54)**		

Observations= 995. Panel ID FARM_CODE=199. Time ID Years=5
Within R^2=0.387 (F=9.57***). Absolute value of t-statistics in parentheses
* $p<0.05$; ** $p<0.01$

of cattle and this is generally desirable; this means negative coefficients will decrease TOD as the variable increases.

Rainfall at End of March is significant, with every extra 10.1 mm of rain in the period increasing the TOD by 1 day. This seems logical, farmers may delay turn out if rainfall is heavy, even if enough grass is present. However rainfall at the end of April is also significant but this time with increasing rain leading to a decrease in TOD, this is difficult to interpret but nearly all farmers will have already turned out by then and we may be capturing a seasonal affect.

Grass growth as indicated by NDVI has less of an apparent influence, NDVI at end of February, when many farmers will be considering turning out, is related such that an early turn out date is more likely with higher grass growth. The NDVI score for Mid-May is significantly related to turnout and this is a seasonal affect, the significance disappears when year dummies are included. The coefficient seems to indicate higher grass in Mid-May is associated with a later turn out date, this is because in a ‘‘good year’’, significant biomass is removed by mid-may through grazing and even silage cutting, so high NDVI in May indicates that perhaps spring began slowly. The ‘‘number of dry days’’ is not influencing, individually, the TOD. Rainfall and number of dry days were both included to attempt to account for intensity of rainfall. Interaction terms for these variables have been investigated and show no significance in the model performance or make up.

It is clear that multi-colliniarity between variables must be high in this scenario- the grass growth in March is strongly related to grass growth in February and so on. Even rain fall shows a relative pattern of decrease across the spring. To attempt to reduce this affect, the bi-weekly variables were reduced to three single metrics to describe the overall spring; Mean NDVI score Jan1st to May 25th (a high mean NDVI score across spring implies good grass growth), the total rainfall Jan1st to May 25th and the total number of dry days in the same period. We also included 3 metrics to characterise TOD, The NDVI score at actual turn out date, the rainfall in 16 days preceding and the number of dry days in the same period.

Table 3 shows the results of a fixed effect panel analysis on TOD using these variables with and without a year dummy. Without year dummies all the variables are significant with average NDVI strongly influencing TOD. If grass growth over spring is high then turn out dates are early, if spring is wet then TOD is late (3.5 days later for every 100mm of rain). But the number of dry days seems to affect TOD contrary to expectation with TOD later if the number of dry days increases.

At the time of turn out an increase in the number of dry days in the previous 16 days makes TOD earlier (0.46 days earlier for every extra dry day) but so does an increase in rainfall and higher grass growth at turn out is associated with a later date. Some of these contrary results are partially explained when a year dummy is included in the result. We can see that, in comparison with 2008, 2010 is associated with TOD being 4.94 days later and 2012 with TOD being 5.96 days earlier. As a result of including the year dummies total dry days are no longer significant and total rainfall is only just significant at the 5% level.

If the assumption of a framer having a target date is true then this could be picked up with a lagged variable- the previous year’s TOD. If farmers have a preference for a TOD regardless of conditions and only change in extremis, using the previous year’s TOD allows us to capture this. One impact of using a lagged variable is that 2008 cannot be used as we do not have 2007 TOD.

The inclusion of the lagged variable in the FE model above has little impact. With the lagged variable itself not significant though the overall model R^2 marginally increases and the RMSE goes from 15.3 to 14.3 (see table 4). Note that the year dummy now references 2009 as 2008 data not included in analysis.

A predictive model

The explanatory approach in the previous section can be expanded to look at prediction of TOD knowing current conditions. For the predictive model we can move beyond the fixed effects into a random effects model that incorporates variance between farms. This is important as formally the fixed effects model can only be used to

Table 3: Seasonal and local factors associated with TOD

Variables associated with TOD	Coefficient (t)	with year dummies Coefficient (t)
Average NDVI Jan 1-May 8	-399.312(11.74)**	-357.209(10.70)**
Total rain Jan 1-May 8 (mm)	0.036(6.77)**	0.015(1.96)*
Total number of Dry Days Jan 1-May 8	0.245(4.54)**	0.093(1.60)
Actual NDVI at TOD	323.206(11.26)**	323.439(11.37)**
Total rain 16 days prior to TOD (mm)	-0.079(4.68)**	-0.082(4.84)**
Total number of dry days in 16 days prior to TOD	-0.464(2.84)**	-0.518(3.19)**
Year Dummy		
2009		0.322(0.703)
2010		4.94(2.83)**
2011		1.2(0.83)
2012		-5.962(-4.13)**
Constant	98.246(8.70)**	83.273(6.54)**

Observations=995. Panel ID FARM_CODE=199.Time ID Years=5
Within R^2=0.323 (F=35.59***), with Year Dummies R^2=0.363 (F=24.91***)
Absolute value of t-statistics in parentheses
* $p<0.05$; ** $p<0.01$

Table 4: Seasonal and local factors associated with TOD in a fixed effects model with a lagged TOD variable added

Variables associated with	**with year dummies**
TOD	**Coefficient (t)**
Average NDVI Jan 1-May 8	-344.342(9.55)**
Total rain Jan 1-May 8 (mm)	0.012(1.34)
Total number of Dry Days Jan 1-May 8	0.037(0.54)
Actual NDVI at TOD	301.930(10.34)**
Total rain 16 days prior to TOD (mm)	-0.072(3.82)**
Total number of dry days in 16 days prior to TOD	-0.227(1.16)
TOD_lag	0.017(0.5)
Year Dummy	
2010	4.57(2.77)**
2011	0.930(0.63)
2012	-6.475(-3.75)**
Constant	83.841(6.13)**

Observations=796. Panel ID FARM_CODE=199. Time ID Years=4
Year Dummies R^2=0.382 (F=22.51)
Absolute value of t-statistics in parentheses
* $p<0.05$; ** $p<0.01$

Table 5: Seasonal and local factors associated with TOD in a random effects model with a lagged TOD variable added

Variables associated with	**i)**	**ii) with lag**
TOD	**Coefficient (t)**	**Coefficient (t)**
X Coor	-0.0000141(-1.03)	-0.00000677(0.77)
Y Coor	0.0000627(7.00)**	0.00000924 (1.56)
Dry Soil Dummy	-4.230995 (2.97)**	-2.581223(3.02)**
Average NDVI Jan 1-May 8	-503.589(23.22)**	-375.260(17.86)**
Total rain Jan 1-May 8 (mm)	0.038(7.4)**	0.0313 (6.37)**
Total number of Dry Days Jan 1-May 8	0.250(6.56)**	0.130(3.92)**
Actual NDVI at TOD	427.206(22.73)**	313.487(16.84)**
Total rain 16 days prior to TOD (mm)	-0.102(-5.95)**	-0.097(5.53)**
Total number of dry days in 16 days prior to TOD	-0.489(3.01)**	-0.199(1.18)
TOD_Lag		0.4868 (20.9)**
Constant	94.168(10.83)**	66.239(9.63)**

Observations=995. Panel ID FARM_CODE=199. Time ID Years=5
Overall R^2=0.589, with TOD lag
Observations=796. Panel ID FARM_CODE=199. Time ID Years=4
R^2=0.745
Absolute value of t-statistics in parentheses
* $p<0.05$; ** $p<0.01$

infer relationships of within the sample where as a random effects model allows for inference and thus prediction from the larger population from which the sample was drawn (due to the assumption of a normal distribution to the residual term). This allows us to include x and y location and soil type (dummy variable for well drained or poorly drained recorded in the NFS) in our model as a between farm affect The result of the random effects models (maximum likelihood) also show the much bigger impact of using the lagged TOD variable, table 5

This random effects model, shows the influence of location and soil drainage found in other studies with Dry soil associated with TOD being 4.5 days earlier and northernliness (y coordinate) leading to TOD being 1 day later for every 16km north. The other terms are similar to the FE coefficients. If the TOD_lag is introduced we can see the R^2 fit of the model increase significantly but the x and y coordinates are no longer significant as the TOD variation is captured in the lagged variable. This model allows us to predict a TOD for the NFS farmers using the equation:

$$TOD = 66.236 + DSM.(-2.581) + meanndvi.(-375.260) + totr.(0.0313) + totdry.(0.13) + truendvi.(313.487) + trurain.(-0.097) + TOD\_lag.(0.487)$$

Predicted TOD and actual TOD for the period are shown in figure 5. Note that in the TOD_lag model the constant value (66.2) is 28 days earlier than the model without the lagged variable (94.2). The lagged coefficient is 0.487. If we apply the coefficient to the mean TOD we get 29.7 days, this is not a coincidence as the lagged variable within the random effects model is moving variation from the alpha term fixed in time into a time variant variable. It would be preferable to have an independent test set to test this predictive power fully.

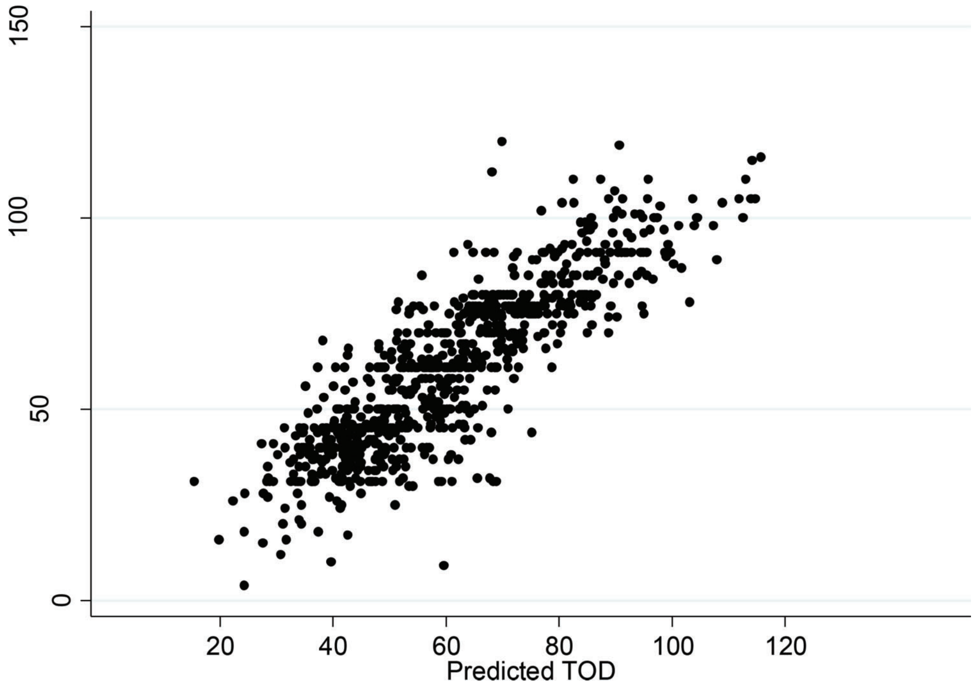

Figure 5: Predicted TOD against actual TOD (Julian days) for the model data

5. Discussion

Better overall growth in spring seems to be related to earlier turn out dates but an opposite, equal effect is present locally at turn out, more grass on the farm at turn out is related to a later turn out. It is important to remember the strong seasonal effects; grass grows over time, all things being equal, the longer you wait the more grass there will be and less rain will fall as spring turns to summer. However we have hypothesised that farmers have a target grass level at their farm they want to achieve before turn out.

Farmers respond to overall conditions, to a ''bad'' spring, like 2010, or to a ''good'' spring like 2012 and adjust their turn out dates but they do not do so optimally, there is a lag in the response, shown by the positive relationship between NDVI at turn out and TOD. In a good year they are letting the grass grow too far before responding quickly enough to a good spring.

If the response of farmers to good conditions was optimal then the coefficient of NDVI at turn out date would be zero in table 4, all else being equal the amount of grass at turn out on the farm should always be the same. The size of the coefficient is an indicator of how farm from optimal the group of farmers are.

The increase rainfall at turn out being related to early TOD could be a seasonal effect, there is more rainfall early in the season and could indicate that farmers are more driven by available grass growth than soil conditions when considering an early turn out. A soil drainage dummy was included in earlier analysis and did not prove significant. The increase in the number of dry days at turn out being associated with earlier turn out is however an indicator that farmers are responding to local weather conditions when deciding to turn out. An interaction term between rainfall and dry days at turn out was investigated and not found significant.

It is likely that better knowledge of soils and drainage on the NFS farms would add considerable nuance to the picture of weather conditions and turn out date as would a more sophisticated handling of the rainfall data (the number of days over which to sum rain to get a picture of soil trafficability would vary considerably by soil type).

Our picture of NDVI and growth is also crude but better resolution satellite imagery, and better geolocation of the NFS farms (mapped parcels rather than location of farmhouse) will allow us in the near future to be able to characterise the grass growth at field scale rather than in the generally location of the farm.

The predictive capabilities of the model seem good, at least for the NFS sample, in the absence of previous TOD for all farms then any national TOD prediction will depend upon the random effects coefficients in table 5. A comparison of the predictive capabilities is shown in table 6. The RMSE of 10.8 days when compared to an intra-farm average TOD variation of 25 days suggests this model could provide useful high resolution measurements of impact on TOD of current spring conditions on the farms in the NFS and wider.

Table 6: Comparison of the internal predictive capabilities of the four models

Model	R^2 predict	RMSE on prediction (days)
Fixed Effects	0.501	15.32
FE+ TOD lag	0.549	14.3
Random effects	0.581	14
RE+TOD lag	0.742	10.8

6. Conclusion

Farmers are responding to general springtime growth conditions and measurements of NDVI over spring by satellite can quantify the size of the response on turn out dates at the farm. Nationally, on average, turnout date gets a day later for every 16km further north of the south coast. Farmers seem to have a lag in their response to good conditions, waiting until there is more grass than is normal at their farm before turning out and turning out early in poor years to low levels of grass cover. The number of dry days in the run up to turning out and the total amount of rainfall are associated with changes in TOD.

National seasonal effects dominate over local weather conditions and for every extra 0.01 in the average spring NDVI value score at the farm location turnout was 3.6 days earlier but this early turnout was associated with a higher actual NDVI on the day, that showed effectively the turn-out was 3.3 days later than it could have been. As 0.01 NDVI equates to a week's growth typically it showed that farmers do respond to good conditions but not as quickly as they could. The rainfall data implied that soil condition was of secondary importance to grass levels, especially in poor springs and year dummies showed that seasonal effects are national- 2010 was a cold spring caused turn out dates to be 4.6 days later, whereas the warm spring of 2012 allowed cattle to be turned out 5.6 days earlier.

The inertia in decision making around a preferred date was shown by using the previous year's TOD in the model. By using this along with the other data we can accurately predict when Turn out occurs with a RMSE of 10 days (compare to the average on farm inter-annual range of dates of 25 days).

This work has quantified some of the real-time factors that farmers do take into account when making decisions. It's also shown there is still considerable capacity for increased exploitation of grassland resources within current management systems and stocking densities.

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Not all risks are equal

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ABSTRACT

Analysis of a survey of Scottish farmers (162) confirmed that they do not perceive all types of risk to be equal. Choices with potential negative ethical or health & safety consequences were perceived to be riskier than those that might have negative financial and social outcomes. A negative relationship was found between perceived riskiness and stated likelihood of taking a risky course of action with one exception - where a health & safety harm might arise. The findings could assist the development of behavioural models with greater predictive powers. In addition, the study suggests that risk awareness is not the most limiting factor for improving health & safety in the Scottish farming industry.

KEYWORDS: decision; choice; risk preferences; risk perceptions; ordinal mixed-effects model.

1. Introduction

Risk and uncertainty are well known and widely researched characteristics of agricultural activity that are fundamental to the choice made in many farm management decisions. Despite the considerable wealth of literature much is still to be learnt and there remain calls for researchers to undertake more studies to gain a better understanding of the decisions made by farmers (OECD, 2009; Ohlmer *et al*., 1998; Webster, 2003). The development of better farm level decision support and dedicated risk management tools are among the leading study areas. However, these commonly promote a risk management process that considers each risk independently such as described by Theuvsen (2013), or focus on a single objective function such as a socially desirable outcome, farm output or farm profit maximisation (for examples see Paulson *et al*. (2016), Arribas *et al*. (2017), Jones *et al*. (2017), Mosnier *et al*. (2017) and Liu *et al*. (2017)). Thus they do not address the common situations where farm management decisions must balance competing sets of, or multiple, risks. An alternative approach has been the study of farmer behaviour and their previous decision choices to identify factors associated with particular actions see for example Mase *et al*. (2017) and Hamilton-Webb *et al*. (2017). Such studies however largely overlook the available alternatives at the decision point and therefore also miss the influence of preferences for options with different risk profiles and expected values. (The term ‘risk’ is used here to encompass all situations where there is potential for negative consequences.) Cases where farmers must rely largely on their own judgement and subjective assessment of the risks are currently poorly understood and rarely studied (Hardaker and Lien, 2010). Yet there is a long standing recognition that risk perceptions have important impacts on the choices people make and their likely response to policy interventions (Slovic, 1987; Tversky and Kahneman, 1974). As noted 30 years ago by Slovic (1987) there is a need to understand how people think about and respond to risk or ‘well intended policies may be ineffective’.

The purpose of this study is to investigate the knowledge gap that exists about the subjective risk preferences of farmers. The aim is to provide some new insights that can contribute to the development of better predictive models of farmer decision choices and thereby enable better policy design. The two main objectives are to determine the relative preferences of farmers to different types of risk and to investigate the relationship between the perceived riskiness of an action and the likelihood that they would engage in the action i.e. take the risk.

The study follows a novel approach in the context of farm management and builds on the approaches of Weber *et al*. (2002) and Blais and Weber (2006) by exploring the risk perceptions of and likelihood of risk taking by Scottish farmers. The statistical methodology used differs from previous studies in that the Likert scale response data is treated as ordinal rather than numeric, thus importantly for the statistical analysis it assumes a flexible distance between scale points (Agresti, 2002; Allen and Seaman, 2007). It involved the development, administration and analysis of data from a survey of Scottish farmers, though the method could be used with other groups and the findings provide insights that are not bounded by geographic region.

2. Study methods

The study consisted of primary data collection using a paper questionnaire from a sample of farmers followed by the development of statistical models to determine whether or not farmers differentiated between different

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types (or 'domains') of risk; their relative order; and any associations with potential explanatory variables.

Domains of risk and risky choices

Many different domains of risk have been identified as affecting agricultural production and farm households. Among these are the five defined by Weber *et al.*'s (2002) in their study of the general population: financial; health & safety; ethical; recreational; and social. In the business context there are also 'production' risks to be considered and for this study this gave a total of six risk domains to be explored (see Table 1). The study of farmer risk preferences by Hansson and Lagerkvist (2012) also builds on the work of Weber *et al*. (2002) explores four risk domains (financial, production, environmental and social), thus this study considers a wider range of the risk types known to affect agricultural activity. For each risk domain an extensive set of risky choices that farmers could encounter were identified then refined by testing their relevance to a wide range of farming situations and likely level of choice farmers were likely have. Thus for examples decisions about actions required by law even if risky were excluded from the study. The final 69 risky choices are given in Appendix 1. As some have the potential for multiple negative consequences they could be allocated to more than one risk domain and arguably have not been allocated to the correct risk domain. Completely avoiding misallocation of questions to domains is difficult, given the nature of decision making by humans (Weber *et al*., 2002). Mis-allocation of questions to domains is likely to reduce the strength of separation between domains, and therefore to reduce the statistical power to detect differences between domains (and so will reduce power to confirm the existence of distinct domains). It is therefore reasonable to assume that any significant differences between domains that are detected by the analysis are likely to be genuine.

The two questions posed to study participants with respect to these risky choices were:

- How risky do you consider the following, given your current situation and assuming they are possible?
- How likely are you to do any of the following, assuming they are possible?

Question one directly investigates respondent's subjective perceptions of the risk and the second their behaviour given the risk, both give an indication of attitudes to each risk. The strength of a respondent's view is captured using rating (Likert) scales, five point scales were used in this study: 1=not at all risky to 5 = very risky and 1=very unlikely to 5=very likely respectively. In this study we therefore ask respondents directly about their perceptions of risk whereas the questions posed by Hansson & Lagerkvist (2012) are directed to the importance of an action that might reduce or increase the level of risk.

Questionnaire design and survey administration

The questionnaire was developed in three sections: The first section asked about the respondent's background, including factors relevant to risk preferences (Burton, 2006; Edwards-Jones, 2006; Rehman *et al*., 2008; The Royal Society, 1992; Wilson, 2011; Wilson *et al*., 2013). These included farm type; farm size; land tenure; age; education; income dependency on the farm business; capital security of the farm business and attitudes to the importance of farming to societal goals such as environmental care and food security. The second and third sections respectively posed the two questions about perceived risk and likelihood of engaging in a risky action. Questions in these sections were separately randomised and the risk domains were not explicitly referred to at any point in the questionnaire, which was piloted with three farmers prior to final release.

Data collection

A convenience sampling method was selected due to the size of the questionnaire and sensitivity of some of the questions. Trusted brokers from SAC Consultancy (16 regional offices) distributed questionnaires according to the following framework: any farmer who they direct contact with during the following 2-3 weeks should be invited to participate in the study – no farm or farmer attributes should be used in the recruitment process. All questionnaires were in paper format and completed anonymously.

Table 1: Risk domains and examples of risky choices

Domain	Number of risky choice questions	Examples of risky choice questions
Financial	18	Borrowing a large sum of money to invest in an existing enterprise. Buying land to increase scale if it was available. Selecting to receive subsidy payments in Euros.
Production	12	Not adjusting crop protection plans in response to weather conditions. Changing your production method significantly.
Health & safety	11	Undertaking potentially dangerous farm activities without someone knowing where you are. Entering a pen with a bull or recently calved cow without a stick or taking other protective measures.
Ethical	12	Knowingly undertake an action that could damage a valuable/protected habitat. Not always notify households neighbouring your fields when you are going to spray crops.
Recreational	4	Pilot your own small plane, if you could. Try out bungee jumping at least once.
Social	12	Disagree with your family peers about how the farm is run. Lend a friend/neighbour valuable equipment.

Model development

The statistical methodology used in this paper is closely related to Weber *et al.* (2002) and Blais and Weber (2006), but differs in one crucial respect: we treat the two risk related response variables (five-point Likert scale) as ordinal categorical data, rather than as continuous data. This is an important difference, because it means that in this paper we make no assumption that the gaps between points on the Likert scale are equal. The scores allocated to categories of the Likert scale provide a ranking but the values themselves (1, 2, 3, 4 and 5) are labels rather than measured values and so are essentially arbitrary, as there is no reason to believe that the gaps between consecutive scores will necessarily be equal on an absolute scale. The treatment of the response variables as ordinal, rather than numeric, therefore improves the defensibility of the methodological approach.

To establish whether or not farmers differentiated between different risk domains with respect to both their risk perceptions and likelihood of engaging in a risky choice an ordinal mixed-effects model was developed. This model also provided estimated values on the relative perceived riskiness of each domain and how likely respondents were to engage in those activities. Finally the model was developed further to test for associations with contextual factors (farm or farmer background characteristics). All statistical models were implemented by using the clmm function in the R 'ordinal' package, which fits mixed-effects models with one or more random effects for ordinal data. The test of the overall domain effect and other explanatory variables were carried out by the likelihood ratio test, and paired Wald tests were then use to further test for differences between specific pairs of domains.

To make interpretation of the result from the models easier a data transformation was applied prior to analysis. This involved reversing the direction of the five-point Likert scale relating to the likelihood that respondents would take a risky choice, thus a score of 1 equated to 'very likely' and a score of 5 represented 'very unlikely' and represent the likelihood of respondents not taking a risky choice. Thus the signs of the coefficients (see below) from the models would be aligned. (During the piloting phase of the survey it was established that the scale direction used in the analysis was difficult for respondents and therefore inappropriate.)

Ordinal mixed-effects models were estimated, with unstructured thresholds, using the clmm function in the Ordinal package for R (Christensen, 2015). This type of model is an extension of linear models, such as ANOVA (Agresti, 2002; McCullagh, 1980; Tutz and Hennevogl, 1996) and it has two key characteristics:

1. Response variables are treated as being an ordinal, rather than a numeric, variable. This is done by assuming that the values of the ordinal variable y represent intervals on a latent continuous variable z (which can be thought of as representing the underlying variable that the Likert scale is trying to quantify), and assuming that this latent variable z - rather than the observed score y - that is related to the explanatory variable. The values of y can be computed deterministically from the values of z through the equation
$$y = \mathrm{I}(z < \alpha_2) + 2\ \mathrm{I}(\alpha_2 < z < \alpha_3) + 3\ \mathrm{I}(\alpha_3 < z < \alpha_4) + 4\ \mathrm{I}(\alpha_4 < z < \alpha_5) + 5\ \mathrm{I}(z > \alpha_5), \quad (1)$$
where $\mathrm{I}(x)$ is the indicator function (so that $\mathrm{I}(x) = 1$ if x is true, and $\mathrm{I}(x) = 0$ otherwise). The unknown cut-points α_2, α_3, α_4 and α_5 are estimated as part of the model fitting algorithm.
2. Random effects as well as explanatory variables (or "fixed effects") are included in the model to capture unexplained sources of variation within the model, including that which could arise from a lack of variable independence.

Thus the final form of the model was

$$Z_{ij} = \beta_{D(i)} + U_i + V_j + W_{jD(i)} + \epsilon_{ij}, \quad (2)$$

where z_{ij} denotes the response to question i by farmer j and $\beta_{D(i)}$ denotes the domain effect (fixed-effect) associated with question i. Three random effects are included here to deal with the multilevel structure in the design of this study. 1) U_i is the question-specific random effect; 2) V_j is the farmer-specific random effect; 3) $W_{jD(i)}$ is the random effect capturing the interaction between domain and farmer. Finally, ϵ_{ij} is the unexplained random error associated with question i and farmer j. All these three random effects and the random error are assumed to be normally distributed with a mean of zero and an unknown variance (estimated from the data as part of the model fitting).

To confirm whether farmers do (or do not) differentiate between the risk domains the model was run twice, first for 'risk perception' and second for 'the likelihood of not taking a risky choice'. A likelihood ratio test, using a single p-value (Equation 2) then determines whether the model that allows for differences between risk domains is better supported by the data than the simpler 'base' model which does not (and hence assumes all risk domains are equivalent). If a statistically significant association is found, it is then meaningful to further test for differences (paired Wald test) between pairs of risk domains and establish their relative ordering. This is achieved by comparing the $\beta_{D(i)}$ coefficients of a 'base' and a 'comparator', testing whether $\beta_{\text{comparator}}$- β_{base} is significantly different from zero, and, if so, the magnitude and sign of this difference. A positive coefficient indicates that scores for the comparator group are higher than those for the base group; a negative value indicates that scores for the comparator group are lower than those for the base group.

Contextual factors such as age, education, farm size as well as general attitudes may provide some explanation of either risk perception or the likelihood of not taking risks. To test for any associations the model was developed by replacing the domain variable by each of the contextual factors in sequence and including domain as a random effect. The model was run for associations with both risk perception and the likelihood of not taking a risk. As respondents' opinions about the importance of agriculture to societal goals were ordinal in nature (on a 5-point Likert scale: score 1-not at all important to score 5-very important) it would be possible to treat these contextual factors as either continuous or categorical.

Both were tested and models which treat them as continuous were found to have a better empirical goodness of fit - as determined by the Akaike Information Criterion (AIC; (Akaike, 1973)) and the Bayesian Information Criterion (BIC; (Schwarz, 1978)) - and we therefore treated these variables as continuous within all analyses.

The coefficients (estimated mean score difference) generated by these models are interpreted in the same way as other regression analysis: a positive coefficient indicates a positive relationship between the two variables and a negative coefficient indicates that as one increases the other decreases.

3. Results

A total of 162 completed questionnaires were returned from across Scotland of which three were excluded from the analysis due to large amounts of missing data.

Descriptive statistics

The respondents (159), while not a statistically representative sample of Scottish farms, encompassed a wide range of situations as shown from the descriptive summary below.

- Farm type: Upland livestock (36%) farms were the commonest type and hill farms the least common (11%). Dairy, lowground livestock and predominantly arable farms each represented approximately 15% of the sample.
- Farm size: the majority (62%) of farms had 81-120 hectares, 4% (6 farms) were less than 40ha, and 12% had 41-80ha.
- Land tenure: almost half (47%) of participants owned all the land they farmed, about one quarter (25%) owned 50 -100% of the land, 11% of them owned 1-50% and 17% seasonally rented or were tenants on all the land farmed.
- Age: 72% of participants were over 40 (52% aged between 41-60 and 20% were over 61). Six respondents (4%) were under the age of 25 and the remaining 24% were aged 25-40.
- Qualifications: Overall just over half (51%) of the total sample had post-school qualifications in agricultural related subject. 40% had either school or college (e.g.) qualifications, 12% had gained a university undergraduate qualification, and a further 7% had a post-graduate award.
- Income dependency on the farm business: around half (51%) of respondents were entirely dependent on the farm business for family income. Most of the remainder (43%) were partly dependent, and nine (6%) of respondents did not draw any income from the farm business.
- Capital security of the farm business: 30% of respondents were in a very secure capital position (they held savings in the bank or equivalent) and a similar proportion were in a secure capital position (little/no savings but has no long term borrowings). One quarter had a small amount of long term borrowed capital and about 13% had a large amount of long term borrowed capital (i.e. were capitally insecure).
- The importance of farming to societal goals: over 80% of the study sample felt that farming had an ‘important’ or ‘very important’ role to play with respect to all the societal goals investigated bar one. For this, ‘Providing the public with space for recreation’, only 23% of respondents felt it was important.

Model results

Confirmation of presence of domains

Likelihood ratio tests comparing a model that allows for differences between risk domains against one that does not confirmed that study participants did not perceive all domains of risks as equal ($p < 0.01$) (perceived riskiness) and their likelihood of not engaging in risky activities varied with domain ($p < 0.01$).

Relative ordering of domains

Following this confirmation pairwise comparisons of risk domains tests are appropriate and the results are shown in Table 2. For ease of interpretation the estimates of the mean score differences are sorted in ascending order by their perceived riskiness within each domain. Significant differences between a number of the domains are found. Specifically, ethical risks were perceived to be a significantly greater risk than production-related risks (coef 1.51, and p-value < 0.01), financial risks (coef = 2.08,

Table 2: Risk domain coefficients (estimated mean scores difference) and standard errors

Base domain	Comparator domain	Perceived risk Coefficient (SE)	Stated likelihood of not taking a risky choice. Coefficient (SE)
Financial	Social	-0.10 (0.51)	0.81 (0.50)
	Production	0.57 (0.51)	0.74 (0.50)
	Recreation	1.71* (0.74)	2.42* (0.73)
	Ethical	2.08** (0.51)	2.68** (0.50)
	Health & Safety	2.14** (0.52)	1.25* (0.51)
Social	Production	0.67 (0.55)	-0.07 (0.55)
	Recreation	1.81* (0.77)	1.61* (0.76)
	Ethical	2.18** (0.55)	1.86** (0.55)
	Health & Safety	2.24** (0.56)	0.44 (0.56)
Production	Recreation	1.14 (0.77)	1.69* (0.76)
	Ethical	1.51** (0.55)	1.94** (0.55)
	Health & Safety	1.56** (0.56)	0.51 (0.56)
Recreation	Ethical	0.37 (0.77)	0.25 (0.76)
	Health & Safety	0.43 (0.78)	-1.17 (0.77)
Health & Safety	Ethical	-0.06 (0.56)	1.42* (0.56)

*Significant at 0.05; **significant at 0.01 level.

and p-value < 0.01) and social risks (coef = 2.18, and p-value < 0.01). Health & safety risks were similarly perceived to be a greater risk than production risks (1.56, and p-value = 0.01), financial (coef = 2.14, and p-value < 0.01) and social risks (coef = 2.24, and p-value < 0.01).

Overall, the perceived 'riskiness' of actions with potential negative ethical, health & safety, and recreational consequences were similar, as coefficients estimated by the model are small and non-significant (see table 2 the final three rows). Similarly, the perceived 'riskiness' of the production, financial and social domains are on a par. Thus the model indicates that perceptions of the risk domains form two clusters.

With regards to the stated likelihood of not following a risky course of action, the model found differences between domains broadly similar to those for perceived riskiness (above). Respondents indicated that they were significantly more likely to avoid ethical risks than those associated with financial (coef = 2.68, and p-value < 0.01), social risks (coef = 1.86, and p-value < 0.01), or production (coef = 1.94, and p-value < 0.01). The stated likelihood of not taking a risky choice for decisions within the ethical and recreational domains were similar, with only a small and non-significant estimate for the differences between these domains (0.25, and p-value > 0.05). One interesting result is that respondents indicated that they were significantly more likely to avoid ethical risks than to avoid those associated with health and safety (coef = 1.42, and p-value = 0.01), even though the perceived levels of risk for these two domains were very similar. The results from Table 2 are illustrated in Figure 1.

To investigate potential relationships between risk perceptions and the likelihood of not taking a risky choice the model estimates can be compared graphically. The Financial domain was selected as the reference domain for this comparison, which can be seen in figure 1. On the x axis are the two response variables – perceived riskiness and likelihood of not taking a risky choice. The y axis represents the estimated mean score coefficients for each domain as given in Table 2 (first five rows). The positive slopes indicate domains where risk aversion is relatively high, and negative slopes indicate domains where risk aversion is relatively low. (As separate models were constructed for risk perception and risk not taking, the significance of the slopes of the lines shown in Figure 1 have not been formally tested, so these results should be interpreted cautiously.) As can be seen from the drawn relationships the highest levels of risk aversion are for the social, recreational and ethical domains, and the lowest levels of risk aversion are for the health and safety domain. The level of risk aversion appears to be substantially lower for health and safety than for any other domain, suggesting three difference types of domain are present:

1. domains with low risk perception and a low likelihood of risk avoidance (production, social, financial)
2. domains with high risk perception and a high likelihood of risk avoidance (ethical, recreational)
3. domains with high risk perception but a low likelihood of risk avoidance (health & safety).

Contextual effects

Although none of the farm and farmer context variables were found to have a significant relationship with risk perceptions two farmer related variables (age and agriculture-related education) were found to have an association with the likelihood of not taking a risk choice (see Table 3). On further examination (see Table 4) respondents over 40 years of age were found to be significantly less likely to take risks than those in younger age categories (p-values < 0.05) and respondents with agriculturally related qualifications were more willing to take a risky choice than respondents with other educational backgrounds (coef = 0.55 and p-value = 0.01).

A significant positive relationship was found between risk perceptions and the importance of farming to all six societal goals (Table 5). In addition, for three of the societal goals a positive relationship was found with

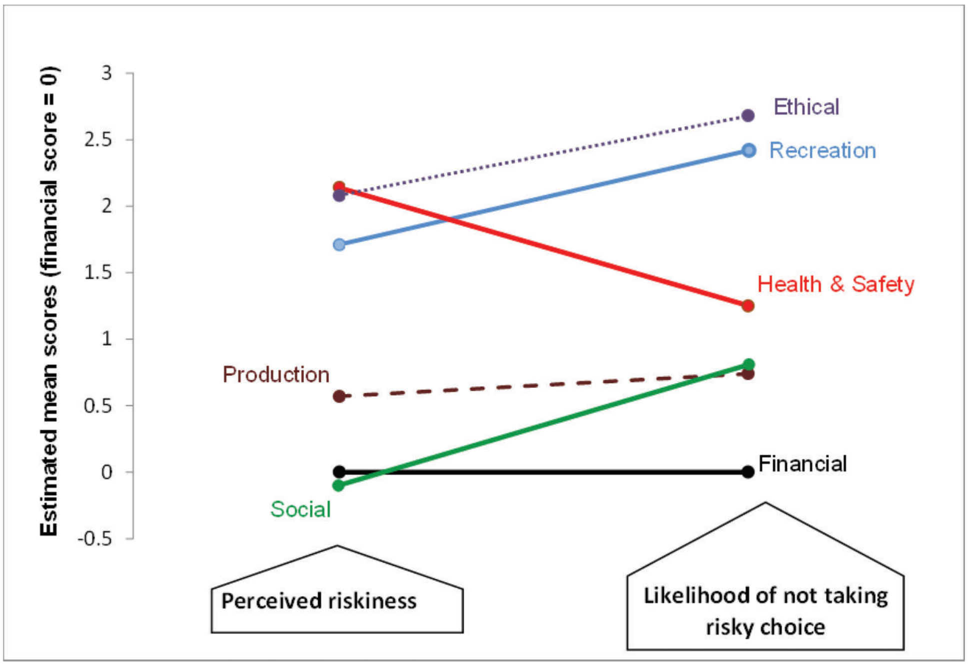

Figure 1: Model estimated mean scores by domains relative to the financial domain (as given in the first five rows of Table 2)

Table 3: Categorical farm-related variables significance using likelihood ratio tests

Variable	Number of categories	Risk perception (p-value)	Stated likelihood of not taking a risky choice (p-value)
Farm business related factors			
Farm type	5	0.08	0.35
Farm size	4	0.26	0.48
Proportion of farmed land owned	4	0.89	0.35
Income dependency on farm business	3	0.81	0.76
Capital security of farm business	4	0.18	0.15
Farm household related factors			
Age	4	0.13	**0.01****
Education level	4	0.52	0.58
Agriculture-related education	2	0.07	**0.01****

*Significant at 0.05; **significant at 0.01 level.

Table 4: Details of significant farm household relationships

	Stated likelihood of not taking a risky choice		
	Base group	**Comparator group**	**Coefficient (SE)**
Age group	<25	26 to 40	0.36 (0.43)
		41 to 60	**0.82*** (0.42)
		61 over	**1.10*** (0.44)
	26-40	41 to 60	**0.46*** (0.19)
		61 over	**0.73**** (0.24)
	41-60	61 over	0.27 (0.21)
Qualification in agriculture related subjects	Yes	No	**0.55**** (0.19)

*Significant at 0.05; **at 0.01 significant level.

Table 5: Effect on opinions about the role of farming

How important is farming to: (1= not at all important; 5= very important)	Risk perception	Stated likelihood of not taking a risky choice
	Coef. (SE)	**Coef. (SE)**
Looking after the environment	**0.47**** (0.09)	**0.42**** (0.09)
Keeping a rural community alive	**0.26**** (0.08)	**0.26**** (0.08)
Maintaining the local landscape	**0.51**** (0.09)	**0.47**** (0.10)
Food security	**0.30**** (0.10)	0.10 (0.11)
Maintaining the land for future generations	**0.26*** (0.11)	0.08 (0.11)
Providing the public with space for recreation	**0.14*** (0.07)	0.09 (0.07)

*Significant at 0.05; **at 0.01 significant level.

the stated likelihood of not taking risky choices. Thus the more important respondents felt farming was to the achievement of societal goals the higher their perceived riskiness scores and lower their stated likelihood of taking risky choices.

4. Discussion and conclusions

This study confirms what is a commonly accepted but largely disregarded assumption in models of farmer decision choice - that not all risks are equal. While a larger and stratified sample would provide greater confidence that the results of the statistical analyses are robust, particularly the relative ordering, the background information on respondents indicates that they are not an atypical sample. The strength of difference between the domains may be greater than that detected here, since the effect may have been reduced as a consequence of the inclusion of risky choices that were not exclusive to a single risk domain.

Decision choices with an ethical component were perceived to be particularly risky and participants were more averse to taking these as compared to other risks. Many of the ethical decision choices investigated were subject to regulations, with the potential for prosecution and fines if an unacceptable outcome arose. Damage to a site of special scientific interest (SSI) or a scheduled ancient monuments for instance can incur fines of up to £40,000 or £50,000 respectively in Scotland (Scottish Parliament, 2011, 2004). It was not possible in this study to distinguishing the extent to which legislation or true ethical values drove respondents' views, but the relatively high level of risk aversion to taking these risks should be reassuring to interested parties whether government, Non-Governmental Organisation or individual member of society.

The financial risk domain was perceived to be one of the least risky and contained choices that participants were least likely to avoid. This finding is consistent with previous studies flowing from the sentinel work of

Gasson (1973) highlighting that profit generation is not the only and is often not the primary goal of farmers. Furthermore, it accentuates the call made by OECD (2009) for holistic studies of farmer behaviour that go beyond financial optimisation if better models are to be developed.

With most respondents considering that farming has an important role to play in wider societal goals and their preference to particularly avoid ethical and health & safety risks the results indicate a positive attitude to issues that in other business environments might be termed 'corporate social responsibility'. However, there is anecdotal evidence that this does not translate into practice in all cases. The study findings therefore suggest that barriers may be preventing farmers acting in line with their risk preferences in many situations. For instance where legislation or markets require farmers to engage in hazardous activities such as tagging calves and clipping cattle which resulted in injuries to 24% of respondents in a survey of Scottish farmers (Lindsay *et al.*, 2004). This supports the viewpoint that there has been too great a focus on farmer attitudes, behaviour and choice in recent years (Burton, 2004; Shove, 2010). Defining these barriers and finding solutions that are effective in commercial conditions could lead to greater consistency between attitudes and behaviours as well as greater progress towards the desired goals of both farmers and society. One hypothesis worthy of investigation would be that the level of perceived or actual control plays a key role. This might also explain why the three types of risk domain emerged from the statistical model as there can be greater opportunities to implement mitigating actions with respect to production, financial and social risks as compared to the ethical and recreational risks explored in the study (domain types 1 and 2). Furthermore, anecdotal evidence suggests that farmers feel they are unable to avoid some health & safety risks. For example, many farmers are sole workers and consequently it was difficult for them to ensure they were not 'Undertaking potentially dangerous farm activities without someone knowing where you are'. Similarly farmers commonly must operate in close vicinity of recently calved cows in order to comply with regulations requiring calves to be tagged within a few days of birth. The apparent acceptance of such risks (type 3 domains of risk) is a concern but since decisions that presented health & safety risks were perceived amongst the riskiest choices the results indicate there is a good level of health & safety awareness. Consequently, while education remains essential, this study suggests that other approaches are likely to be required if the annual level of agriculture related fatalities, which has changed little in more than ten years, is to be improved (the average rate of fatality per 100,000 workers was 9.2 for the five years to 2002/3 and averaged 9.9 for the five year period to 2012/13 (HSC, 2001; HSE, 2014, 2004, 2003, 2002).

A mixture modelling approach of the data collected is currently being undertaken to explore the domains and associated risky choices in greater depth, including issues associated with the fact that many risky choices cannot readily be assigned to a single domain. A key question in this work is whether the assumed domain structure accurately describes that perceived by farmers. In addition, further investigation of relationships between farm-farm household factors and risk preferences is planned since, arguably, more may have been expected than were found in this analysis.

Confirmation that farmers hold heterogeneous, as compared to constant, risk preferences opens new research pathways for those interested in improving policy effectiveness and potential responses of farmer managers to changes in their operating environment. Specifically, where decision choices are holistically being examined the inclusion of heterogeneous risk preferences may improve the explanatory and/or predictive power of models, particularly in cases where balancing multiple and competing goals strongly feature.

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Appendix 1 Risky choices investigated in the study

Risk domain	Risky choice
Financial	Continuing to employ someone you don't have enough work for Using an overdraft rather than a loan to fund a capital purchase Selling livestock at auction Continuing to employ someone that you can't really afford Investing a large amount of your own capital in a new enterprise Investing a large amount of your own capital in an existing enterprise Buying land to increase scale if it was available Selecting to receive subsidy payments in Euros Renting land to increase scale if it was available Forward selling produce Borrowing a large sum of money to invest in a new enterprise Borrowing a small sum of money to invest in a new enterprise Investing in a significant new farm building Borrowing a large sum of money to invest in an existing enterprise Trading Single Farm Payment entitlements Forward buying inputs Not having spare capacity in machinery/equipment in case working windows are shorter than average Borrowing a small sum of money to invest in an existing enterprise
Ethical	Disposing of a chemical/chemical container in a way that is not recommended Not calling the vet immediately to treat a sick animal when you cannot identify the cause Not always notifying households neighbouring your fields when you are going to spray crops Not acting to make safe an animal straying on the road that belongs to neighbour who is out Spraying crops or grassland when there is a risk of wind drift Applying fertiliser including FYM/slurry at a time that could lead to pollution Leaving a lambing/calving/farrowing animal unsupervised to attend a family event Not checking breeding animals regularly during lambing/calving/farrowing Knowingly undertake an action that could harm a protected species Not treating an injured animal immediately it was identified Knowingly undertake an action that could damage a scheduled monument Knowingly undertake an action that could damage a valuable/protected habitat
Production	Buying inputs from a known new supplier Buying inputs from an unknown supplier. Not adjusting crop protection plans in response to weather conditions Buying replacement females at auction from an known source Buying replacement stock at auction from an UNKNOWN source Employing someone who you are not entirely comfortable can do the job/fit in to your business Not responding immediately to an unusual livestock health problem Starting an entirely new enterprise on the farm Selling produce into a new market Changing your production method significantly e.g. finishing cattle off grass instead of a housed system. Significantly changing the scale of one or more enterprise on your farm Not adjusting stocking & grazing fertiliser rates from year to year
Health & safety	Not wearing full protective clothing whilst working with chemicals Working with machinery that does not have all its safety guards Driving when you know or think you might be over the legal alcohol limit Not wearing a seat belt when being a passenger in the front seat and on a public road Undertaking potentially dangerous farm activities without someone knowing where you are Enter a pen with a bull or recently calved cow without a stick or taking other protective measures Not providing workers with the full protective clothing recommended for a task Consuming five or more alcoholic drinks in a single evening Not wearing a helmet when riding the farm quad bike Not wearing a helmet when riding a motorcycle Driving a quad bike or tractor over terrain which has a slope which might be dangerous
Recreational	Occasionally engaging in dangerous sports e.g. sky diving Going down a ski run that is beyond your ability or closed Trying out bungee jumping at least once Piloting your own small plane, if you could
Social	Arguing with family peers about a major issue not relating to the farm Disagreeing with your family peers about how the farm is run Telling a friend that you don't agree with their behaviour Defending an unpopular issue that you believe in at a social event Admitting that your tastes are different from those of your friends Not assisting a farming friend/neighbour when they ask for help Taking time off during harvest to go to a family event Arguing with a friend Not informing a neighbour immediately if his/her animals were straying Selling something to a friend/neighbour without accurately stating any quality problems it might have/has Selling something to an unknown person without accurately stating any quality problems it might have/has Lending a friend/neighbour valuable equipment

REFEREED ARTICLE

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PerfCuma: A framework to manage the sustainable development of small cooperatives

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ABSTRACT

Agricultural cooperatives evolve in a context with complexity and changes of their legal, social and business environment. Strategic management could be a relevant approach to help cooperative members to improve the global performance and the social responsibility of their cooperatives. To formalize and to manage their strategy, we propose as an accompaniment a method entitled PerfCuma. The theoretical framework is based on the concept of systemic approach to change. The method is organized in four steps: i) an in-depth stakeholder's analysis of the cooperative situation (including sustainability) and the cooperative goals; ii) formalizing the strategy by defining strategic lines. We use the cognitive map approach to model the complexity to understand the strong drivers of the strategy; iii) drawing up the balanced scorecard and an action plan to manage the strategy; iv) monitoring the implementation of the strategy. A test of the method on five Cooperatives for the Use of Agricultural Equipment (Cuma) has been successful. The method is now unfolded in France.

KEYWORDS: strategic management; causal map; balanced scorecard; cooperative; systemic approach to change; Corporate social responsibility

1. Introduction

For 40 years in France, the prices of agricultural commodities have been falling at an annual rate of close to 2% in constant euros. At the same time, French farmers have produced more. Production has increased in volume by just under 25% (from 1980 to 2014) thanks to crop production (Insee.fr: Annual national accounts). But this growth has not been enough to stop the downward trend in French total agricultural income. There has been a downward trend in the value of farm production (from Index 100 in 1980 to Index 78 in 2013), whereas the value of farm expenditure has been constant (from Index 100 in 1980 to Index 100 in 2013). Nevertheless, the agricultural income per farmer has increased over this period (from Index 100 in 1980 to Index 160 in 2013). Farmers have succeeded in improving their income per worker because they have developed their competitive advantage through a cost leadership strategy (Porter, 2008). To reduce their production costs, farmers have developed numerous methods, such as specialization, extension, and modernization, to increase labour productivity (from Index 100 in 1980 to 306 in 2013). Their main objective has been to fight against the decreasing French total agricultural income. The number of farmers has dramatically decreased over the last 40 years. They have specialized their farms and organized regrouping of land. In 40 years farm land per worker has risen by nearly three times. In this context agricultural production is becoming increasingly complex. Farm sizes have increased, and this phenomenon has been accompanied by a saturation of working capacity (Madelrieux and Dedieu, 2008). In order to produce more with fewer workers, farmers have continued to invest in their fixed assets over the last 40 years. The French gross fixed capital (GFCF) consists of fixed asset acquisitions and corresponds to an investment of about 10 billion euros a year. Because technologies and assets are costly, farmers try to pool their agricultural equipment to reduce their average production costs. In France, for a long time, many farmers have joined cooperatives to share use of agricultural equipment (Cuma). There are 13,000 Cumas in France, and one in two farmers is a member (225,000 farmers are involved in this kind of cooperative). The Cuma gathers farmers together to buy agricultural equipment, to obtain specific subsidies, to improve their competitiveness, and to organize their work for higher efficiency. Every type of farmer is involved in these cooperatives. However, the biggest farms, those which have chosen the legal status of company, and those whose managers are under 50 years of age, are more involved in Cumas.

Meanwhile, due to environmental, health, and economic crises, the supervision of agricultural production

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by the public authorities has intensified. Farms are facing rapid changes in the Common Agricultural Policy (CAP) [1] with the reorientation of first pillar subsidies to the second pillar, and the gradual disappearance of support mechanisms and market regulation. The supervision of farms by upstream and downstream actors[2] has also increased, especially with the strengthening of specifications and regulations in relation to production, and the consolidation of contractual relationships between producers and collectors/processors. Farmers are operating in an increasingly competitive environment, one from which they had previously been relatively protected. Just as happened in the industrial sector, farms may be forced to progressively improve their technical, economic, environmental, and social performance in order to maintain their activity (Pretty, 2008); (Darnhofer *et al.*, 2010). Cooperatives for the use of agricultural equipment (Cuma) can help them to meet these challenges. The complex competitive environment poses a number of issues for both cooperative members and the advisors supporting them: how to obtain and maintain competitive advantage; how to integrate new developments into every day business activities; and how to develop the capacity to guarantee a response to downstream demand while maintaining or improving the performance level, especially in the case of a Cuma and its member farms. The specific issue faced by Cumas is to define and implement a collective, shared, and structured strategy. The challenge is to create new collective capabilities to help cooperative members to remain viable and sustainable, i.e. to be able to cope with their changing and complex environment.

These issues are typically addressed by business management specialists in terms of strategic management and strategy of the firm. The challenge is to have a common approach and a management tool to implement and to control the strategy (Freeman, 2010); (Kaplan and Norton, 1996); (Stacey, 2007). The strategic management approach remains marginal and is poorly developed in farms and Cumas in France. Often, if it exists, it is not organized and not formalized. The Cuma is a specific cooperative, generally without professional staff because it is small: from 4 to 60 members (average 25 members) with a turnover of between €10,000 and €200,000 (average €49,000). Although marginal from an economic point of view, Cumas have major implications for the competitiveness of farms. We assume that strategic management could be a relevant approach to help farmers to manage their Cuma, to improve its overall performance, and thus the overall performance of the Cuma.

In France, few original studies of farm management and Cuma management have been carried out in the area of management science (Jeanneaux and Blasquiet-Revol, 2012), while a large body of literature exists in the English language on strategic management as it applies to farming: For example, 15 handbooks dealing with farm management have been published since the early 1980s (Barnard and Nix, 1979, Kay, 1986, Turner and Taylor, 1998, Casavant and Infanger, 1999, Olson, 2004), but no French farm management handbook has addressed farm management as a continuous process (planning, implementation, control, action). French farm management academics have ignored this literature for the last 30 years and have not published in the English language. Agricultural economics is more developed in France than Farm management science, especially because the French National Institute for Agricultural Research (INRA) has paid less attention to this subject. In France, farm management has been largely influenced by economic concepts. Even today, farm management methods are based on an economic diagnosis using a comparative benchmarking analysis between farms. The best farms are considered to be those which are the most profitable, based on the assumption that farmers are only motivated by profit with a substantive rationality (Simon, 1982). The objective of the present French system is to identify the factors which explain how to be more profitable, and to give advice to use these levers (Chombart de Lauwe *et al.*, 1969). Of course, other approaches consider farmers as agents with bounded rationality who try to obtain a situation that is not Pareto optimal (Simon, 1982). In reality farmers can have numerous goals, which are in competition with each other, and the advisor in a systemic approach has to make a diagnosis of the whole farm to understand how to help the farmer to be satisfied (Marshall *et al.*, 1994). These approaches based on diagnosis are static, use historical and obsolete data, and are not designed to help farmers to be more adaptive. A notable exception in France is Hémidy *et al.*, (1996) who, in the mid-1990s, proposed the implementation of a strategic management approach in farming.

To develop strategic management in farming, the challenge is to be able to give advisors the ability to initiate and support farmers in their development of strategy.

The objective and originality of this paper is to present the outline of a methodological framework to assist in the implementation of strategic management within Cumas in a complex world where sustainable development is a main issue; in other words, to help cooperative members to formalize and to manage a strategy in order to be more sustainable and more resilient.

As Bossel and the Balaton group consider (Bossel, 1999; Bossel 2000): ''*Human society is a complex adaptive system embedded in another complex adaptive system - the natural environment - on which it depends for support. These systems coevolve in mutual interaction, and they each consist of a myriad of subsystems that coevolve in mutual interaction. There is permanent change and evolution. Moreover, this ability for change and evolution must be maintained if the systems are to remain viable (able to cope with their changing system environment) and sustainable. The sustainability goal translates more accurately into a goal of sustainable development*''.

Sustainability is a dynamic concept. Societies and their environments change, technologies and cultures change, values and aspirations change, and a sustainable society must allow and sustain such change, *i.e.* it must allow continuous, viable, and vigorous development, which is what we mean by sustainable development.

This methodological framework has been developed as part of 2 research projects named PerfEA (i.e. overall

[1] The EU's Common Agricultural Policy (CAP) is the system of agricultural subsidies and programmes. It covers farming, environmental measures and rural development, and controls EU agricultural markets. It is the EU's single largest common policy and accounts for over 40% of the entire EU budget. Since 2003, the CAP has been divided into two 'Pillars': production support and rural development.

[2] Upstream actors correspond to agricultural input (fertilizers, pesticides, concentrates…) suppliers. Downstream actors correspond to agricultural commodities processors and/or purchasers (dairy and cheese processors, millers, slaughterers…). Upstream and downstream actors are often the same and have a lot of influence on farmers' decision.

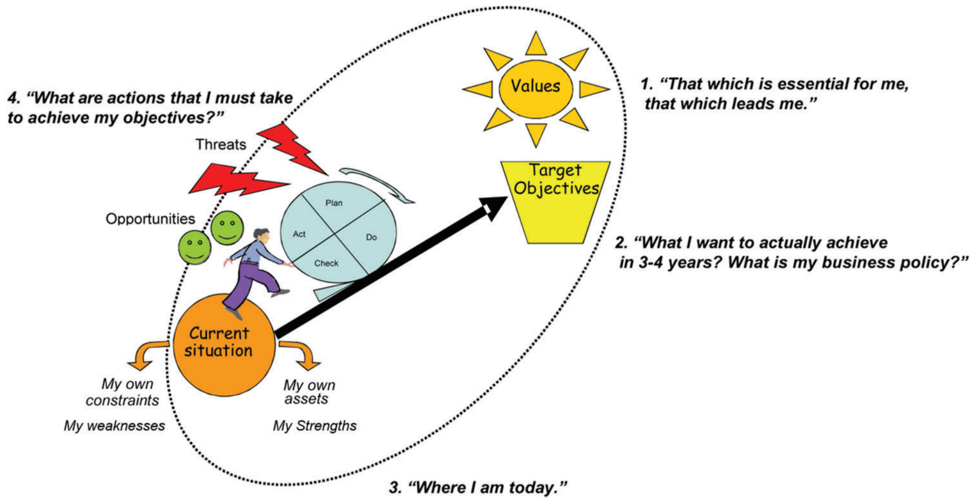


Figure 1: The strategy is the overall approach which allows the achievement of cooperative members' objectives

farm performance), and more recently, PerfCuma (i.e. overall performance of Cuma)[3].

Before presenting this research, we review the conceptual framework that governs the project in section 2. Then we present the research system in section 3 and the methodological framework in section 4. Finally, we review the implications that such a study can have for farming advisory services in section 5.

2. Analytical framework of the strategic management approach

2.1.The conceptual framework underlying the project

We chose to build on a framework that is well known in management science: a continuous improvement cycle (Deming or Shewhart cycle). We used this cycle in order to organize the thinking around the building of our methodological framework to support strategic management. The concept of continuous improvement involves a number of sequential steps:

(1) Planning the strategy requires the definition and formalization of a general policy, broken down into strategic objectives and action areas, and then the construction of an action plan;
(2) *Implementing* the action plan brings the ''as is'' or current situation to the ''to be'' or future situation;
(3) *Monitoring* the results allows the assessment of the desired performance and the action plan;
(4) *The* examination of the strategy as part of this assessment should include the adjustment of strategic objectives as necessary and the modification of the action plan. Based on the analysis that the members of the cooperative perform of their specific situation and the changes in their environment, the strategic management approach allows them to establish and implement a cooperative management project. It is a question of being able to build a strategy and obtain the necessary elements to make choices and adjust the priorities of the different objectives. The approach must be able to give members the means to manage their activity and to engage them in a process of continuous improvement (Figure 1).

[3] PerfEA is a research project about the issues surrounding farm management carried out from 2009 to 2012. PerfEa is centered on the commitment and participation of numerous and different stakeholders to co-construct a method to help farmers to plan and to implement and to monitor their strategy. PerfEa was supported through European Regional Development Fund, French National Development Fund, Auvergne Regional Fund and Ademe funds. PerfCuma, based on PerfEA but dedicated to Cuma was conducted in 2014/2015.

2.2.Two conditions for acceptance by the decision makers in cooperatives

We chose to use the strategic management approach and took into account two extra requirements. The first requirement is the desire not to produce normative recommendations, but to work within a methodological framework that produces an appropriate and relevant strategy taking into account the specific situation of each cooperative and its specific environment. The second is to go beyond the definition of strategic objectives and to give members the opportunity to develop management tools and performance indicators that are relevant to a continuous assessment approach. This approach allows the members to build tools that can help them take stock of their strategy and their ability to achieve the defined objectives.

3. Research with public agricultural school farms and ahe cuma

We chose to work with 7 farms owned by public agricultural education institutions based in the Massif Central region (central France) to create the PerfEA method. These farms play an experimental and developmental role which is an appropriate framework for our research. They also enable an initial design activity that would not be supported by private farms (risk-taking and freeing-up time for design activities). Farms owned by agricultural education institutions are complex structures. In addition to the need to ensure economic balance, they must be a powerful teaching aid. These farms are dependent on the institutional environment and local agricultural policy, and may at times be caught in the middle of power games. There are often many stakeholders associated with what currently happens in the Cuma. To build a farm management project therefore requires real strategic thinking. Indeed, farm managers are faced with methodological difficulties in relation to the successful management and control of the farm: how to mobilize employees, manage the processes, facilitate discussion, prioritize objectives and actions, and define the evaluation process.

We carried out the PerfCuma research program in 2014 and 2015, with the 4 following aims. 2 main criteria for success for the PerfCuma project were stated: (1) the first was to educate Regional Cuma Federation advisors so that they could help Cumas to implement a strategic management process based on PerfCuma. (2) The second was to adapt the PerfEA methodological approach for Cumas using the PerfCuma research project in the Auvergne region (central France). 3 advisors were trained and the methodological process adapted to Cumas is now operational, and numerous Cumas have benefited from this scheme.

To adapt the PerfEA methodological approach to Cuma, 5 Cumas and their cooperative federations were involved in the project. A third objective (3) was, for the Cuma members, to define their strategy themselves and to have a balanced scorecard (BSC) to implement and manage the strategy for the next 5 years (cf. section 4. and Appendix to get an overview of the BSC). The Cumas were volunteers and had to respect 2 conditions: They had to want to take part in collective strategic thinking by including, if possible, all their members; due to the financial support they had to be located in the Auvergne Region. The implementation was successful. PerfCuma is a success story because Cuma members are satisfied. Participant satisfaction surveys were organized. The members appreciated having the opportunity to express their opinions and to have been listened to. They also appreciated the advisor's behavior, because the atmosphere was respectful, sympathetic, and constructive. They felt that everybody was at the same level. They appreciated the quality of the discussions, and enjoyed the originality and the wide range of the topics covered. Finally, they appreciated deciding their own strategy, and having a Balanced Scorecard to manage it. Both the PerfEA and the PerfCuma approaches are now used by numerous stakeholders: farms owned by public agricultural education institutions, private farms, and Cumas all over France. A new educational program within Agricultural High Schools has implemented PerfEA and PerfCuma, and an ongoing training for agricultural teachers, Cuma advisors, and agricultural advisors was created 3 years ago.

The final objective (4) was stated by the funding authorities who financed the PerfCuma research project and who allocate subsidies to help Cumas to be more efficient, related to the new part of regional policy dedicated to supporting Cumas. The regional political authorities wanted to take into account new criteria related to management (without knowing exactly what kind of criteria). At the end of the PerfCuma research programme, the regional authorities, in agreement with the Regional Federation of Cuma decided, starting in 2016, to make their financial assistance (to fund equipment) dependent on the implementation of a strategic management process like PerfCuma. Since 2016, the same strategy has been implemented by the French ministry of agriculture in collaboration with the French National Federation of Cumas.

The Cuma methodology uses specific tools to collect the individual point of view of each cooperative member. This method helps the group to decide collectively in a participative and consensual way. The aim is to have a project shared by all the stakeholders in the Cuma. The framework is now formalized as a guidebook, and 3 cooperative advisors were trained in the PerfCuma method. They can use it to respond to the needs of Cumas. The guidebook helps them to integrate social innovation and strategic management to improve overall performance in their business models. The method can be deployed in other cooperative federations because we have developed a curriculum to train cooperative advisors.

4. A methodology for the implementation of strategic management in a cuma

4.1. Three successive steps

The methodology has to support cooperative members in a process that is broken down into three successive steps.

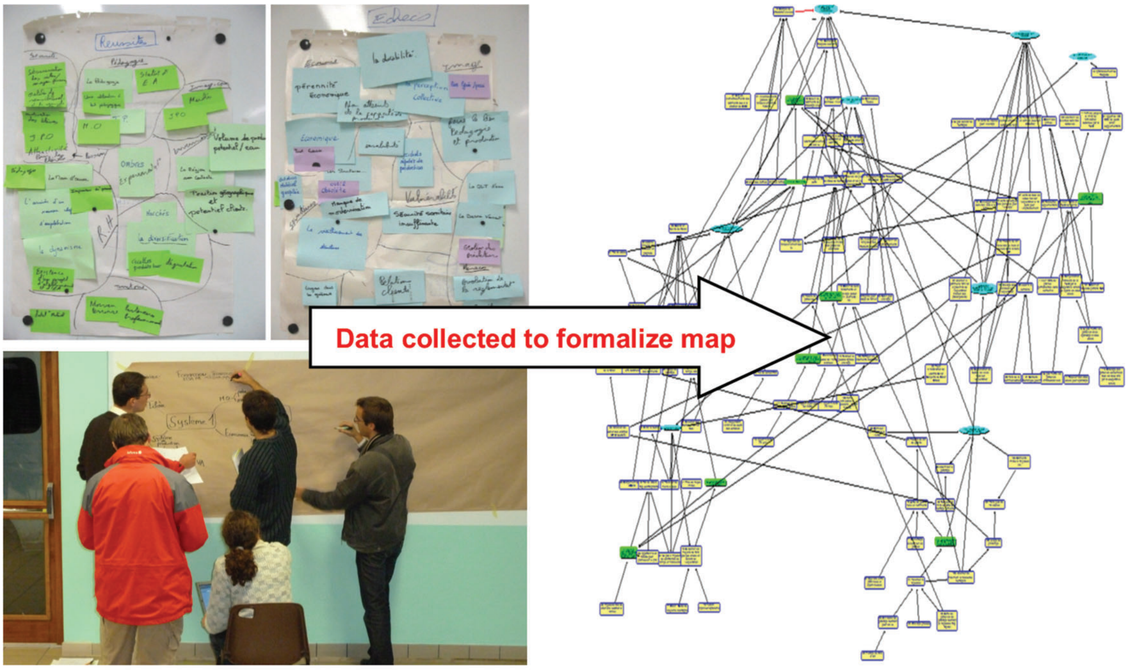
The first step (Figure 2) is based on an analysis of the future of agriculture, the environment, and the motivation of the cooperative's members. This strategic thinking approach typically involves several areas for consideration, each representing different goals. A review of past successes and failures, the expression of a vision by projecting into the future (4 to 5 years), and the expression of the values that drive the organization. Cooperative members must also discuss missions. The internal and external analysis is necessary for the strategic approach, because it allows the organization to agree on the goals to be achieved and actions to be implemented.

To illustrate it, we give below an example based on the Cuma Smith. Cuma Smith is one of the largest in France. The cooperative has 60 members with 16,500 acres and 5,900 Livestock Units (See Appendix 1). The main collective value defined by Cuma Smith members is mutual assistance and solidarity. A mission is to provide low operating cost equipment, and the vision is to stay on course: to always move forward in satisfying members by keeping a good atmosphere in the Cuma, and by the development of the equipment. The simplistic measure of success is to succeed in growing, which would mean the members are satisfied. But the main issue is to maintain a good atmosphere, low cost, and commitment.

Because the challenge is to help cooperative members to deal with complexity, we carried out a theoretical methodology based on the concept of a systemic approach to change. The discussion with cooperative members is based on the capacity of the cooperative to deal with its environment and unforeseen circumstances.

We use the framework from Bossel and the Balaton Group (1999) to encourage cooperative members to discuss the overall performance of the cooperative. This methodology is based on the systemic approach and considers the Cuma as a system which has to deal with its environment (Figure 3). We postulate that sustainable systems necessarily meet certain conditions as determined by the relationship between the system and its environment. From this perspective, the framework defines a set of 6 basic features which characterize the various types of relationships that define the sustainability of a system in its environment: existence, effectiveness, security, adaptability, freedom of action, and co-existence.

Cooperative members have to discuss the sustainable development of the Cuma. Several indicators are



1.1 Workshops to debate the values and the vision of the organisation

1.2 A causal map to formalize individual and collective representations of the organisation

Figure 2: First step: From the workshops to a causal map

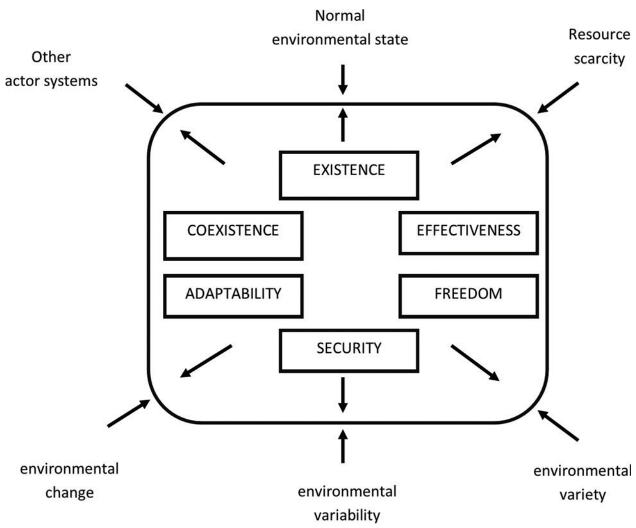


Figure 3: Fundamental properties of system environments and their basic orientor (Source: Bossel 1999)

scrutinized. For each basic feature, questions are posed to members (Figure 4).

For example, for the security of the Cuma, we ask members if they think their Cuma is secure, safe and stable, what shocks could drastically affect the Cuma, and what members can imagine as actions to become more resilient. We ask members to bring together their perceptions about resource scarcity in order to discuss the effectiveness of the cooperative. Figure 5 presents an overview for Cuma Smith of all answers the members gave in a collective workshop.

This first step needs an advisor, a facilitator (Schuman, 2005), to organize the discussion in such a way as to collect the information necessary for the next step, a causal map.

The causal map formalizes individual and collective representations about what members want to do together. The causal map is presented below (section 4).

From an epistemological point of view, this method takes its roots in the socio-constructivist paradigm (Vygotsky, 1978). The interactions between the actors and the tools used to help to design a collective representation of the behaviour of the system are also articulated in order to support individual and collective learning. Following Kaplan and Norton (1996), we consider that there are some central ideas linked to various causal idea chains, and the challenge is to identify them, and to focus the farm management on what has become a specific strategic target. This is the objective of the next step (2).

The second step (Figure 6) is to formalize the strategy, and to support the strategic management and the evaluation of the performance obtained. This step involves supporting cooperative members in the definition of strategic areas, and the selection and prioritization of business objectives. It is based on the creation of a balanced scorecard as a primary tool (Chabin, 2008). This scorecard can be multi-dimensional, integrating criteria that are financial and non-financial, short and long term, qualitative and quantitative, retrospective and prospective. Using the measurements produced, the Balanced Scorecard reflects the degree of success of the strategy. It also aims to integrate non-financial indicators that are expected to provide a prospective overview of the company and its environment, which explains why we talk about a balanced scorecard (Kaplan and Norton, 2004); (Noell and Lund, 2002).

Following Kaplan and Norton (2004)'s point of view, we consider that measurement is fundamental to managers. If companies try to improve the management of their intangible assets, they have to integrate the

Basic orientor	Viability of affecting system	Contribution to affected system
Existence	Is the system compatible with and can exist in its particular environment?	Does the system contribute its part to the existence of the affected system?
Effectiveness	Is it effective and efficient?	Does it contribute to the efficient and effective operation of the total system
Freedom of action	Does it have the necessary freedom to respond and react as needed?	Does it contribute to the freedom of action of the total system?
Security	Is it secure, safe and stable?	Does it contribute to the security, safety and stability of the total system?
Adaptability	Can it adapt to new challenges?	Does it contribute to the flexibility and adaptability of the total system?
Coexistence	Is it compatible with interacting subsystems?	Does it contribute to the compatibility of the total system with its partner systems?
Psychological needs*	Is it compatible with psychological needs and culture?	Does it contribute to the psyshological well-being of people?
Responsability*	Does it take into account its impacts on the futures and current generations in the decision making?	Does it contribute to the durability of the total system?
Reproductibility*	Is it able to be self-produced and be passed?	Does it contribute to help others by using or saving it in the total system?

*only for systems with sentient beings

Figure 4: General scheme for identifying indicators of viability (Source: Bossel 1999)

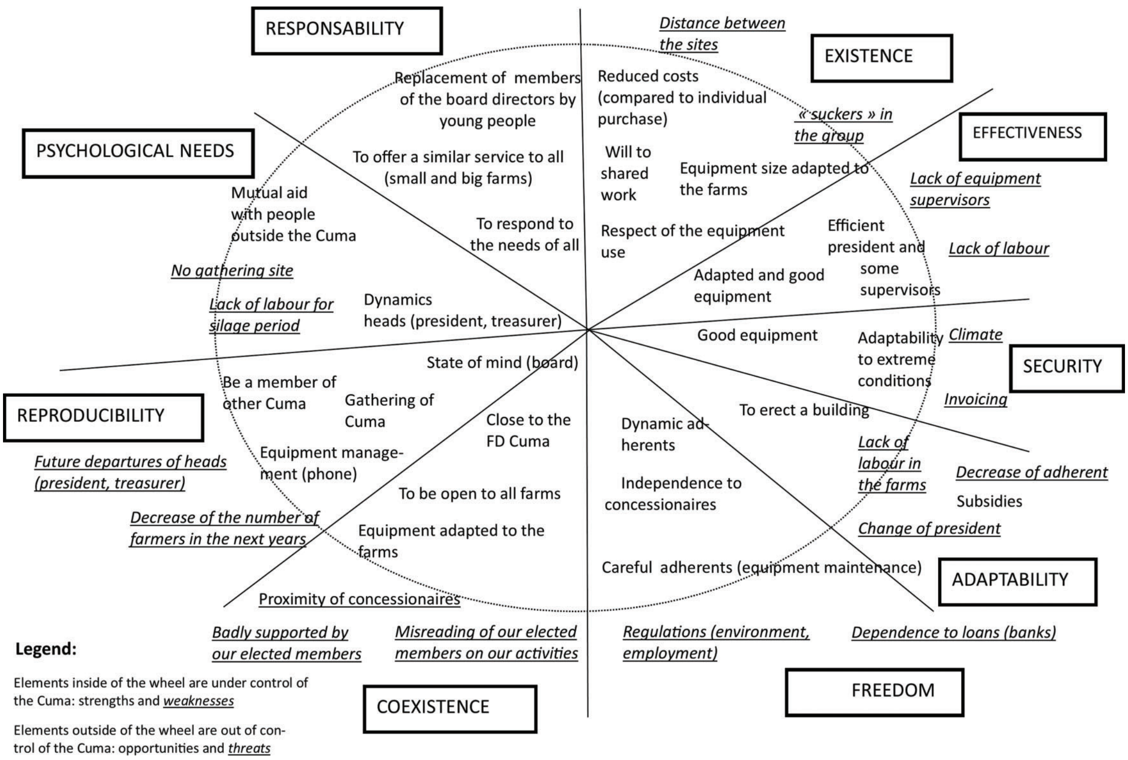


Figure 5: Analysis of the Cuma Smith by its members using Bossel indicators

measurement of intangible assets into their management systems. The first step helps us to take into account these strategic intangible assets. But contrary to Kaplan and Norton, we do not impose the 4 topics raised by them, because PerfCuma is not a normative approach. Bossel and the Balaton group (1999) propose to consider that sustainable development requires systems of information. It needs indicators are needed to provide comprehensive information about the systems which shape sustainable development.

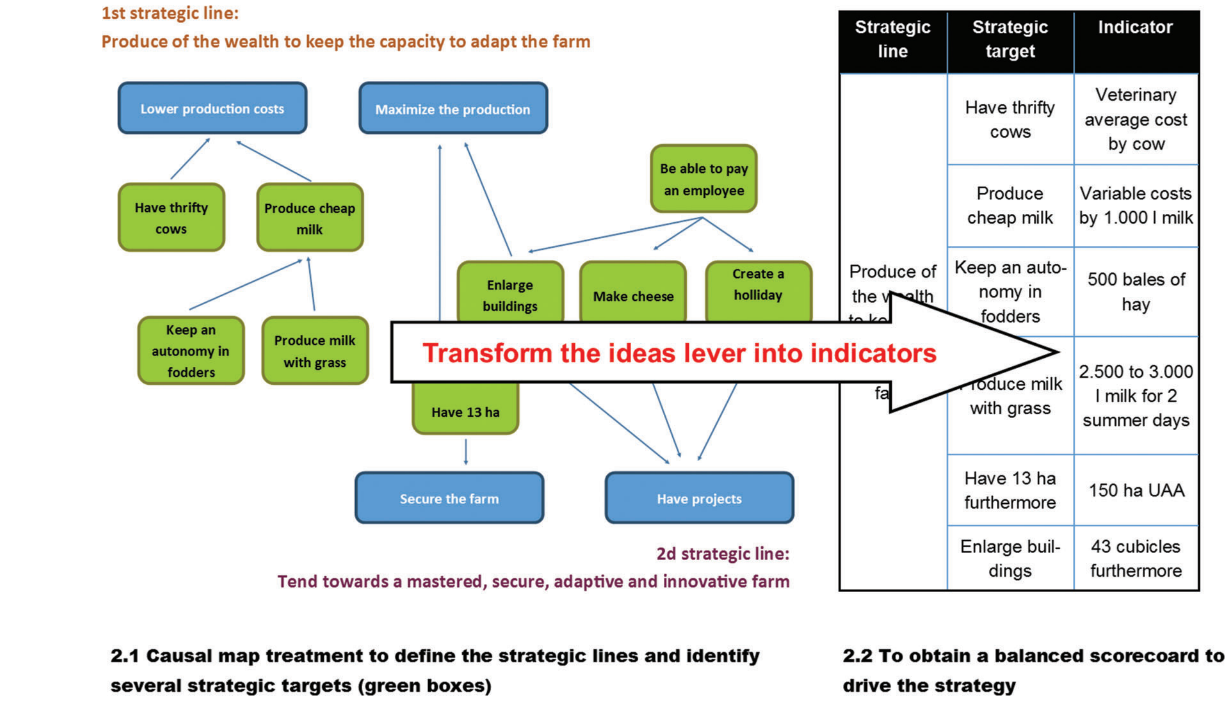


Figure 6: Second step: From the causal map to a balanced scorecard

Balanced scorecard				Action plan	
Strategic target	indicator	Target value	Frequency of control	Actions	Means of action
Produce cheap milk	Operating costs per 1.000 l milk	Not upper than 120 €	Every dairy campaign	Improve forage quality	Re-sow with a mixture grasses/legumes
				Add drinking ...ughs	
				Limit tue concentrate by daidy cow	Define a ration with 700 kg of concentrate/cow/year

Creation of an action plan

Figure 7: Third step: Implementation of the strategy

Thus, indicators of sustainable development are needed to guide strategy and decisions, and they are chosen by the members. Each selected measure must be an element of the causal relationship string, expressing the strategic direction chosen by the Cuma. The number of indicators based on the central ideas should be as small as possible, but with as wide a coverage as possible.

The third step (Figure 7) is to define an action plan which presents the means (financial, technical, human, etc.) necessary to implement the strategy, and then to support the monitoring of the implementation of the strategy. The balanced scorecard includes the action plan and helps the monitoring of the roadmap over a 4–5 years period (see Appendix 2 for an example of such a balanced scorecard).

The balanced scorecard focuses on less than 10 indicators, to allow Cuma staff members to monitor clearly the implementation of the strategy. For each strategic target based on the central ideas of the causal map, there is a SMART strategic indicator (Doran, 1981): Specific; Measurable; Assignable; Realistic; Time-related. And for each indicator, there are between 1 and 3 actions to complete.

For Cuma Smith, a central point concerns the ability to stay a step ahead. After discussion, Cuma members chose collectively a "Regular investment" indicator. In fact, they decided that it should be to spend 100,000€/year to finance equipment, and they wanted to maintain this effort for the next 4 years (it is a SMART indicator), so the action plan includes both "to renew equipment as soon as it is amortized" and "to keep a watchful eye on robustness of the equipment at purchase".

4.2. A causal map ensures the link between steps

The link between the first two steps is ensured by a tool used to build, represent, and negotiate strategy: the causal map. This is a tool which has not been used in France previously to define strategic choices in relation to farming. The use of a causal map to explore the cognitive structures of an organization is now widespread in management research (Huff, 1990; Laukkanen, 1998). Particularly suitable for strategic approaches (Eden, 1988; Cossette 2003), a causal map helps to formalize individual and collective ideas. The cognitive approach allows company management to gain a greater understanding of their strategic situation, and facilitates the identification of problems and their interrelationships. It also helps to develop new ideas for possible directions for the company, in order to facilitate decision-making in relation to strategic choices. The causal map has been used to study the cognitive representations of different actors in various different contexts, some similar to those studied here, such as the performance of cooperative wine makers, or the modelling of perception with regard to the socio-ecosystem of farming among farmers (Fairweather, 2010), or with the Strategic Options Development and Analysis framework (SODA) which has been used extensively with organizations public and private, large and small (Ackermann and Eden, 2010). In practical terms, it is a graphical representation of defined concepts based on causality links which are identifiable by the statements that unite them. The causal map is relevant for representing the complexity of a system by creating links between all the concepts which are involved in the context studied.

The representation of elements in a map can help to clarify meaning. It shows the causal relationships and the reasoning behind the decisions taken. The causal map is both a tool for communication, and an analysis tool (Cossette, 2003). The causal map is a mediation support tool that clarifies thinking and decision making, and facilitates agreement on a strategy and the creation of a vision.

The structure of the map is an analytical support. It identifies causal links between different ideas and thus facilitates the identification of the processes represented by the map. It is possible to identify multiple links (more or less interdependent, more or less competitive, more or less contradictory, more or less important) that lead to the achievement of the same objective. These links form part of different coherent sets from which the strategy can be developed. In a Cuma, coherent sets of goals emerge that are focused around economic, social, and local development themes. The links can also identify the strategic areas that form the basis for the implementation of the cooperative's management project.

In practical terms, in our project, a causal map is iteratively established with the assistance of a data processing software expert, experienced in the use of suitable software (Decision Explorer® – Banxia® Software), based on the elements provided by each of the tools used in the first step. The different maps produced are presented for discussion, amended, and validated by the stakeholders of the strategic approach. For a Cuma involved in the project, the stakeholders are, for example, farmer members, employees, members of other Cuma, members of administrative boards. The final map obtained is used to support the definition of the strategic objectives, the actions agreed, and the indicators to be used to assess performance.

In addition, the causal map provides multiple analyses that can be used as part of a strategic approach. Therefore, it is possible to perform statistical analysis based on the map. One possible analysis can highlight the concepts that are essential to the strategy. The software helps the analyst and the cooperative members to identify the goals, the key ideas, the driving forces, and the performance measures from the mass of ideas (Figure 8). We accept that the causal map is unreadable, but our objective is to show how we represent complexity. Complexity comes from the Latin word "*Complexus*" that means "*what is weaved*".

Next the analysis indicates strategic targets, and cooperative members have to select 8 to 10 key issues on the causal map. They are key because they are nodes at the heart of the map and, as a result, they are the relevant strategic issues. If any of these issues is magnified it has an impact on the whole system. Then Cuma members have to define an indicator for each of the 8 to 10 selected key issues to drive the strategy, and they have to define the goal for each indicator to build the balanced scorecard.

Causal mapping takes a central place in the proposed methodological journey because it is:

(1) a support tool that acts as an intermediary, facilitating the cognitive process (Vinck, 2000);
(2) an aid that provides a representation of the processes implemented in an organization, and facilitates the identification of the core elements of the strategy;
(3) a tool that takes complexity into account without removing it (Axelrod, 2015);
(4) a mediation tool that helps to ensure that a group has a shared vision of a given strategy (Eden, 1988).

5. The place of advice and the conditions of transferring the approach to the cuma

The effectiveness of the strategic thinking is dependent on the relevance of the processes involved. Strategic thinking cannot be satisfied with a single individual thought; it requires an external, distanced, and independent perspective. This observation is not new (Hémidy *et al.* 1996); it requires the involvement of an advisor. The advisor plays an important role in ensuring that all participants understand the thought processes involved, and in facilitating communication (Von Korff and Guetta, 2005); (Schuman, 2005).

The implementation of strategic management requires the support of an advisor, and requires some consideration as to the organizational arrangement for such advice. Starting with the idea that a successful strategy is not only defined by the degree of achievement of the objectives set, but also that it is the result of a collective vision that has its foundations in individual propositions which each person develops from his own organization and strategy, we suggest that structuring advice around groups of farmers and collective groupings will help to achieve the required results (Pervanchon *et al.*, 2007, Compagnone, 2009).

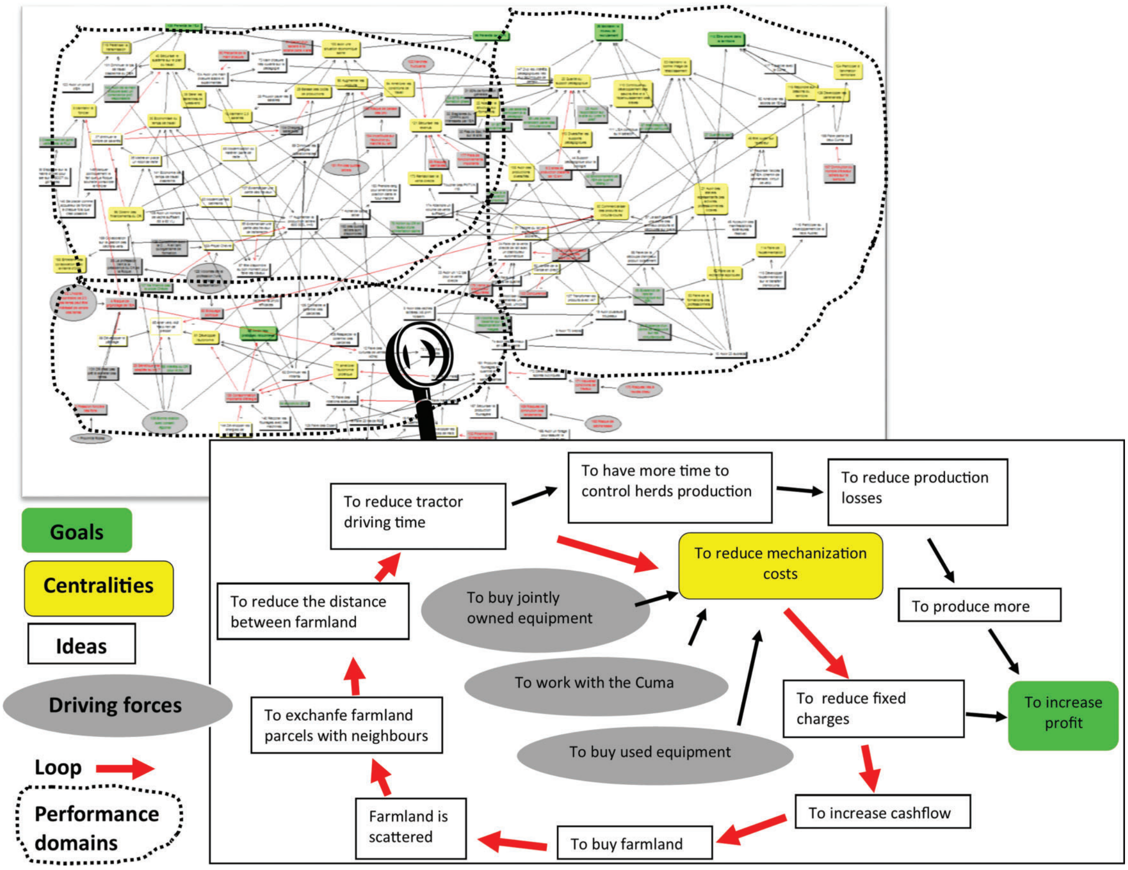


Figure 8: The causal map of the Cuma Smith

At the beginning of our research project, by taking into account academic literature (Jermann *et al*., 2001), we postulate that the advisor is responsible for guiding the participant in the process toward effective collaboration and learning. He is a facilitator who is able to address collaboration issues as well as task-oriented issues. Collaboration issues include the distribution of roles among members, equality of participation, and reaching a common understanding and a shared point of view without neglecting divergent opinions, while task-oriented issues involve the understanding and application of key domain concepts. Based on this definition of the advisor position, we have built our ongoing counselling methodology to implement management strategy for farms and cooperatives (Cuma).

After numerous experiences of PerfEa and PerfCuma, the following lessons were learned: The function of the advisor is to ensure the smooth implementation and efficiency of strategic processes. The advisor relies on the methodological itinerary to identify the content and performs a synthesis and analysis function. His only intervention in relation to content is to reformulate or summarize it. The advisor should have a good knowledge of the tools used in the methodological journey in order to be able to adapt them at any time according to the group's outputs. Collective and individual expectations are not the same; some participants already have established strategic thinking abilities, others do not. This is where the advisor's role is essential: he must be able to immediately adapt the processes he wishes to implement with the group to support its thought processes, adjusting them to the group's specific stage of development.

The relevance of the proposed methodological framework relies heavily on the capacity of the advisor to create satisfactory conditions for its use, and the advisor's capacity to mobilize actors according to the different stakeholders involved in the operations of each cooperative. That is why one of the objectives of our research was to train advisors to deploy the method.

6. Conclusion

Based on the view that cooperative members can identify their own situation with the help of a third party, the strategic management approach we propose allows farmers to establish a cooperative management project, and set up the continuous improvement of their projects. The methodology is suitable for any kind of cooperative. The test on the Cuma was successful and we think that the framework is flexible enough to be adapted to other contexts and to other cooperatives. It is currently formalized as a guidebook, and we have developed a curriculum to train advisors in Cuma and farm management strategy.

This paper is a contribution to the discussion about the support of the strategic management process in agriculture. We discuss how the ongoing counselling methodology, as exemplified by PerfEA and PerfCuma to implement management strategy and its tools, is a learning support to facilitate the transition towards sustainable development. This learning is individual, collective, and organizational. According to loop-learning theories, this learning addresses, to different extents, improvements in practices, revisiting assumptions, and reconsidering values and beliefs.

This work might be extended to the expected development in the environmental certification of farms, or the increased focus on sustainable development and corporate social responsibility. The strategic management approach could emerge as a lever for action with regard to public agricultural and environmental policy, both in terms of the adaptation of farmers to changing public policies, and in terms of the conditionality of public support.

The approach of providing advice to farmers and agricultural cooperatives in the area of strategic management should be considered as a learning aid that will strengthen the capacity for the strategic thinking of individuals and collective groupings, as well as strengthening their ability to integrate sustainable development issues into their activity.

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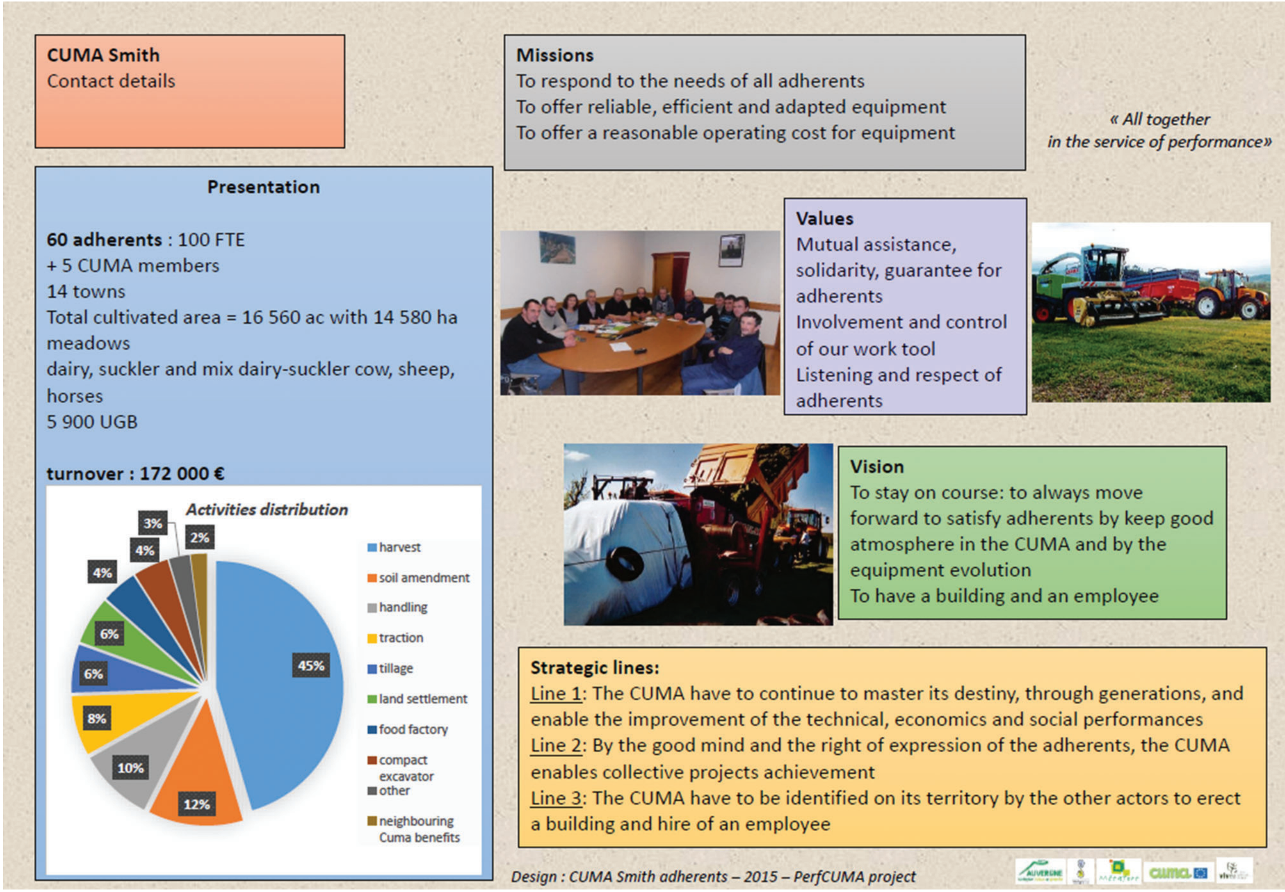
Appendix 1: Strategic paper (recto) of the cuma smith



Appendix 2: Strategic paper (verso) with the balanced scorecard of the cuma smith

STRATEGY		BALANCED SCORECARD			ACTION PLAN
Line	Strategic target	Indicator	Present state of indicator	Wished state and deadline	Main actions
1	The equipment respond to the adherents needs	-Global activity of the CUMA -Activity /tool	-turnover = 170 000€ -turnover/tool (refer to accounting)	To preserve	A1. To deal with the variations of turnover/tool and identify the meanings in case of decrease, every years in December during the invoicing A2. To ensure the respect of starting commitments until the end of tool amortisation
	To stay on course (to stay a step ahead)	Regular investments	100 000€/year	To preserve	A3. To renew equipment as soon as it is amortized and there are costs A4. To be watchful on the tool robustness at the time of purchase
	To decrease the production costs of the adherents	-Adherents number -Unities number	-65 adherents - Unities number (refer to accounting)	To preserve	A5. To let adherents know when a tool is under-employed and encourage them to use it A6. The maintenance is made by the adherent after each operation A7. The tool responsible checks the maintenance of the tool after each à return A8. To raise awareness among adherent to they feel actors of their CUMA (meeting with adherents, communication in meeting)
	To master the control and the management of the CUMA	The board is dynamic	-5 to 10 meetings /year -All the attendees are here	To preserve	A9. To keep the frequency of the meetings A10. To plan the next meeting at the end of the last meeting A11. To be vigilant on the dialogue in meeting A12. To keep the motivation of the board members
2	To have a good mind in the CUMA	Participation rate to the meeting	80%	100% Now	A13. To have 2 general assembly/year : in spring and in autumn with a meal A14. To organise a yearly meal outside general assembly, < 2 years A15. The executive board is vigilant on the good mind in the CUMA
	All adherents have an opportunity to express themselves	To have moments of exchange	2 general assembly /year	To preserve	A16. The president goes around the table during each meeting A17. To invite each new comer to a meeting of the executive board before to integrate him in the CUMA
3	To have a building	To have the plot (2400 to 3600 sq. yd.)	The spot is located (0,6 mi around Soubizergues)	Municipal decision is taken to acquire the plot < 5 years	A18. To meet the mayor and invite him to the general assembly of May 2015 A19. To meet the president of the federation of municipalities during 2015 A20. To put a figure on the project during 2015 A21. To evaluate the financial impact for the CUMA and its adherents during 2015
	To hire an employee	An enough hours number	Nothing	An enough hours number for an FTE <5 years	A22. To acquire the plot for the building as soon as possible A23. To conduct a survey of adherents to estimate the needs of labour (hours number) after the erecting of the building A24. To define precisely the skills of the employee when the hiring decision is taken

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Farm labor management trends in Florida, USA – challenges and opportunities

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ABSTRACT

Reliance on foreign guest workers, rising minimum wages, and corporate social responsibility are three trends emerging within the Florida agricultural economy, particularly among labor-intensive specialty crop farms. These trends are creating higher costs and pushing employers into new management relationships with their farmworkers. On one hand, higher costs compromise the competitive position of agricultural operations. On the other hand, new management strategies could increase overall worker productivity, offset some administrative costs associated with labor management, and create new avenues of market access for their products. The success to which agricultural employers adjust to these trends with cost effective management strategies likely will determine their long-term economic success.

KEYWORDS: farmworkers; specialty crops; H-2A; corporate social responsibility; minimum wage

Introduction

The definition of ''specialty crops'' is enshrined into U.S. law as part of the Specialty Crops Competitiveness Act of 2004 (7 U.S.C. 1621 note) and includes fruits, vegetables, tree nuts, and nursery crops (USDA, 2014). For specialty crop producers in Florida, particularly fruit and vegetable growers, the production and harvest of specialty crops is labor intensive and, hence, they depend on a significant number of seasonal and migrant farmworkers. Specialty crop producers are facing increasing challenges with respect to both the availability and cost of farm labor services. The goal of this paper is to present a comprehensive picture of the farm labor trends as well as discuss potential management options to maintain economic viability of Florida growers. While mechanization of production and harvesting jobs could ultimately resolve many farm labor concerns, at this time those technologies are not commercially available. In the near term, which we define as the next five to ten years, growers still have to rely on hand labor and must adjust and accommodate their labor management practices to secure an adequate supply of workers in a cost-effective manner. Insights gained through this analysis should carry over to other states and production regions facing similar farm labor challenges.

Florida specialty crop growers and their affiliated farm labor contractors face three interrelated trends with respect to farm labor: 1) increasing reliance on foreign guest workers; 2) rising minimum wages; and, 3) evolving supply chain relationships, which require growers to be accountable to the precepts of corporate social responsibility. Each trend, separately and collectively, can be viewed as both a challenge and opportunity to long-term economic sustainability of the state's agricultural economy. This paper begins with a description of Florida's specialty crops and historical patterns of farm labor management. We discuss guest workers, minimum wages, and corporate social responsibility separately and at the end of the paper, discuss how these trends are linked and potential ways to mitigate costs and maximize benefits in a changing farm labor market.

Agriculture and farm labor management in Florida

Florida is second only to California in the production of U.S. specialty crops. In 2013, citrus, fresh vegetable, strawberry, and blueberry production combined to deliver $5 billion of farm gate sales, representing 60% of Florida's

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total agricultural value (USDA-NASS 2013). Fruit and vegetable growers depend on a significant number of seasonal and migrant farmworkers to grow and harvest their crops. University of Florida crop enterprise budgets estimate that one hectare of fresh market tomatoes requires 500 hours of manual labor, 300 hours during the growing season and another 200 hours to harvest an average marketable yield of 3,500 cartons (11.3 kg) (Van Sickle and McAvoy, 2016). Harvesting one hectare of oranges with an average yield of 1,000 boxes (41 kg) requires more than 120 hours, or two people working six, ten-hour days (Roka and Cook, 1998). A survey of the Florida strawberry industry in 2016 indicated that one hectare of fresh strawberries requires roughly 1,980 hours of manual labor to produce an average of 7,620 flats (3.6 kg), 1,420 hours for harvesting and 560 hours for non-harvesting activities (Guan, 2016). This makes strawberry the most labor intensive crop of all crops grown in Florida. In Southwest Florida alone, growers employ more than 16,000 seasonal and migrant farmworkers during the peak of the agricultural season (Zurn, 2016; Roka and Cook, 1998).

Florida's specialty crop growers in the south and southwest regions begin employing seasonal workers in late August when they prepare fields and start their planting cycles. Winter vegetables and strawberry beds are planted from late August through October. Winter vegetables are harvested from November through the latter part of January. Spring vegetable crops are planted in late January with harvesting in March and April. Strawberry harvesting starts in late November and continues through mid-March. Citrus harvesting begins in late November and lasts until late May (FDACS, 2017).

Seasonal and migrant farmworkers plant, prune, and harvest nearly all fruit and vegetable crops in Florida (NC Farmworker Institute, 2007). The number of seasonal and migrant workers across the state reaches a peak in January and remains steady through March. Migrant workers begin to leave Florida in April, as they follow the crop cycles north into the Carolinas and Mid-Atlantic states. The number of farmworkers continues to decline across Florida as vegetable, berry, and citrus harvesting end by late May (Roka and Cook, 1998).

Until recently, most of the seasonal and migrant farmworkers hired by Florida growers were considered "domestic" workers, although a large percentage of these workers are foreign nationals and work in the United States without legal authorization (Gunderson, Wysocki, and Sterns, 2009; Guan et al., 2015). When hired, these workers present documentation that attest to their identity (i.e. driver's license with picture ID) and authorization to work in the U.S. (i.e. social security card). If the documents appear reasonable, employers are not required to verify their authenticity. Another important feature of the workplace relationship has been that Florida's agricultural employers hired domestic farmworkers on an "at-will" basis. "At-will" employment means that no contractual obligations exist between workers and employers other than to abide by the daily "terms and working conditions" statement (Doyle, 2016). An at-will employer has no obligation to offer the same job or rehire the same worker from one day to the next. Likewise, an at-will worker has no obligation to return to the same employer day after day. Consequently, growers generally have little economic incentive to invest in the training and development of their domestic seasonal and migrant workforce. Some growers, particularly strawberry growers, recognized the value of on-farm housing as a means to recruit and retain workers (Guan, 2016). Providing housing, however, adds additional layers of government oversight and cost (FDOH, 2018), leading many employers not to invest in on-farm housing. This calculus, however, may be changing.

For a number of years, growers have become increasingly concerned about the availability and legality of their domestic workforce. There is a widespread belief among growers that native-borne Americans are generally not willing to do farm work (Barbassa, 2010). This belief was particularly evident in a 2013 survey of Florida strawberry growers, where it was claimed that a significant portion of their crop was not harvested because the normal number of domestic workers was not available (Guan et al., 2015). In our 2016 survey (Guan, 2016), the average monthly labor shortages growers reported ranged from 14% to 31% over the strawberry season (September through March). Among workers reporting as "domestic," there has been an ongoing concern about their legality. While federal law requires all employers to verify an employee's identity and U.S. work authorization via the I-9 form created by the Immigration Reform and Control Act of 1986, it has been common knowledge that many of these documents are forged (Monty, 2017). More than 50% of the workers interviewed for the National Agricultural Worker Survey (NAWS) self-report that they do not have legal documentation to work in the USA (DOL-ETA, 2014). Data from the Social Security Administration on the number of "miss-matches" between names and social security numbers suggest that the percentage of undocumented agricultural workers may be closer to 70% (Gunderson, Wysocki, and Sterns, 2009). The 2013 survey of strawberry growers suggested that half of the growers in Florida believed undocumented workers account for 90% of the industry's work force. Only one-fifth of the growers interviewed believed that the unauthorized workers were less than 70% (Guan, et al., 2015).

The uncertainty over the number of legal farmworkers and increased efforts by federal agencies to enforce immigration laws encouraged citrus growers in the late 1990s to explore mechanical harvesting systems (Brown, 2005). Between 1999 and 2008, significant efforts were made to mechanize the harvest of sweet oranges for juice processing. Nearly 15,000 hectares were being mechanically harvested annually until a disease known as citrus greening (or HLB) became widespread (Florida Dept of Citrus, 2012). The HLB bacteria impedes the movement of nutrients between a tree's canopy and root system. Any stress, be it mechanical or environmental, accentuates HLB's symptoms and hastens a tree's productive decline. As current mechanical harvesting systems inflict some damage to a tree's branches and leaf canopy, citrus growers quickly curtailed mechanical harvesting as they sought to minimize tree stress and maintain economically viable yield levels.

Efforts to harvest fresh vegetable crops mechanically achieved mixed results as well. Crops such as green beans and potatoes have been fully mechanized from planting through harvest (Roka, 2012). Little advancements, however, have been made with respect to harvesting strawberries and important vegetable crops grown in Florida, including fresh market tomatoes, bell peppers, eggplant, and cucurbits (cucumber, squash, and watermelon).

Robotic harvesting may be the future for these fresh-market vegetables and soft-skin fruits. The strawberry industry in particular has been investing to develop a robotic harvesting system (Rusnak, 2017). Such technology, however, is not yet commercially available and hence, most vegetable, berry, and all citrus growers in Florida will continue to rely on seasonal and migrant farmworkers.

Reliance on foreign guest workers

The agricultural guest worker program, known as H-2A, has been in place for more than 20 years. The United States Department of Labor (DOL) describes the H-2A program as a way for U.S. agricultural employers to legally hire foreign workers to perform temporary/seasonal agricultural jobs (DOL, 2016). The H-2A program is open to a specialty crop employer provided he or she satisfies two conditions: first, the domestic workforce is not sufficient to meet the employer's labor needs; and second, importation of foreign workers will not adversely affect earnings of domestic workers doing similar jobs (DOL, 2016).

Prior to 2010, Florida growers annually hired between five and six thousand H-2A workers (Table 1). Since 2010, the number of Florida H-2A visas certified by the US Department of Labor (DOL) has grown more than four-fold (Table 1). During fiscal year (FY) 2010, the DOL certified Florida employers to bring in 4,510 H-2A workers, or 5.7% of the total H-2A workers certified across the U.S. In FY2016, the certified number of Florida H-2A workers had grown to nearly 23,000 and accounted for 13.8% of the total U.S. H-2A positions. Since 2016 Florida is the largest state by number of H-2A workers and in FY 2017, Florida's number of certified H-2A position rose to more than 25,000 (DOL-ETA, 2017). During FY2012, 84% of the Florida H-2A workers were hired as citrus harvesters, and by the 2015-16 season, industry experts estimated that H-2A workers harvested 80% of the citrus (Carlton, 2016). While the number of H-2A workers harvesting citrus has steadily increased, the overall percentage of H-2A workers in the citrus industry decreased to 51% during FY2015, reflecting an increasing number of vegetable, blueberry and strawberry growers participating in the guest worker program (DOL-ETA, 2017).

Table 1: Number of H-2A certified positions by the U.S. Department of Labor, Office of Foreign Labor Certification in the United States and in Florida between FY 2007 and 2016.

Fiscal Year (FY)	US[1]	FL[2]	FL%
2007	76,814	5,362	6.9%
2008	82,099	na	na
2009	86,014	5,820	6.6%
2010	79,011	4,510	5.7%
2011	77,246	5,741	7.4%
2012	85,248	6,945	8.1%
2013	98,821	10,051	10.2%
2014	116,689	13,544	11.6%
2015	139,832	17,942	12.8%
2016	165,741	22,828	13.8%
2017[3]	200,049	25,303	12.6%

Sources:
[1] Philip Martin, April 13, 2017. http://www.epi.org/blog/h-2a-farm-guestworker-program-expanding-rapidly/. Accessed Aug 23, 2017.
[2] DOL-ETA. 2011-2016. Annual Performance Data by State – Florida. Office of Foreign Labor Certification. http://www.foreignlaborcert.doleta.gov/pdf/PerformanceData/. Accessed Sep 13, 2017.
[3] DOL-ETA. 2017. Annual Performance Data by State – Florida. Office of Foreign Labor Certification. https://www.foreignlaborcert.doleta.gov/pdf/PerformanceData/2017/H-2A_Selected_Statistics_FY2017_Q4.pdf. Sep 30, 2017. Accessed Jan 2, 2018.

The strawberry industry has seen rapid growth in the number of H-2A workers. In 2013, only one Florida strawberry grower hired less than 200 H-2A workers (Guan et al., 2015). A 2016 survey showed that 20% [3,000 workers] of the strawberry labor force were H-2A workers (Guan, 2016). The number of H-2A workers harvesting strawberries is impressive considering the high fixed costs involved with the application and hiring process and a relatively short harvesting season (Roka, et al., 2017).

Employers complain that the H-2A program is bureaucratically cumbersome, as they must deal with three federal agencies and at least two state agencies to navigate the H-2A hiring process (Roka, 2017a). A 2014 survey of citrus harvesters estimated the pre-employment costs to hire one foreign guest worker to be between $1,900 and $2,000 (Roka, Simnitt, and Farnsworth, 2017). The cost to lease bed-space accounts for more than 60% of the pre-employment costs. Petition filing costs, domestic worker advertisement, and H-2A visas are estimated to cost $350 per certified worker. The remaining costs are associated with travel expenses from the worker's hometown, through the consulate office, and finally to the employer's Florida housing facility (Table 2).

A substantial amount of the pre-employment costs, perhaps as much as $1,000 per worker, are offset by the amount of payroll taxes an employer does *not* have to pay to foreign guest workers (Table 2). As a numerical example, consider a typical H-2A contract during 2017: 21-week contract period, minimum offered hours of 35 hours per week, and at a minimum wage of $11.12 per hour. An employer's FICA contributions to a domestic worker are 7.56% of a worker's taxable earnings (IRSa, 2017). Under the contract conditions above, the employer would not have to pay $620 per foreign worker of FICA taxes that would have to be paid to a similarly employed domestic worker. In addition, state and federal unemployment insurance policies (FUTA) require an employer to pay 6% of the first $7,000 of a domestic worker's earnings, or $420 per worker (IRSb, 2017).

As previously mentioned, most domestic farmworkers have been hired on an "at-will" basis. The H-2A program represents a fundamental change in the relationship between employer and farmworker. As opposed to "at-will" workers, H-2A workers are under "contract" with pre-determined start and end dates. Unless an "act-of-God" destroys a crop, or an H-2A worker violates preset performance criteria or a written code of conduct, he or she cannot be terminated before the end date of the contract (Roka, 2017a). Correspondingly, the foreign guest worker is bound to the employer who hired him or her for the duration of the contract. Foreign workers may choose to leave early and return home, but at their own travel expense. The H-2A contract stipulates a minimum number of weekly "offered" hours and a minimum wage,

Table 2: Comparison of pre-employment hiring costs and in-season management of H-2A and domestic workers employed by Florida citrus harvesters.

	H-2A Foreign Worker	**Non-H-2A Domestic Worker**
HIRING		
Worker recruitment costs	$350/worker[1]	$0
Housing with kitchen facilities	$1,200/worker-season[1] (Housing required)	$0 (Housing voluntarily. If offered, employer can charge workers for cost reimbursement.)
In/Out-bound transportation	$400/worker[1] (Round-trip)	$0
Total estimated cost to hire one H-2A worker for an average 4-month contract period.	**$1,950/worker-season[1]**	**$0**
MANAGEMENT		
Employment status	Contract	"at-will"
Minimum average hourly earnings (as of Jan 1, 2018)	$11.29/hr	$8.25/hr
Guaranteed hours	75% of total "offered" hours in job-order	None
In-season transportation	Free from housing location	Free from designated pick-up spot
Workers' Compensation Insurance	Yes	Yes
Employer Payroll taxes	None	Yes
FICA (Social Security and Medicare)	0	$620[2]
FUTA (unemployment)	0	$420[3]

[1] Source: Roka FM, S Simnitt, and D Farnsworth (2017).
[2] FICA taxes: [7.56% x 21 weeks x 35 hours per week x $11.12 per hour].
[3] FUTA taxes: [6% x $7,000].

Table 3: History of federal and state (Florida) minimum wages rates and the federal Adverse Effect Wage Rate (AEWR) for Florida, 1995-2018.

Year	Federal minimum wage[1] ($/hr)	Florida (state) minimum wage[2] ($/hr)	AEWR[3,4] ($/hr)
1995	$4.25	$4.25	$6.33
1996	$4.75	$4.75	$6.54
1997	$5.15	$5.15	$6.36
1998	$5.15	$5.15	$6.77
1999	$5.15	$5.15	$7.13
2000	$5.15	$5.15	$7.25
2001	$5.15	$5.15	$7.66
2002	$5.15	$5.15	$7.69
2003	$5.15	$5.15	$7.78
2004	$5.15	$5.15	$8.18
2005	$5.15	$6.15	$8.07
2006	$5.15	$6.40	$8.56
2007	$5.85	$6.67	$8.56
2008	$6.55	$6.79	$8.82
2009	$6.55/$7.25	$7.21/$7.25[5]	
2010	$7.25	$7.25	$9.20
2011	$7.25	$7.25/$7.31	$9.50
2012	$7.25	$7.67	$9.54
2013	$7.25	$7.79	$9.97
2014	$7.25	$7.93	$10.26
2015	$7.25	$8.05	$10.19
2016	$7.25	$8.05	$10.70
2017	$7.25	$8.10	$11.12
2018	$7.25	$8.25	$11.29

Sources:
[1] https://www.dol.gov/whd/minwage/chart.htm
[2] http://www.floridajobs.org/minimumwage/FloridaMinimumWageHistory2000-2014.pdf
[3] https://www.foreignlaborcert.doleta.gov/adverse.cfm, (1995-2010).
[4] https://www.foreignlaborcert.doleta.gov/pdf/AEWR/AEWR_trends_2011-2017_versionII.pdf
[5] Federal minimum wage rate increased in July of 2009. Florida minimum wage rose to match the higher federal rate.

which is higher than the state or federal minimum wage rates. The "adverse effect wage rate" (AEWR), which is set by the US Department of Labor, typically is the minimum wage paid by an H-2A employer. As of January 1, 2018, the Florida AEWR increased to $11.29 per hour, more than $3 per hour higher than the Florida minimum wage of $8.25 (Tables 2 and 3). Under the current H-2A regulations, the employer pays all costs including the visa and fees associated with the petition. The employer also covers in-country recruitment expenses, in-bound travel costs, and housing costs. If the worker completes the contract, the employer pays return trip travel costs.

It is illegal for an employer or any third party to charge H-2A workers a ''recruiting fee.'' If recruiting fees are collected, the employer will be obligated to reimburse the workers and face DOL penalties.

Critics of the H-2A program argue that any guest worker program attempts to replace domestic workers with ''cheaper'' foreign workers (Harkinson, 2017). In principle, the H-2A program is designed and enforced as a ''supplemental'' labor supply program (DOL, 2016). The pre-employment costs, AEWR, and housing requirements ensure that labor costs for an H-2A employer will be higher than if only domestic workers had been hired. Furthermore, U.S. law stipulates that an employer must hire any domestic worker seeking the same positions being offered to foreign workers and receive all the same terms as specified under the H-2A contract, including the same number of guaranteed hours paid at the AEWR rate. If a domestic worker lives outside the ''area of intended employment,'' the employer must offer housing and in-bound transportation free of charge.

Like any regulation, enforcement is an ongoing challenge. Worker advocates and their attorneys are concerned that more than a few H-2A employers do not abide by the terms of the contract (Schell, 2016). Investigators from the U.S. Department of Labor – Wage and Hour Division are charged with investigating all violations related to H-2A contracts. As usage of the H-2A program increases, the likelihood of violations will increase. Of particular concern to both worker advocates and agricultural employers is the seemingly annual increase in the AEWR. The challenge of complying with higher AEWRs relates to how farmworkers are typically paid and is the basis of discussion in our next section, rising minimum wages.

Rising minimum wages

Most migrant and seasonal farmworkers including H-2A workers perform labor-intensive jobs and are paid a piece rate for their efforts. As a management strategy, payment by piece-rate works well in many agricultural situations where the work involves performing repetitive tasks (Billikopf, 2008). Further, a piece-rate system motivates individual effort with minimal supervision. A worker's earnings equal the number of units completed multiplied by the stated piece rate. A worker's average hourly earnings, however, must comply with the relevant minimum wage. If a worker's average hourly piece-rate earnings are less than the minimum wage, an employer must supplement, or ''build-up,'' the worker's total earnings until his or her average hourly earnings are at least equal to the relevant minimum wage.

The Fair Labor Standards Act of 1939 established a federal minimum wage whose rate would be set by the U.S. Congress. Until 1995, the minimum wage paid to farmworkers was less than what was paid to non-farmworkers. The federal minimum wage after 1995 was the same for everyone. During the 2004 general election, Florida voters passed a constitutional amendment to establish a state minimum wage and a process by which it would be adjusted annually according to increases in the consumer price index (Florida Dept of Elections, 2004). Florida's minimum wage initially was set at $1 per hour more than the federal rate in 2004 (i.e. $6.15) and has increased every year since, except in 2016 when it remained the same rate as in 2015 (Table 3). The federal minimum wage was amended in 2006 and increased over a three-year period to $7.25 per hour, where it has remained ever since (Table 3). In the event that the state minimum wage is different from the federal rate, an employer complies with whichever rate is higher. Pressure to increase minimum wages will likely continue. In 2016, New York and California legislatures passed bills increasing their state minimum wages to $15 per hour over the next five years (Ballotpedia, 2016), and there appeared to be some support within the U.S. Congress (at least prior to the 2016 presidential election) to increase the federal wage rate.

Table 4: Minimum piece rate necessary to meet target hourly wage rates given a constant level of productivity.

Target Rate ($/hr)	Productivity (8 boxes/hour)
$4.25	$0.53
$8.10	$1.01
$11.12	$1.39

The economic challenge of rising minimum wages is that worker productivity is ultimately limited by individual physical capacity. Consequently, an employer's primary recourse to comply with a higher minimum wage is to raise piece rates, which translates directly into higher unit costs of production. As an example, consider a citrus harvester who in 1996 harvested 8 (41-kg) boxes per hour. He had to be paid at least $0.53 per box in order to satisfy the existing federal minimum wage of $4.25 (Table 4). By January 2017, the state minimum wage had increased to $8.10 and for the same level of productivity, the worker now had to be paid $1.01 per box. If the productivity of an H-2A worker is 8 boxes per hour, in order to satisfy the 2017 AEWR of $11.12 per hour his effective minimum piece rate has to be at least $1.39 per box (Table 4).

Higher piece rates needed to comply with higher minimum wage rates puts pressure on the competitive position of Florida's specialty crop growers. Mexico, a major competitor in both the winter fresh tomato and strawberry markets, can produce an 11 kg (25 lbs) carton of fresh tomatoes with a labor cost of $1.75 per carton (Rojas, 2016). In Florida, the labor cost needed to grow and harvest one hectare of fresh tomatoes is estimated to be $11,737. If one assumes a marketable yield of 3,500 cartons per hectare, Florida's unit cost of labor is $3.35 per carton (VanSickle and McAvoy, 2016). For strawberry growers, labor cost accounts for approximately 40% of the total cost (Wu, Guan, and Garcia-Nazariega, 2017). Each flat of strawberries costs $2.81 in seasonal labor in Florida, which is 121% higher than that of strawberries produced in Mexico ($1.27/flat); overall, the labor costs from producing one hectare of strawberries are $14,000 more in Florida than in Mexico (Wu, Guan, and Garcia-Nazariega, 2017).

Corporate social responsibility

Farm labor advocates have a long history of lobbying for farmworker welfare through unionization, enacting tougher regulations, and pushing for stricter enforcement of state and federal labor laws with direct legal action against individual employers. In 1993, the Coalition of Immokalee Workers (CIW) started to build a ''worker-driven'' model to advocate on behalf of farmworkers

(Asbed and Hitov, 2017). Their initial strategies utilized hunger strikes and protests at employer locations. Starting in 2001, the CIW initiated a different strategy and shifted its focus to retail buyers (CIW, 2017). Between 2001 and 2017, the CIW organized a network of ‘‘participating buyers’’ (Table 5) who agreed, not only to enhance worker income by paying an additional penny-a-pound for the tomatoes they bought, but also to require that their tomato growers adopt a ‘‘code of conduct’’ (FFSC, 2016). The CIW achieved a major breakthrough in 2011 when the members of the Florida Tomato Exchange agreed to embrace the ‘‘code of conduct’’ and become ‘‘participating growers.’’ Shortly thereafter, the Fair Food Standards Council (FFSC) was created to enforce the Code with annual audits and investigations of worker complaints.

The efforts of the CIW and FFSC are examples of a growing trend to incorporate the principles of ‘‘corporate social responsibility’’ (CSR) within the agricultural supply chain. One core objective of CSR, which is familiar in the apparel and electronics sectors, has been to uplift the economic, emotional, and physical welfare of workers (Henkle, 2005). A generic CSR plan with respect to labor can be separated in two parts (see Table 6). The first part is a restatement and commitment to comply with existing labor laws and regulations. The second part captures a more fundamental change in the employer-worker relationship.

Historically, dialogue between agricultural employers and their workers has been one-directional. Employers/supervisors set work place policies and expect their employees/workers to adhere without discussion (Asbed and Hitov, 2017). CSR guidelines explicitly bring worker voices into the management operations and formally create processes through which worker grievances are heard and addressed. While trade unions have achieved similar results, these aspects of CSR will push employers in states like Florida, where unions are not widespread (i.e. ‘‘right to work’’ laws), to be accountable to worker concerns and grievances.

Table 5: Fair Food Standards Council’s ‘‘participating buyers’’ and the year each company signed the agreement.

Company	Year Agreement Signed
Yum Brands	2005
McDonald’s	2007
Burger King	2008
Whole Foods Market	2008
Subway	2008
Bon Appétit Management Company	2009
Compass Group	2009
Aramark	2010
Sodexo	2010
Trader Joe’s	2012
Chipotle Mexican Grill	2012
Walmart	2014
The Fresh Market	2015
Ahold USA	2015

Source: FFSC, 2016.

Discussion

Increasing reliance on foreign guest workers, rising minimum wages, and evolving workplace relationships through corporate social responsibility (CSR) bring both costs and opportunities to agricultural operations in Florida and across the U.S. H-2A pre-employment costs are costs agricultural employers do not have to incur when they hire domestic workers. One could argue that harvest costs would have been lower if more domestic workers had been available and willing to work. Employers argue further that the contractual obligations of an H-2A contract creates secondary costs by restricting their ability to terminate a low-productive worker during the contract period. The higher AEWR and generally rising minimum wage rates accentuate the effects of low productivity and add pressure on the employer to increase piece rates, which directly increases unit cost of production. Florida fruit and vegetable growers compete in

Table 6: Components of a generic management plan to follow corporate social responsibility (CSR) guidelines with federal and state enforcement agencies.

Component	CSR Provisions	Federal/State Agency
Part I:		
Child labor	Discouraged	US Dept of Labor; FL Dept Bus Prof Reg
Forced Labor	Prohibited	US Dept of Justice
Discrimination	Eight protected classes	US Equal Employment Opportunity Commission; FL Human Rights Commission
Working hours and pay	Min wage; Standard week (40 hrs); Overtime pay	US Dept of Labor; FL Dept Bus Prof Reg
Safe & Healthy Workplace	Minimize risks; Safety training; Clean bathrooms potable water	US/DOL - Occup Safety & Health Admin; US Env Protection Agency (WPS)
Disciplinary Practices	Corporal punishment prohibited.	Local prosecutor or State Attorney
Part 2:		
Freedom of Association	Formation of unions or company level worker organization;	No corresponding federal or state regulations.
Management Systems	Written policies; Joint worker/management committees; Grievance and complaint resolution process; 3rd party audits.	

global markets. Added costs from importing foreign workers, managing higher minimum wage rates, and/or adjusting to CSR practices force unit costs of production higher and erode the competitive position of Florida growers.

Offsetting some of the costs associated with guest workers and higher minimum wages are benefits, some of which could be significant. In addition to the direct cost offsets of not paying social security and unemployment taxes to foreign workers, the same contractual obligations that reduce in-season flexibility to terminate workers, allows for a more efficient hiring process. Employers prior to entering the H-2A program complained of high worker turnover rates (Roka, 2017b). When relying on domestic workers, they had to process two to four times the number of job applicants throughout the season in order to secure a sufficient number of workers. With the contractual format of the H-2A program, an employer processes and hires only the number of workers needed. In addition, the contractual certainty of an H-2A workforce allows an employer to plan more efficiently how to manage workers across the entire contract period. More importantly, H-2A employers have the opportunity to "build" workforce productivity over time. That is, the most productive H-2A workers are identified and invited back the following year. Over successive years, an H-2A employer can increase the productivity of his or her overall workforce and create additional efficiencies that are derived from a workforce that is familiar and comfortable with the operational environment of the company (Roka, 2017b).

The trend of increasing numbers of H-2A workers in the Florida specialty crop industries is expected to continue. On one hand, this trend reflects the gravity of labor shortage problems and the serious economic consequence of not having enough labor to grow and harvest the crops (Guan and Wu, 2018). On the other hand, it suggests having a stable and secure labor force under contract has a value to specialty crop growers. As an example, consider strawberries. Strawberry yields fluctuate and are subject to high uncertainties over the season. Further, the crop is highly perishable and fruit prices are sensitive to supply. Berries need to be harvested every two to three days and shipped to the market in a relatively short time (Wu, Guan, and Whitaker, 2015). Fruit perishability, volatile yields, and market prices create risks, which can be mitigated to some extent by having a stable and secure labor force to ensure timely harvest, and handling that is critical for strawberry growers. Guan and Wu (2018) proposed a model to quantify the economic value of the availability and stability of labor force, which justifies the growth of the H-2A hiring within the strawberry industry.

The principles of corporate social responsibility (CSR) are becoming more integrated into agricultural operations. CSR is being driven by retail companies, which are mandating adoption of CSR guidelines throughout their supply chain. For agricultural producers within such a supply chain, market access of their products will be dependent on their adoption of CSR principles. The CIW/FFSC model aggressively enforces its code of conduct. Those growers who violate the code are debarred from the Fair Food Program and unable to sell their fruit to "participating buyers," many of whom are their primary buyers (Asbed and Hitov, 2017).

The cost of adopting many CSR components should be minimal, as federal and state laws already require many of these components. CSR certification, however, will involve the costs associated with third-party audits and additional record keeping requirements that are part of any certification process (Roka, 2016). Probably, the biggest challenge for many agricultural employers to adopt CSR principles will be adjusting their management polices to be more inclusive of worker input and implementing a worker grievance system which will empower workers to challenge long-standing employer policies (Asbed and Hitov, 2017).

Potential benefits of CSR certification are two-fold. First, some evidence exists that working conditions are correlated directly to worker productivity (Billikopf 1999; 2001). If the culture of CSR enhances the workplace environment, then one should expect an improvement in overall productivity and/or cost efficiency. Any improvement in worker productivity offsets to some degree the adverse cost implications of higher minimum wages. A second benefit could be in the form of market access beyond the punitive consequences found in the CIW/FFP model. Florida tomato and citrus growers often cite U.S. regulations, particularly with respect to agricultural labor, as creating a competitive disadvantage with foreign growers. If social responsibility or social justice ideals resonate sufficiently among US and foreign consumers, retail brands and their affiliate suppliers who embrace CSR may realize benefits in terms of greater market share and perhaps, at higher prices. At the very least, widespread demand for production under CSR principles will force foreign agricultural producers to adopt a CSR framework and thereby incur additional costs associated with CSR compliance that may not be required by their respective governments.

Concluding comments

Farm labor trends in the United States suggest that growers will have to hire more H-2A foreign guest workers, pay higher wages, and comply with more robust CSR rules and practices. These trends are challenging growers to rethink their traditional labor management policies. Pre-employment costs to hire guest workers and rising minimum wage rates push total costs higher and could erode the competitive position of Florida fruit and vegetable growers as they compete in an increasingly global marketplace. Recognizing the evolving trends should help employers to adjust appropriately to the changing conditions. Those employers who embrace the potential positive aspects of these changes may actually enhance their future economic sustainability. For example, the structure of the current H-2A guest worker program provides incentives for employers to recruit, train, and retain their most productive workers. The principles guiding corporate social accountability could foster a more collaborative working environment by increasing the engagement between company supervisors and workers, which in turn could increase the likelihood of improving overall efficiency within the farming operation.

To address ongoing changes in the farm labor market, specialty crop growers in Florida will need to innovate and adjust to the new market, policy, and production environments. In particular, the development of labor-saving technologies is a necessity to bring down the cost of production, which is essential to keep any industry competitive in the face of global competition.

Labor cost-saving systems and technologies include not only mechanical/robotic harvesting devices, which replace manual labor, but also new production systems, such as new plant cultivars, bed designs, or other changes, which could enhance the productivity of manual labor. These solutions, however, are often beyond the capabilities of individual growers. Even for the largest corporations, these technological innovations may be beyond their control because their expertise and overall business plan is on production and marketing of their crops and not in research and development. Research projects often take a long time to develop a useful and cost-effective product. Public funds from state and federal governments will be needed to develop the new technologies to increase labor efficiencies.

At the policy level, government officials may negotiate or re-negotiate trade agreements more favorable for U.S. growers. Buyers of foreign grown fruit and vegetables could also encourage adoption of good labor management practices to make it consistent among all sources of products, imported or domestically produced. Whether this would occur and the extent to which such practices can be effective depend on the degree of social awareness among consumers and market forces behind consumer preferences.

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Agricultural break point

JOHN VARLEY[1]

It is clear that we are at an agricultural break point, potentially on a scale not seen since at least the 1970s: for the first time in more than 40 years, the UK government has an opportunity to take control of agricultural policy. However, while most commentators are focusing on Brexit, there are other linked disruptors that may shape the future for those who own and manage land-based businesses:

1. consumers, markets and trade;
2. competitiveness and productivity;
3. rural economy priorities;
4. environmental awareness.

Consumers, markets and trade

Consumers have always wanted inexpensive, high-quality and safe food, and they now have more information about it at their fingertips. They more than governments have the power to change industries, as can be seen in the successful pressuring of Primark to think harder about conditions in its factories in Asia. Social media and connectivity are also driving shifts in consumer thinking and behaviour; my youngest daughter is 18 and has been a committed vegan since watching the documentary *Cowspiracy*, for instance.

Over the past 50 years or so, spending on food has fallen from around 40% to 11% of household income (British Nutrition Foundation, 2017). For some, though, 11% is still too high, and Policy Exchange, a right-wing think tank, claims that UK food prices remain higher than in a pure market. There is emerging opinion (eg. Lightfoot *et al.*, 2017) that a significant cause of perceived higher prices has been the combination of tariffs and agricultural support, increasing costs and subsidising inefficient methods of production.

But some fear that lower prices will come at the expense of lowering standards. In the EU, the European Food Standards Agency has adopted an approach based on the precautionary principle, leading to a divergence between producers in and outside the union; for example, the EU bans products such as chlorinated chicken, hormone-treated beef and genetic modification, which are permitted elsewhere.

There is pressure for the UK to adopt a more objective, scientific and evidence-led approach to food standards once it leaves the EU, though this may bring both opportunity and risk. What we should expect is much more transparency and accreditation to help consumers make informed choices. The British Red Tractor[2] scheme is already looking at slurry capacity on dairy farms and there is talk of a Green Tractor label considering wider environmental outcomes. But is this enough?

At Clinton Devon Estates, in the South West of England, we are funding research to understand and reduce the environmental impacts of our business, including monitoring the links between our farming practices and water quality downstream, with a view to making the data available publicly. We take our responsibilities not to pollute water very seriously, and know that society increasingly expects such a protective approach to the environment.

Competitiveness and productivity

In 2015/16, more than half of the UK's farms earned less than £20,000, and 42% made no profit at all; income per worker remains only £19,000 a year (Defra 2017). These statistics would make most investors that are not looking for tax breaks steer well clear.

Total income from UK farming is £3.6 bn, including subsidies of £3.1 bn (Defra 2018a) or 87% of total income. The existing financial model for agriculture does not appear robust and neither does it offer confidence for the future – especially if direct subsidies will be reduced and the outcome of new international trade agreements remains uncertain.

British farmers used to be among the most productive in the world, especially in the 1970s. In recent decades, however, productivity has stagnated and is now below that of numerous other countries and many farms today are not sustainable without substantial subsidy. Managing the withdrawal of farming support is therefore going to be central for the new domestic policy. The goal should be to create a highly productive, dynamic farming sector that is more specialised and capable of competing in global markets.

The low productivity of UK agriculture cannot be blamed entirely on the EU's Common Agricultural Policy (CAP): other member states have seen better performance, despite the negative influences of the regime. Cuts to investment in research and development, high land prices, energy costs and an ageing and non-specialist workforce have all had an impact. As a sector, we need to demonstrate active leadership in addressing these issues. Technology, skills, new business models and innovation will surely have a role to play.

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[2] https://www.redtractor.org.uk/?src=landing

We need to establish the next generation of farming leaders, with succession based on merit and entrants encouraged from new backgrounds. The median age of British farmers is 60 (Defra, 2018) compared to 40 in the workforce as a whole. But bringing young people into farming is not straightforward, given the high cost of buying or renting land, expensive rural housing and poor career paths. An irony of one of the core objectives of the CAP, ''the creation and maintenance of employment'', is that UK employment in agriculture has fallen dramatically from more than 3% of the workforce in 1960 to just above 1% today (Lightfoot *et al*., 2017).

Subsidies allow investment in mechanisation, substituting capital for labour. CAP support proportionately benefits larger farms, which grow more rapidly than smaller ones. Since 2005 the number of smaller farms has shrunk, with the average size of holdings rising from 69 ha to 80 ha. As technology and machinery get more expensive, there is pressure on the larger farms to grow and spread costs. The smaller farms, on marginal land, may have neither the capital nor the opportunity to take on more land. CAP support is in many cases the only driver of on-farm investment. Without the policy or a new business model, the consequences for farm viability, or improved performance, may be bleak.

There is nevertheless an opportunity to evolve new forms of collaboration between farming enterprises, different types of ownership, landlords and tenants and non-farming enterprises to drive benefits and investment in skills and capital. At Clinton Devon, we have commissioned legal opinion on a concept called a ''cooperative contracting agreement'', where a landlord and one or more tenants form an LLP, or similar, to establish a new kind of business partnership valuing relative inputs including land ownership, tenancy valuation and assets, and enabling all parties to take a role in the governance of a professionally managed farming operation.

The industry should be benchmarking itself against not just the most efficient farming enterprises globally but also against other industries, being the best in class for procurement, business processes, human resources, skills and financing. We need to upskill and ensure that farmers have the knowledge to make more informed decisions, increasing productivity and competitiveness. We also need to focus on health, safety and well-being: agriculture is in the spotlight for its woeful record in serious work-related injury, fatalities and mental health.

The opportunity to change work practices also applies to animal health, in which the UK is a leader, although there is much more to do. We need to embed animal health along with workplace safety in our business-as-usual practices. This should be a unique selling point, a clear example of the high standards for which we strive that can be used to differentiate our products.

As business leaders, we should be commissioning research and development and knowledge transfer, providing the tools to help farming enterprises make the transition to new business models and developing centres of academic excellence. Our local colleges and universities should be rising to the challenge, reinventing themselves to be ready to support future industry models with science and evidence rather than unguided research or courses, pointing the most able students to careers in agriculture – careers in a globally competitive business that exploits emerging technology, artificial intelligence and science.

Qualifications and licensed training must also become prerequisites for some agricultural roles, perhaps leading to the introduction of the ''Chartered Farmer''? Foresters, environmentalists and other professions involved in land management provide a route to chartered status. For farming, chartered farmer would recognise the importance and professionalism of the farmer's role and, whilst not every farmer would be expected to seek chartered status (as continuous professional development would be the underlying benefit of repositioning farming as a profession), the farming industry would be seen as being one worthy of attracting highly motivated and qualified individuals and offering life-long learning in satisfying and rewarding careers.

Rural economy priorities

There are obvious synergies between agriculture and rural economies. But agriculture is no longer the biggest employer, and in terms of gross value added (GVA), agriculture, forestry and fishing combined represent just 2% of the overall rural economy and 0.55% nationally. However, is GVA the right measure?

My experience is that, in Devon, policymakers have undervalued agriculture's contribution to the local economy. After the 2001 foot-and-mouth disease outbreak, our estate struggled to get the then South West of England Regional Development Agency to take seriously the need to support land-based business in the recovery. There was a level of ignorance then, and even now some Local Enterprise Partnerships (LEPs) and local authorities view agriculture and forestry as something other than a real business: their plans need to recognise the value of land-based business to the economy, support joined up strategies to attract investment and develop the skills required to sustain and grow successful farming and forestry enterprises.

Valuing natural capital is gaining traction, which is potentially a big disruptor, both in policy and market terms. The challenge is how value can be generated from the natural capital that farmers in rural areas provide, including the value created from food and fibre production, renewable energy generation, wildlife, air pollution removal, waste water cleaning, flood protection and education. The value of day trips alone to the natural environment is estimated to be £6.5 bn – not far below the entire GVA of agriculture. Many of these visits are to experience an environment delivered by farmers – so will farmers get paid for it?

Environmental awareness

Agriculture dominates land use in the UK. Farmers, foresters and land managers can shape the environmental costs and benefits resulting from their work and make a huge difference to the value and quality of this country's natural capital. The challenge is to decouple agricultural production from environmental degradation, so that agriculture can continue to meet increasing demand for food without putting undue pressure on natural resources.

Agriculture's contribution of 0.55% of UK GVA contrasts with its generation of 10% of total greenhouse gas emissions. Other significant environmental impacts from UK agriculture are associated with water pollution, air pollution, soil degradation and the impact on biodiversity; indeed, in 2017 agriculture became England's number one polluter of water.

The costs to society of cleaning up these impacts are huge and are met by taxpayers by, for instance, an extra £100 m on water bills, and the government is looking to reform agricultural policy after Brexit to reduce these. Soil degradation is already in the spotlight, with an estimated 2.2 m tonnes of soil eroded each year in UK catchments, costing £1 bn.

At Clinton Devon, we are working with the local catchment partnership to install sediment traps, monitor outcomes and host farm visits. It is widely argued that there has been a decline in on-farm biodiversity as a result of increasingly homogenous landscapes. While entering Mid-Tier Stewardship, Clinton Devon farms are using the options to complement and support our own nature improvement strategy and optimise outcomes for wildlife. Our recent management contract with Velcourt to run the in-hand organic dairy is novel in that, as well as agreeing financial performance targets, we have included development of goals for biodiversity, the environment, animal health and employee satisfaction. These are being jointly agreed and reviewed annually, ensuring that the farm is achieving year on year improvement in biodiversity, animal health and employee engagement. The first formal targets will be in place from April 2019.

We have also just let a farm not for the highest rent but on a balanced scorecard of financial return and alignment of objectives for Cirl buntings[3], improved soil quality and education. We have also invested in comprehensive soil and bird and butterfly surveys to benchmark agreed targets over the course of our partnership with the tenant. This is now our model for all new tenancies, and we are undertaking soil analysis on some already tenanted land to identify improvements as well.

We need to understand what we are stewards of today by commissioning audits and working on a landscape or catchment scale across farm boundaries, to be ready to provide what society wants. In 2016, at Clinton Devon, we undertook a comprehensive audit of 3,108 species across the Pebblebed Heaths Site of Special Scientific Interest[4]. We now have baseline evidence to improve future conservation management. Recently, we published our *Wildlife Prospectus – Space for Nature* which identified all the important areas for biodiversity across the Estate, along with our key partnership projects. From this we have developed 13 priorities for action that we are discussing with our farm tenants, commercial partners and stakeholders with a view to implementing integrated, landscape-scale conservation improvement schemes.

Opportunity

These four areas of disruption present a once-in-a-generation opportunity for reform and putting agriculture and land-based businesses back into the heart of the rural economy where they belong. Many feel it is our collective role to challenge the policymakers and politicians to own the problem on behalf of farmers by ensuring continuity and stability. But isn't it our role to question our own business models and transform them to be fit for the future?

About the author

With UK agriculture facing many disruptions, including Brexit, John Varley OBE TD, Estate Director at Clinton Devon Estates (10,000 ha rural estate and property business centred on land holdings in north and east Devon in the South West of England), considers how emerging trends may shape land-based rural businesses over the next few years.

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Evaluating the multiple benefits of multi-layered agroforestry systems

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ABSTRACT

Globally, the contribution of own-growers' to food security is over-looked. We explore a novel temperate, own-growing, agroforestry method that originates from Britain; the forest garden. Inspired by ancient tropical multi-layered homegardens, forest gardens integrate nature and food production. Consequently, they have spread globally despitebeing little researched.

We sub-sampled 51 British forest gardens described as: Mature (⩾15 years old), Young (⩽10 years old) or Mixed (Young forest garden with an experienced manager). Using a semi-structured telephone questionnaire, we characterise forest gardens as: diverse food systems containing on average 64.2 (± 6.65) predominantly perennial plant species; spread over at least four layers. Typically, they are ⩽0.8 ha; on sloping, low value agricultural land.

Forest gardeners are principally motivated by environmental protection and a lifestyle that enhances well-being. Their diet is broadened by foraging wild plants and common garden species, considered a delicacy in other cultures; thereby reducing their reliance on environmentally challenging annual crops.

Forest gardens, like homegardens, could deliver social, economic and environmental benefits. They also illustrate that exploring ancient cultures and techniques can provide ideas and solutions to our modern food conundrums. However, combing a holistic academic approach with forest and homegarden practitioner knowledge will enhance our understanding of their alternative crops.

KEYWORDS: perennial; crops; sustainable food production; food security; ethnobotany

1. Introduction

The need for diverse environmentally sensitive production methods (Pilgrim *et al.*, 2010; Godfray and Garnett, 2014; Gunton *et al.*, 2016) is growing with the global population (United Nations, 2013). Concurrently, our desire to know the origin of what is on our plate, whilst improving our health and well-being (Winter 2018), has fuelled a burgeoning public interest in growing-your-own food (Crouch and Ward, 1994; van den Berg *et al.*, 2010; Coley *et al.*, 2011; Breeze *et al.*, 2012; Goodman *et al.*, 2012; Edmondson *et al.*, 2014). Considering there are an estimated, 800 million worldwide own-growers, in urban areas alone, producing food, in anything from pots to vegetable plots (Edmondson *et al.*, 2014), they can make a huge contribution to our global food supply.

One advantage of producing food on a smaller scale, is that we can be more inventive with what and how we grow. The forest garden (Hart, 1993), is a good example of this. Described as a low maintenance method, that promotes wildlife and food production (Hart, 1993; Crawford, 2010), it is gaining worldwide popularity though it has been little researched (Hathaway, 2015). They are designed to mimic young woodlands, containing a wide variety of predominantly perennial crops with either edible, medicinal or practical uses, or any combination of the three (Crawford, 2010). Food is provided throughout the year by growing early, mid, and late crops (Mollison, 1994; Hart, 2001). The forest gardener's ancient foraging based diet (Coppolino, 2016), enables this, consuming plants others consider weeds e.g. *Allium triquetrum,* an invasive garlic substitute (Plants for a future, 2016) and *Aegopodium podagraria,* an introduced Roman delicacy and pernicious weed (Wong, 2012). Forest gardeners broaden their diet by seeking inspiration from other cultures e.g. the north American 'first nations' who consumed over 200 plant species (Muckle 2014); *Fushia* berries, enjoyed by Incas; and *Hemerocallis* common in Asian cuisine (Wong, 2012).

It is a 'closed' system whereby the plants provide the nutrients. Species in the Fabaceae family and non-legumes such as *Alnus* species provide nitrogen. *Symphytum* species are commonly planted around crop trees as their deep roots are believed to accumulate potassium, a mineral required to promote flowering and subsequently fruit or nut growth. Mulching is a common practice with the dual benefit of retaining soil moisture and the recycling of nutrients from dead plant material.

Intriguingly, plants are stacked in layers (Figure 1) enabling more species to be planted in a small area.

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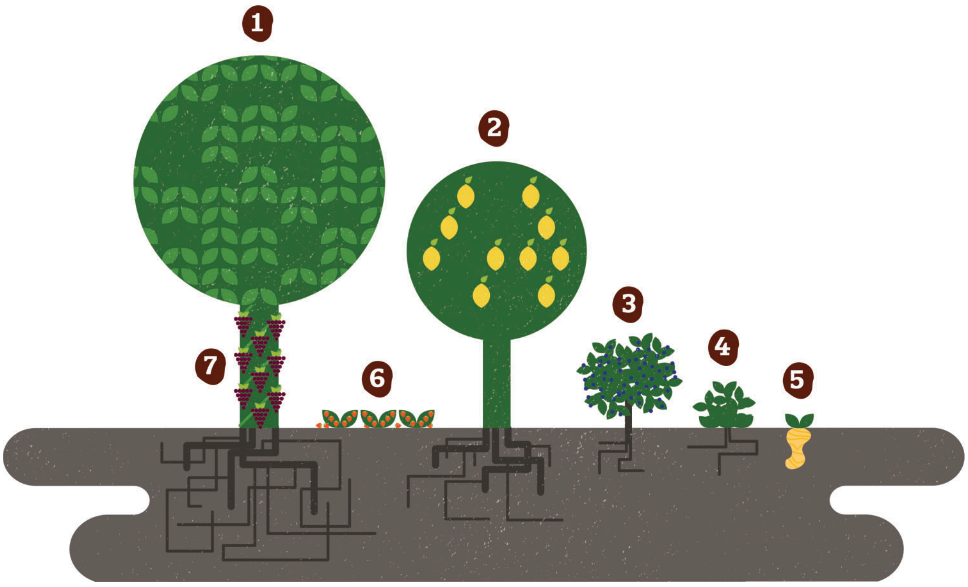

Figure 1: The multi-layered forest garden. 1. Canopy (large fruit and nut trees), 2. Dwarf fruit/nut trees, 3. Shrubs (fruit bushes), 4. Herbaceous layer, 5. Rhizosphere (root crops), 6. Ground cover (strawberries), 7. Climbers. (Image reproduced with permission of the Eden Project)

Though it is described as novel, originating in Britain in the 1980's, the technique has ancient origins (Hart, 1993).

The forest gardens' history

Robert Hart (1993) who created the forest garden concept, found inspiration from other cultures. This included tropical agroforestry systems, over 12,000 years old called homegardens (Crawford, 2010). These small-scale, community-run systems predominately contain economically exploitable perennial plant species (Boom, 1989), grown over several layers (Jose, 2009). They also provide locals with food, income (Jose, 2009; McIntyre *et al.*, 2009) and environmental benefits (Nair, 1993) over a range of spatial and temporal scales (Mendez, 2001; Jose, 2009).

Hart (1996) also admired the Japanese scientist Toyohiko Kagawa, who in the 1930's pioneered 3-Dimensional Forest Farming, comprising conservation, trees and livestock (Sholto Douglas and Hart, 1978). By encouraging Japanese hill farmers to plant walnut trees on their slopes soil erosion was reduced whilst improving the animals' nutrition and farming capability.

Forest gardens are now considered, by some, to be a form of Permaculture (Mollinson and Holmgren, 1978). However, though they share similar ideals, these two concepts arose concurrently. Similarly, Permaculture, an Australian concept, promotes perennial crops and subsequently a more **Perma**nent Agri**culture** (permaculture). Mollinson and Holmgren (1978) also explored other cultures and techniques including multi-layered agroforests in Australia and Papua New Guinea. Mollinson was influenced by Russell Smith's (1929) Tree crops: a permanent agriculture, which promoted edible tree crops, from throughout the world, as livestock fodder. Like Kagawa, Russell-Smith advocated planting trees to reduce soil erosion. Interestingly many species Russell Smith (1929) lists, feature in forest gardens e.g. *Morus nigra*.

Furthermore, Mollinson admired Japanese Scientist and farmer Masanobu Fukuoka's One Straw Revolution (1992), which described how natural farming methods could be beneficial to both to humans and wildlife.

Forest garden's today

Crawford (2010), a leading forest garden expert, manages the *Agroforestry and Forest Garden Network* (Agroforestry Research Trust, 2014), an annual index of sites welcoming visitors. The list contains 176 systems spread across: Britain, 68%; Western Europe, 22%; Ireland, 5%; North America, 3% and Northern Ireland, 0.5%. Crawford (*Pers. Comm., 2016*) estimates there are 2000–5000 UK forest gardens, typically up to 0.4 hectares in size. This proliferation, without traditional academic research, demonstrates the public's capability of developing environmentally sensitive food systems.

Here we explore key forest garden characteristics, including similarities to its predecessor the homegarden. We focus on British systems, where the method originated and subsequently contains some of the world's oldest sites. To determine whether the method is robust we sought *mature* systems, that were at least 15 years old and compared our findings with *young* forest gardens up to 10 years old. We define a forest garden as "a multi-storey combination of trees, annual and perennial crops, (Fernandes and Nair, 1986) spread over three or more layers (Hart, 1993; Whitefield, 1996). Situated near dwellings, some contain domestic animals (Nair, 2006)."

2. Materials and Methods

We identified 138 British forest gardens meeting our criteria using: the Agroforestry and Forest Garden Network (Agroforestry Research Trust, 2014) and Permaculture Plot (Pratt, 1996). Systems were sub-divided into two categories depending on the system's age and their land manager's experience: i) *Mature/experienced manager:* forest garden established and managed for 15 or more years ii) *Young/inexperienced manager*: manager's first forest garden which was up to 10 years old.

We sub-sampled 51 sites, inviting them to participate in a telephone questionnaire from April–November 2015. During this process an additional category was identified: *Mixed/Young FG/experienced manager:* a *young* system up to 10 years old whose manager has previous forest garden

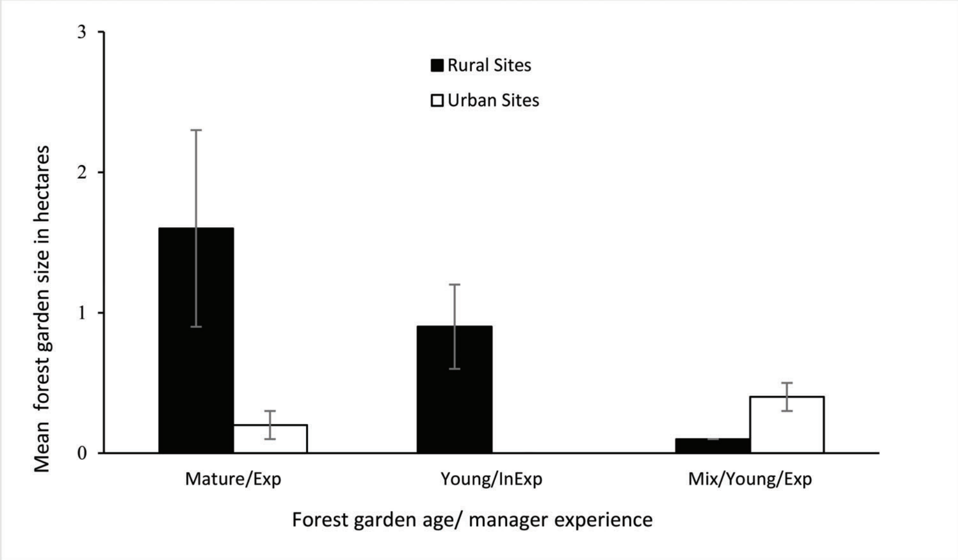

Figure 2: Forest garden size by age and location

expertise. For simplicity, these three system categories are hereafter referred to as *Mature, Mixed* and *Young*.

A mixed methods approach was used, collecting quantitative and qualitative data from 51 forest gardens: 21 *Mature,* 10 *Mixed* and 20 *Young* systems, using a pre-tested, semi-structured questionnaire containing 53 questions (Appendix 1). For compatibility with published homegarden research, original questions were mixed with those in the literature (Eilu *et al.*, 2007; Vlkova *et al.*, 2011; Clarke *et al.*, 2014) and pertinent queries from Permaculture Association Britain's 2013, non-targeted, online forest garden survey for systems at least five years old (Remiarz, 2014).

Our semi-structured questionnaire solicited information on forest garden: manager demographics; characteristics (size, location, purpose); species diversity and actors influencing: plant choice; creation; maintenance; successful attributes; challenging attributes and ways to improve the method. Closed questions had a Likert scale design where responses ranged from zero for "not important," to four for "very important."

Statistical analysis

R Statistical Software version 3.2.3 (R Core Team, 2015) was used for data investigation. Chi-squared analysis was completed on all variables. The three exceptions, which required the data to be square root transformed to normalise their residual errors, were (i) a one-way ANOVA to compare forest garden sizes across the three categories of *Mature, Mixed and Young*. One data point was removed, due to missing information; (ii) a two-way ANOVA to assess whether species number was affected by forest garden age and number of layers (categorised as 'two or fewer', 'three' or 'four to seven'); (iii) a linear regression of species richness against forest garden size.

3. Results

Manager demographics

Typically forest gardeners were well educated, with 76.5% holding a degree/higher degree/professional institute membership. Their age ranged from 29–85 years (mean 56 ± 1.9).

Forest garden characteristics

The average age, in years, of the forest gardens per category were: *Mature:* 23.1 ± 0.22, *Mixed* 11.2 ± 0.7 and *Young* 5 ± 0.11. Two *Mixed* systems aged 25 and 20, inflated this average, because both *Mature* and *Young* forest gardens were simultaneously managed on the same site. Thus, the median values are a better representation of category age: *Mature,* 23; *Mixed, 8.5 and Young,* 5.

Forest gardens were created on land considered to be of low value agricultural land with 67% of sites containing slopes whilst 39% had clay soils**.** Most, 75% were in rural locations, with 25% in urban areas. Forest garden size ranged from 0.002–11.3 hectares (ha), with an average of 0.82 (± 0.27 sem) ha. Removing the largest forest garden outlier, a rural *Mature* 11.3 ha site, reduced the average forest garden size to 0.6 (± 0.18 sem) ha.

Rural forest gardens were the biggest ($F_{1,48}$=5.22, p=0.03), measuring 0.85 ± 0.39 ha and typically, these were *Mature* systems (Figure 2). In contrast urban sites measured 0.15 ± 0.27 ha, with the largest a 0.81 ha *Mixed* site. One *Mature* urban forest gardener commented, "*A very small forest garden fits in [everywhere]. [A] larger one requires a lot more labour*."

Respondents were asked to categorise their forest garden into one of four types (table 1). The majority were for private use (53%); whilst 25% were community projects; 12% charities and 10% commercial ventures. Comparing forest garden purpose across age groups, we found that all commercial ventures were *Young* and all charities were *Mature* (table 1). Equal numbers of *Mature* and *Young* forest gardens were private.

Species diversity

Typically, 70% of sites had four or more layers. Overall mean forest garden plant diversity was 64.2 ± 6.65. For sites over 2 ha, plant diversity significantly increased with site size ($F_{1,48}$=8.53, $p < 0.01$ R^2=0.13, Figure 3). Neither forest garden age ($Ftotalspecies_{2,48}$=0.57, $p > 0.05$) nor layer type influenced species diversity ($Ftree_{2,48}$=1.95, $p > 0.05$; $Fshrub_{2,48}$=0.21, $p > 0.05$; $Fherb_{2,48}$=0.27, $p > 0.05$; $Fgroundcover_{2,48}$=0.36, $p > 0.05$; $Froots_{2,48}$= 0.43, $p > 0.05$ and $Fclimber_{2,48}$=0.95, $p > 0.05$). However, the herbaceous layer tended to have the most crop variety (table 2).

Actors influencing plant choice

Most forest gardeners, 66% chose locally adapted species to enhance plant establishment and persistence. Specifically, 76.5% grew local fruit tree varieties, particularly apples (table 2) thereby maintaining genetic diversity. Other important factors included plant productivity (59%) and multifunctional plants that fulfilled numerous roles (45%). However, one *Mixed* respondent felt this attribute was over emphasised since, "*Not all plants perform many functions well. A forest garden is a multi-functional system as a whole, so not every plant has to* [be]."

Though taste influenced 49% of respondents, others considered this to be subjective. A *Mature* forest gardener aptly bridges this divide by describing their daily salad as "*an orchestra – all the plants play together to create flavour, whilst on their own they may be bland.*"

Table 1: Different forest garden types by age category

Type	Mature	Mix	Young
Private	11	5	11
Community	4	4	5
Charity	6	0	0
Commercial	0	1	4

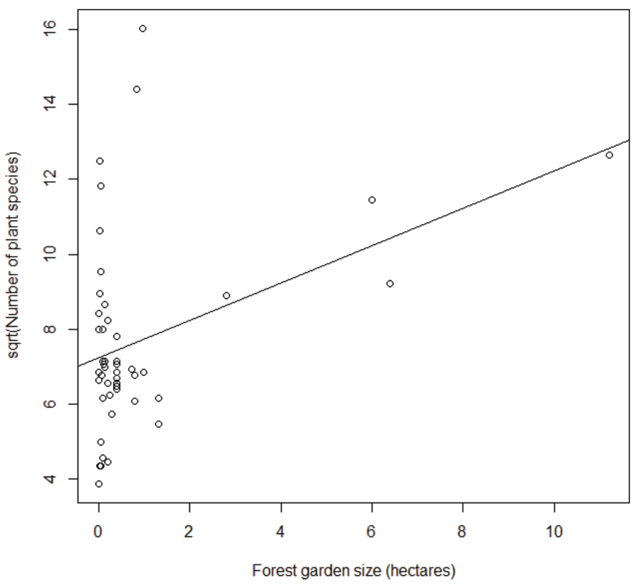

Figure 3: Plant diversity and forest garden size

Actors influencing forest garden creation

Permaculture Association Britain's online survey (Remiarz, 2014) had 44 British respondents, six of whom participated here. We re-used their question to determine the key actors driving the creation of forest gardens. These were defined into five categories: production (food, fuel etc.), environmental benefits, lifestyle choice, financial benefits and research. Participants were asked to rank these categories in order of importance with five being the most influential actor and conversely one the least important (Figure 4). Overall the primary motivation was environmental protection, closely followed by food production and lifestyle. Many considered these three actors to be interlinked, "*the environment drove it and the passion to produce food drove the lifestyle.*"

Typically, respondents felt that it was important to enhance local biodiversity (90%); reduce soil disturbance, eliminate inorganic fertilisers/pesticides (86%) and contribute to national biodiversity (74%).

With respect to food production, many thought it was very important to know their food's origin (78%), preferring to grow it themselves as it was tastier than shop bought produce (78%). Some also enjoyed growing and eating uncommon food (46%).

In terms of lifestyle choice, the majority thought their forest garden was very important for relaxation and or recreation (62%). One *Young* respondent commented, "*The way we grow.. shouldn't just be for.. food. It can very easily feed other parts of your life, making it a*

Table 2: The top three forest gardens plants by layer

Layer	Plant species	% of Forest Gardens	Median no of species at each level
Canopy	*Malus domestica*	96.1	5
Canopy	*Corylus spp.*	96.1	
Canopy	*Prunus spp.*	88.2	
Shrub	*Ribes nigrum*	96.1	12
Shrub	*Rubus idaeus*	92.1	
Shrub	*Ribes uva-crispa*	88.2	
Shrub	*Ribes rubrum*	88.2	
Herbaceous	*Symphytum spp.*	92.1	21
Herbaceous	*Melissa officinalis*	86.3	
Herbaceous	*Rumex spp.*	82.3	
Ground Cover	*Fragaria spp.*	80.4	4
Ground Cover	*Rheum spp.*	68.6	
Ground Cover	*Mentha spp.*	68.6	
Rhizosphere	*Armoracia rusticana*	45.1	2
Rhizosphere	*Helianthus tuberosus*	47.1	
Rhizosphere	*Allium spp.*	45.1	
Vertical	*Rubus fructiosa*	84.3	3
Vertical	*Vitis spp.*	43.1	
Vertical	*Humulus lupulus*	51.0	

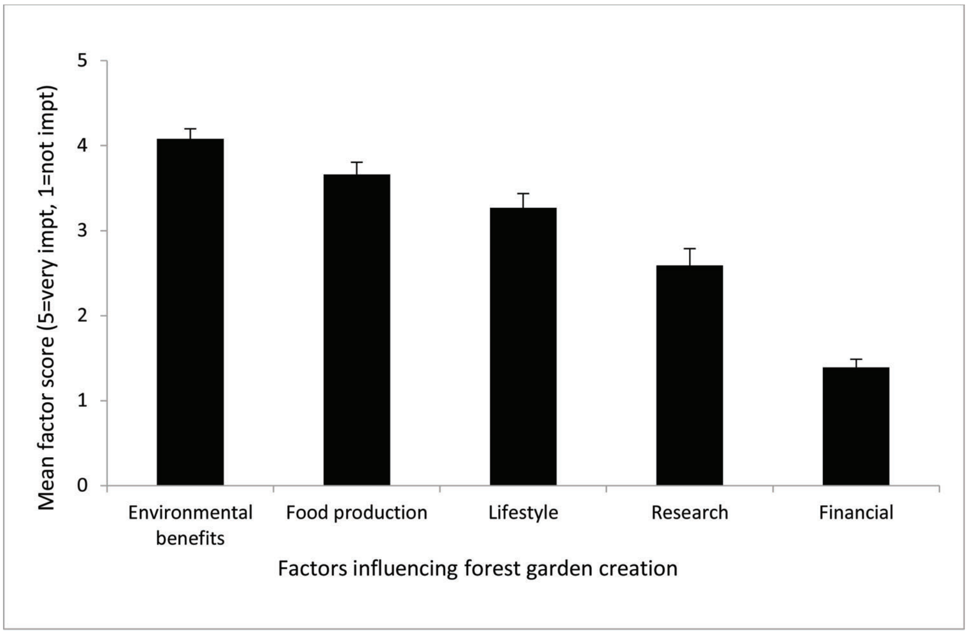

Figure 4: The five main actors that influence forest garden creation. The modal value, is ranked in order of importance 5=most important and 1=least important

place you are more inclined to be.'' Another *Mature* community forest garden, noted, ''*Many of our volunteers have mental health issues. They often state it is beneficial.*''

Though research was not highly ranked, some felt it was integral to food production as, ''*you* [learn] *from what you do,*'' particularly from what doesn't work.

The least important factor, particularly amongst *Mature* sites was, financial gain, yet 46% thought food production was quite important for saving money. Only 40% of sites generated an income. These were mainly commercial and charity forest gardens though typically the forest garden only generated 25% of their annual earnings. There were exceptions: three *Young* systems provided 50% of the manager's revenue (table 3), through: selling medicinal herbs; running a campsite and receiving a grant to create and use the forest garden as an educational resource.

Table 3: Income by forest garden type

	Income earnt from any aspect of the forest garden?	
Forest garden type	**Yes**	**No**
Private	8	19
Commercial	4	1
Community	4	9
Charity	4	2

Forest garden maintenance

Prior to planting, forest gardeners cover strips of land for up to two years with compostable material, topped by a cardboard layer, overlaid with black weed suppressing material. The aim is to build up organic matter through decomposition and to create friable soil, that simplifies planting, making heavy digging redundant (*E. Pilgrim, Pers. Obsv.*). Irrigation using natural water resources namely by siphoning rain water from ponds (42%) or water butts (28%), is reserved for crop planting, particularly trees. Some surround their planted crops with mulch (42%) ''*to maintain soil moisture,*'' and reduce the need for additional watering other than that received through rainfall.

Most respondents made natural (i.e. non-chemical based) pest control integral to their forest garden design. Consequently, they created a species rich area of plants that provided habitats for insects and other wildlife. Ponds encouraged amphibians, slug predators. In addition, a small proportion (12%) kept chickens and or ducks for the dual purpose of providing eggs and mollusc control. Others tried to reduce crop failure by either using varieties less susceptible to pests or using alternative planting methods such as using hanging baskets for salads.

Nutrients are typically provided by nitrogen fixing or 'accumulator' plants. However, most supplemented this with organic solid manure (80%) which included compost; cutting and dropping comfrey or nettle leaves and animal manure.

The forest garden method is described as low maintenance, yet most, 60%, spent significantly less time maintaining their system than anticipated, particularly in *Mature* sites where, ''*for very little work I get a big yield.*'' Some sites, particularly *Young* ones felt more labour was required than they had foreseen (24%). Only 16% of respondents felt they had correctly predicted their workload.

Generally Spring was the busiest period (76%) with jobs including weeding and (re-) planting especially in *Young* forest gardens. This was followed by Summer (64%) as it was the beginning of the main harvest period. Pruning occurred throughout Autumn and Winter.

Successful attributes of a forest garden

Respondents were asked to respond to describe, using a closed question with the potential for elaboration, what they felt were successful aspects of their forest garden. Generally, this was increasing biodiversity (80%) and plant establishment (80%). Most, 62% were very satisfied with the system commenting, “*It’s fabulous to go.. and pick things. A… more inspiring way to invent a meal*”; “*you don’t get massive gluts; just lots of produce over a longer season which is more enjoyable*” and, “*it’s a biological pension plan.*” However less than half felt that food production exceeded expectations (46%).

Challenging attributes of a forest garden

A forest garden’s design and the manager(s)’s horticultural experience is pivotal to its success. Consequently design, plant choice and maintenance caused some dissatisfaction. During the interview selection process, it became clear that several potential *Mature* sites had failed in the early years through poor planning. This included planting trees planted too close together, affecting light and humidity levels in the lower layers which promoted plant-fungal infections.

Mature forest gardens, particularly had to learn through trial and error as they were experimenting with crop species when plant availability and information were limited, “*There’s.. more information.. now.. about what to grow or do. In many ways* [it's] *more exciting and enjoyable.*” Other *Mixed* forest gardeners felt the paucity of advice, had affected their expectations, “*Things flower but not fruit* [so] *I feel I don’t… get the required knowledge of.. care.*”

Some felt food production was insufficient commenting, “*for a family* [it’s] *fine. I wouldn’t set it up to feed lots of people.*” Two *Mature* managers, preferred allotments for growing food. Some hadn’t anticipated that it took at least five years before their trees bore large quantities of crops. Forest gardeners with horticultural expertise ensured that there were other additional crops to fill the void whilst the trees matured.

Not all respondents enjoyed the unusual produce, “*It’s a good way of growing fruit. For vegetables, you need to like eating wild.*” Similarly *Mature* foraging proponents only believe forest gardens will become more widespread when the public accepts different food resources, “*We need to treat foraging as window shopping; seeing plants….. in the local community as.... food.*” Another *Mature* forest gardener further explained, “*many wild plants are bitter to our palate because modern food processing methods have accustomed us to sweeter flavours.*”

Participants’ felt that their greatest unforeseen challenges were: the unpredictability of the weather (68%); pests, particularly grazing deer/rabbits, killing/damaging young trees, (58%) and weeds, particularly grasses smothering plants (56%). Whilst some challenges seem obvious, they reflect the range of participant knowledge and expectation.

Improving the method

The forest garden’s maintenance often proved challenging, particularly for community types. Most responsibility lay with, at most, a few individuals. Consequently, suggestions for improving the forest garden method included having: an additional pair of hands (37.3%); more time to spend in it (33.3%) and money (11.8%). However, assistance was a double-edged sword. The individual(s) required gardening/horticultural knowledge to prevent damaging precious plants or failing that direct supervision which took up time.

4. Discussion

Forest garden characteristics

We provide the first academic assessment of forest gardens. Typically, they are created by well-educated, middle-aged people with similar socio-economic backgrounds, whose primary motive is environmental protection. Most sites are privately owned, indicating that the forest gardeners have earnt a disposable income to buy both the land and the plants. Community ventures typically received temporary start-up grants as no local government scheme existed for planting agroforests exists.

Most forest gardens were rural. *Mature* systems, established for 15 years or more years, were targeted to evaluate their vast experience as well as determine the method’s robustness. Characteristically, these pioneer *Mature* sites are bigger than *Young* ones. Consequently, larger plots are more likely to be available in rural locations compared with urban areas. However, our *Young* and *Mixed* sites were also predominantly rural; perhaps reflecting our selection methods. Future studies would benefit from exploring more urban locations.

Interestingly, *Mixed* sites were smaller than *Mature* or *Young* ones (Figure 2). This suggested that experienced forest gardens realised, like their homegarden counterparts that smaller systems, measuring up to 0.4 ha (Fernandes and Nair, 1986) have a greater chance of success. Homegardens are also carefully structured: each component has a specific space and function (Fernandes and Nair, 1986). System design and management is crucial for successful plant establishment and production. Each forest garden is unique, as they are purposefully designed for each specific location making replication of fruitful designs difficult. Vargas Poveda (2016) began addressing this, by developing six simplified forest garden archetypes defined by the system’s primary purpose: environment enhancement, production, community involvement, education, recreation and health. These were based on the 10 eldest, most renowned temperate forest gardens, all UK based.

Most forest gardens were established on land considered to be of poor agricultural value i.e. they were not suitable for growing traditional annual crops. However, forest gardens can be hugely productive. One *Mature* 26-year-old Scottish site, produced over 16 tonnes of food from 0.08 ha (James, 2017). Their 2013-2016 harvest comprised 52% top fruit (predominately apples), 28% vegetables, 12% soft fruit, 4% salads, 2% nuts and 2% herbs (G. Bell, *Pers. Comm.*, 2017).

Plant choice

Both forest gardens and homegardens are highly diverse (Nair, 2006), containing at least 64, predominantly perennial (Boom, 1989) crop species, spread over at least four layers (Jose, 2009). Provincial species, that thrive in their local environment are favoured, thus demonstrating that forest gardens, like homegardens conserve genetic diversity (Eilu *et al.*, 2007; Clarke *et al.*, 2014), particularly apple tree varieties, difficult to source elsewhere.

The crop composition is similar between forest garden sites as respondents selected species recommended by their role models, Hart (1993) and Crawford (2010). Consequently, like homegardens (Eilu *et al.*, 2007) certain plant traits were considered more important than others. Plant function was valued more than its aesthetic qualities (Eilu *et al.*, 2007). Multi-functional plants, with at least two attributes are sought (Eilu *et al.*, 2007) though more cautiously in forest gardens than homegardens. This may reflect the difference in plant knowledge exchange between the two systems; in homegardens plant expertise is passed down the generations. Contrastingly, much of this information in the western hemisphere has been lost so respondents experimented with plants they've learnt about from books/videos/site visits rather than first-hand experience.

Forest gardens contain a mixture of exotic and native plants and are akin to homegardens owned by high income earners (Eilu *et al.*, 2007; Clarke *et al.*, 2014). This reflects the British flora's paucity, including edible species, compared with tropical countries. Typical forest garden exotics are common British garden plants. Crawford (2010) has particularly promoted non-natives; convinced they are more adaptable to climate change than conventional crops.

Forest gardeners believed like their homegarden counterparts, that the food they produced was tastier and more nutritious, than shop bought produce (Vlkova *et al.*, 2011). Freshness was key, as food was picked immediately before consumption, something unachievable with supermarket produce.

The mixed success of perennial vegetables and foraging is due to participant expectation. The food they found unpalatable could be attributed to our modern relatively restricted diet. The austerity measures required during World War One saw a decline in crop diversity, including exotic species, typical in Victorian allotments last century (Wong, 2012).

Those with limited botanical/horticultural knowledge weren't confident foraging. Many preferred growing different, sweeter tasting soft-fruits including Queen Victoria's favourite Chilean guava, *Myrtus ugni* (Wong, 2012). Though conventional soft fruits were common (table 2), Japanese wineberry, *Rubus phoenicolasius*, was often recommended. This Asian species, has raspberry flavour berries enclosed in their calyx until ripe, limiting bird predation.

Actors influencing forest garden creation

As the primary motivator for the forest garden was environmental production, most respondents were delighted that the system increased wildlife diversity on their sites. Like homegardens the structural and ecological gradients affiliated with agroforestry provided a greater variety of habitats to enable wildlife to flourish (Vlkova *et al.*, 2011; Clarke *et al.*, 2014). This also enhances ecosystem service delivery: soil nutrient cycling, pollinator diversity and biological pest control (Clarke *et al.*, 2014), boosting food production and restoration of degraded land e.g. improved grassland (Fern, 1997) and sand dunes. This demonstrates that with a little imagination you can grow food almost anywhere.

Participants lead a non-competitive and non-commercial life, enhancing their well-being (Crouch and Ward, 1994). This is particularly relevant now, when modern technology's proliferation inhibits quality leisure time away from our daily pressures. Consequently, doctors in New Zealand, Australia and the United States, prescribe "Green prescriptions" to encourage people outdoors (Hilpern, 2015). Given the benefits people derive from trees (Bloomfield, 2014), forest gardens would be exceptionally well placed for this. Most respondents, like their homegarden counterparts highly valued the sites as relaxation spaces and for cultural traditions (Clarke *et al.*, 2014) e.g. apple wassailing, a custom in Southern England's cider orchards, where trees are blessed to encourage a good harvest.

Whilst *Mature* forest gardeners acknowledged the financial benefits of own-growing, few strived for economic independence. Contrastingly, commercial viability was important for *Young* and *Mixed* sites. *Young* forest gardens have greater capacity for economic success, benefiting from the knowledge and experience of *Mature* sites. This functional shift reflects the public's change in attitude following a harsh economic climate, whilst recent processed food scares made us question what we eat (Pilgrim, 2014). Foraging is increasingly popular, particularly amongst those with a disposable income, with many top chefs promoting wild plants, which ironically are free. The resurgence in 'natural' plant-based medicinal remedies provided one *Young* site with a livelihood. Forest garden crops, both native and exotic, have a high economic value relative to allotment produce; *Berberis sp.* fruits add flavour to breakfast cereals and candied *Angelica sylvestris* stem for cake decorations. Product price could be influenced by supply and demand; being only readily available in organic health food stores, and high-end supermarkets (E. Pilgrim, *Pers. Obsv.*), sought by people with the knowledge to use them. However, it's premature to judge their financial success as commercial forest gardens had an age range from 4–8 years.

Maintenance

It is unclear how much labour is required to maintain forest gardens as without a legal obligation to do so, few record this information. Due to the system's complexity, all the forest gardens benefitted from volunteers. Many offered fresh produce in exchange for help. Vargas Poveda (2016) suggests labour could be reduced by grouping plants by harvest period.

One successful food producer (James, 2017), attributing their efficiency to living on site, warning, "*if you don't live in permaculture* [it] *won't work.*" This isn't possible for all forest gardens, particularly community ventures. Whilst some bought the land to inhabit, factors beyond their control prohibited this; namely local objection either from the council, neighbours/others, wary of their unorthodox methods. Whilst such reactions to *Mature* systems were common, one *Young* forest garden has relocated due to complications over land classification i.e. the land is designated for agricultural use only so no domestic dwellings are permitted. Another commented that their immediate neighbours remain sceptical though visitors come from surrounding towns and villages. Consequently, for many forest gardens their current primary product is education, with the aim to allay fears by demonstrating the system's benefits.

Potential benefits of forest gardens

Two *Mature* forest gardens provide their local food bank with fresh produce; illustrating their potential role for improving nutrition amongst our society's neediest. Consequently, forest gardens could: like allotments in the aftermath of world war one, restore and or nurture community mental and physical health (Crouch and Ward, 1994). This includes integrating the immigrant population for the benefit of society and the environment (Lapina, 2015). This will require the successful combination of: a robust system design, a cohesive management team, and supporters/helpers that share similar aims/values. Typically, unsuccessful community ventures failed to get consistent local support, leading to overall disillusionment. Thus, new community ventures require: local council support, to gain access to suitable sites; early engagement with the local community, to meet their needs and; contact with successful ventures to benefit from their experience.

Potentially forest gardens, like homegardens, can deliver social, economic and environmental benefits. Global interest in forest gardens has inspired the Food Forest International Research Network (FFIRN) to promote collaborative investigation. However, our understanding of this method and their alternative crops will be enhanced by combing a holistic academic approach with both homegarden and forest garden practitioner knowledge.

Conclusion

We need diverse environmentally sensitive production methods. Globally, we are heavily reliant annual crops, particularly rice, wheat, maize and potato to meet our daily needs. As these need replanting yearly, they increase the risk of damage the soil and the environment. By seeking alternative food resources, including perennial crops, we can both broaden our diet and the potential of finding more sustainable methods of food production.

We have focused on own-growing methods as, given its global resurgence, we believe that this sector of society can make a vital contribution to the food supply; something that has previously been overlooked. The forest garden, with its curious blend of old and new methods, demonstrates that by exploring ancient cultures and techniques we can find ideas and potential solutions to solve our modern food conundrums. Through this system we have also been introduced to a wide variety of different crops and cultural uses of plants that can broaden our diet and plant knowledge for the benefit of mankind.

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Appendix 1: Semi-structured questionnaire: Establishing the benefits of forest gardens in the UK

Questions

About your forest garden

1. Forest garden number
2. Name of forest garden
3. What year did you start your forest garden?
4. Is your forest garden
   - Rural
   - Urban: city or town?
5. How would you describe your forest garden?
   - Private enterprise
   - Community enterprise
   - Commercial enterprise
   - Other (please define)
6. Size of the plot
   Acres / hectares / metres
   - Area owned
   - Area rented/leased
   - Other

Total Area

Landscape features of the forest garden

7. Altitude
   - on a slope
   - flat
   - other
8. What is the orientation of the site?
9. Soil Type
   - loam
   - clay
   - sandy loam
   - silty
   - peat
   - Chalky/lime rich
   - Other

The inspiration behind your forest garden

10. Why did you decide to create a forest garden?
11. How important to you are the potential environmental benefits of forest garden in terms of
    - Increasing the local biodiversity?
      - very important
      - quite important
      - not sure
      - not important
    - Increasing the national biodiversity?
      - very important
      - quite important
      - not sure
      - not important
    - Reducing fertiliser and pesticide application on the land?
      - very important
      - quite important
      - not sure
      - not important
    - Less disturbing to the land through the use of permaculture principles i.e. limited use of chemical fertilisers and pesticides, no soil disturbance through the use of the no-dig method etc?
      - very important
      - quite important
      - not sure
      - not important
12. How important to you is it to produce:
    - Food with minimal impact on the environment?
      - very important
      - quite important
      - not sure
      - not important
    - your own food as it saves money?
      - very important
      - quite important
      - not sure
      - not important
    - alternative food which you can't buy in the shops?
      - very important
      - quite important
      - not sure
      - not important
    - your food which you know how it has been grown?
      - very important
      - quite important
      - not sure
      - not important
    - that tastes better than shop bought food?
      - very important
      - quite important
      - not sure
      - not important
13. In terms of life style choice how important is it to you that you use your forest garden for
    - Pleasure/recreation/relaxation
      - very important
      - quite important
      - not sure
      - not important
    - Spiritual
      - very important
      - quite important
      - not sure
      - not important
    - Physical exercise
      - very important
      - quite important
      - not sure
      - not important
    - Social activity within the local community
      - very important
      - quite important

- not sure
- not important

please elaborate

- Social activity outside of the local community
  - very important
  - quite important
  - not sure
  - not important

please elaborate

14. What are the most important factors which influenced your decision in creating a forest garden? Please use a scale of 1 to represent least important to 5 very important.
    - Produce food
    - Lifestyle choice
    - Environmental benefits
    - Financial benefits
    - Research

Can you elaborate more on that?

15. Have you been influenced by any of the following people in creating a forest garden? Please answer Y or N
    - Robert Hart
    - Patrick Whitefield
    - Graham Bell
    - Martin Crawford
    - A relative/friend
    - Other: please specify
16. Who was the most important
    - Robert Hart
    - Patrick Whitefield
    - Graham Bell
    - Martin Crawford
    - A relative/friend

Please elaborate

17. Please answer Y or N to the following: Have you sought additional inspiration on forest garden
    - Visiting other forest garden
    - By attending practical forest gardening training courses?
    - Watching videos on forest garden
    - Reading Books other than those authors listed above
    - Other please elaborate

The Plants in your forest garden

18. Robert Hart, who began the forest garden movement here in the UK, described it as having several different layers: the first a canopy with standard or half-standard fruit trees; a second low-tree layer of fruit & nut trees on dwarfing rootstock, bamboo; the third a shrub layer: currant and gooseberry bushes, *Rosa rugosa;* the forth a herbaceous layer comprising herbs and perennial vegetables; the fifth a ground- cover layer of creeping plants such as *Rubus sp*; the sixth: the rhizosphere: shade tolerant and winter root plants and finally the seventh vertical layer: climbing berries, nasturtium, runner beans and vines trained up trees, over fences and buildings. How many layers are there in your forest garden?
    - 2 or fewer
    - 3
    - 4 to 7
19. Have you obtained your plants in the following ways?

    Y N

    - From previous owner of the production system
    - Bought from various kinds of retailers
    - Seed/plant swap
    - Collected seed from the wild
    - Propagated plants from friend/neighbour
    - Given as a gift

    If Other please state

    Please elaborate
20. In choosing plant species how important is it that they are
    - Attractive?
      - very important
      - quite important
      - not sure
      - not important
    - Good producers?
      - very important
      - quite important
      - not sure
      - not important
    - Tasty?
      - very important
      - quite important
      - not sure
      - not important
    - Best suited to local conditions?
      - very important
      - quite important
      - not sure
      - not important
    - Recommended (include info by whom)?
      - very important
      - quite important
      - not sure
      - not important
    - Fufills a number of purposes (beneficial to wildlife/good final product/easy to grow/propagate)?
      - very important
      - quite important
      - not sure
      - not important
21. Do you specifically grow any local/old varieties of plants in your forest garden?
    - No (Please go on to Q 17)
    - Yes
    - Not sure

    If Yes please elaborate

What other species do you grow of

22. Fruit trees
23. Fruit bush
24. Vegetable/Herbs
25. Ground level
26. Climber
27. Tuber

NB this has been expanded to a species list for each of the different layers

28. Do you grow raspberries? [Need a jump to Produce Q 32 if select No]
    - Y
    - N
29. If you grow raspberries what varieties do you grow? Please name
    - Summer fruiting?
    - Autumn fruiting?
    - Mix of summer & autumn?
30. How old are the raspberry canes?

    Summer Autumn

    - <3 years
    - 3-6 years
    - 6 or more
    - Mixture (state) Only interested in 3-6
31. Have you ever had any problem with raspberry beetle?
    - No
    - Yes last year
    - Yes 2-5 years ago
    - Yes more than 5 years ago
    - Don't know

The Produce from your forest garden

32. At your forest garden do you
    - Only produce food?
    - Produce food but also use the area as an educational resource too?
    - Other (please specify)
33. Do you obtain any monetary income from any aspect of the forest garden?
    - Yes
    - No (go to q37)
34. If yes how is the income derived? (multiple answers possible)
    - Food produced alone
    - Courses in land management
    - Courses in environmental education for adults
    - Courses in environmental education for children
    - Courses in growing and propagation techniques
    - Tours
35. What are the three most important products and why?
36. And what proportion of your income comes from your forest garden?
    - <25%
    - 25–50%
    - >50%

Maintenance of the forest garden

37. How has the forest garden been successful?
    - The plants established
    - Produced more food than expected
    - Wildlife has increased in the area
    - Have an area where you can relax
    - Other please elaborate
38. Have any of the following created unforeseen challenges?
    - Weather
    - Plants in unsuitable locations
    - Pest/disease
    - Weeds
    - Too far from site
    - Other please elaborate
39. Who did most of the planting in the forest garden?
    - Respondent male
    - Respondent female
    - Other family member male
    - Other family member female
    - Other please state
40. Who spends over 50% of their time looking after the forest garden e.g. pruning, weeding, fertilising, planting etc.?
    - Respondent male
    - Respondent female
    - Other family member male
    - Other family member female
    - Other please state
41. Do you get any help from any of the following.

    Answer Y or N

    Family members (adults)
    Family members children
    Friends adults
    Friends children
    Woofers
    Local community adults
    Local community children

Please elaborate on other and age of any children that help

42. When is most help/maintenance on the forest garden required

    Winter
    Spring
    Summer
    Autumn

Please elaborate

43. Do you spend more or less time on your forest garden than expected? Please elaborate
44. What if anything would help you maintain and look after your forest garden?
45. Has the forest garden lived up to your expectations
    - Y
    - N

Please elaborate

46. Please tick which fertilisers you use? (NB there can be more than one answer)?
    - ○ Organic solid (horse, chicken, garden compost; other!)
    - ○ Organic liquid (like comfrey; nettles)
    - ○ Green manure
    - ○ Other
47. How do you irrigate?
    - ○ Mains tap
    - ○ Use a water butt
    - ○ Other
48. Do you implement pest control?
    - ○ Yes
    - ○ No (go onto Q 34)
49. What type of pest control do you use?
    - ○ Plant umbellifers such as dill, fennel or daisies and marigolds to attract predators of pests
    - ○ Plant sacrificial plants for pests to attack
    - ○ Animals such as ducks/frogs
    - ○ Other? Please specify
50. How satisfied are you with your decision to grow food in this way?
    - ○ Very satisfied
    - ○ Quite satisfied
    - ○ Not sure
    - ○ A little satisfied
    - ○ Not at all satisfied

Please elaborate

51. Would you recommend creating a forest garden to your friends and family?

    Y N

    - ○ Friends
    - ○ Family
    - ○ Schools
    - ○ Farmers
    - ○ Other please elaborate

About you

52. Male/Female (I tick)
53. Respondent's DOB
54. Educational Background
    - ○ Degree, higher degree, member of a professional institute
    - ○ Higher educational qualification but lower than degree level (HNC/HND)
    - ○ ONC/OND/BTEC
    - ○ A level or highers
    - ○ O'level or GCSE equivalent
    - ○ Other qualifications
    - ○ No formal qualifications
    - ○ Refuse
    - ○ Don't know

Thank you very much for taking part in this survey

REFEREED ARTICLE

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Are farmer personality traits associated with farm profitability? Results from a survey of dairy farmers in England and Wales

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ABSTRACT

Although the personality of the manager has been shown to predict performance in many fields, in agriculture, this relationship has not been studied in detail. In the study presented here, 59 dairy farm managers in England and Wales completed psychological assessments; on 40 of 53 measures, farmers were found to be distinct from the general working population norm. Significant correlations to farm profitability for four of the 53 measures were found. Almost 40% of the variation in farm profitability was predicted by a simple linear model with just three of these personality measures: 'Detail Conscious' and 'Leadership' measures positively and, 'Relaxed', negatively, predicted farm profitability. Though observational, and not demonstrating cause and effect, the associations are strong. These three measures are, thus, candidate variables for personality measures that drive farmer and farm manager performance. Longitudinal, or intervention studies, may demonstrate causality in the future. In the interim, being cognisant of these attributes during the hiring and training of farm staff, particularly those with management roles, may well result in improvements in farm profitability.

KEYWORDS: farm profitability; farmer personality; management; talent; performance; psychology

1. Introduction

That more than 40% of the variation in job performance can be predicted by personality and intelligence has been established in numerous meta-analyses and reviews (e.g. Hunter and Hunter, 1984; Schmidt and Hunter, 2004; O'Boyle *et al*., 2010; Schmitt, 2014). Assessing human attributes has, thus, become a focus in Industrial and Organisational Psychology with General Cognitive Ability (GCA) consistently found to predict more variation in job performance than any other attribute (Reeve and Hakel, 2002). GCA, IQ, 'g' or intelligence is generally described as consisting of two components: fluid and crystallised intelligence (Nuthall, 2001). Fluid (non-verbal) intelligence is thought to be largely genetic, relating to the capacity to solve problems in novel situations. Crystallised (verbal) intelligence relates to learned and cultural intelligence and familiarity with the situation at hand (numerical, verbal and social ability).

Personality has also been found to be generally independent of GCA and to have incremental predictive ability over GCA for job performance (Schmitt, 2014). Personality, in particular measures from the Five-Factor Model (FFM) of individual personality, has been shown in these reviews of studies from a range of sectors (though not including agriculture) to predict up to 25% of the variation in job performance. This indicates personality is a major predictor of job performance, although coming somewhat behind that of GCA (40%) (Schmitt, 2014).

The Five-Factor Model (FFM)/Big 5 is the predominant personality model in psychology and has surpassed other theories, such as the Myers Briggs Type Indicator, in research contexts. The main components within the FFM are agreeableness, conscientiousness, neuroticism (emotional stability), extraversion, and openness (McCrae & Costa, 1985). Of these, conscientious and emotional stability have been found to be predictors of capability in a wide range of sectors. The remaining three can be important to a lesser extent depending on the context. Openness and agreeableness are advantageous during training for example (Poropat, 2009).

Nuthall (2009) adapted FFM theory to create 25 questions to assess 40 New Zealand farmers' 'management style'.

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Following factor analysis, six 'style factors' were identified, two of which aligned somewhat with two of the FFM factors, while four factors did not. Two variables predicted financial performance and are related to conscientiousness. 'Thoughtful creator' was positively associated with profitability and 'concern for correctness' was negatively associated with profitability with an effect size of about 0.1 each.

From an agricultural and farm economics perspective, there is a relatively extensive literature looking at farm characteristics such as size and enterprise mix as predictors of farm financial performance and sustainability. In general, a clear picture emerges that only a proportion of the variation can be explained by these variables, and that the main drivers of this variation are scale, efficiency and market prices (Tey and Brindal, 2015). All three have a relatively well developed associated literature with efficiency, in particular, being a prominent area of discussion (Wilson *et al.*, 1998; Alvarez and Arias, 2004; Barnes, 2006; Johansson and Öhlmér, 2007; Wilson and Harper, 2011). The proportion of variation explained by these variables is surprisingly small, considering the considerable research effort these topics have had, and continue to garner. As Tey and Brindal (2015) showed in a review of studies on the topic of farm financial performance being predicted by farm characteristics alone, statistical significance is not consistently found for most variables and, even then, the direction of the association is not even consistent. Beyond the token inclusion of age and education, a full investigation of the role of farmer attributes as drivers and correlates with farm business profitability is missing from the literature. Conversely, there is a significant core of literature that looks at farmer attitudes, perceptions and motivations which does not include consideration of financial information (e.g. Sutherland and Burton, 2011; Gasson, 1973; Burton, 2004). Given the relative paucity of agricultural research linking GCA, and personality in particular, to farm profitability to date, and the established importance of these attributes in the field of occupational psychology, more research on these topics is likely to be fruitful and to add significantly to our knowledge of the drivers of farm business performance.

Research on these topics in agriculture to date has been curiously modest with a few notable exceptions (McGregor *et al.*, 1996; Austin *et al.*, 2001; Hansson, 2008; Nuthall, 2010). There has been some research on the related topic of attitudes and beliefs (Gasson, 1973; Edwards-Jones, 2006; Mäkinen, 2013; O'Leary *et al.*, 2018). However, this focus on attitudes and beliefs is closer in scope to the well-developed theme of understanding and influencing specific farmer behaviours such as individual practice adoption (Mattison and Norris, 2007; Garforth, 2010; Schroeder, 2012; Jones *et al.*, 2016). The focus of agricultural economists and rural sociologists to date has thus been assessing the data that is readily available in datasets such as those in the European Union's Farm Accountancy Data Network and those farmer attributes assessed when trying to influence farmer behaviour. One set of studies, the Edinburgh Study of Decision Making on Farms, did assess the personality and GCA of farmers in Scotland but did not assess associations between these measures and farm profitability in detail (McGregor *et al.*, 1996; Willock *et al.*, 1999; Austin *et al.*, 2001). McGregor *et al.* (1996) did have a table that indicated that lower GCA farmers were less profitable, though this was not discussed in detail or followed up in the subsequent publications coming out of the project.

Assessing the personality of managers and staff on farm, and using this information during selection and training may, therefore, be a way to improve farm profitability that is currently not part of the farm management research paradigm. Farm-specific research confirming such findings in general occupational studies would aid the application of these insights in agriculture, and so are likely to improve farm profitability.

This paper, which is inter-disciplinary in nature, drawing on aspects of farm economics, rural sociology and occupational psychology aims to address the paucity of research to date of how farmer personality is associated with farm business performance. A sample of British dairy farmers completed the Occupational Personality Questionnaire (OPQ) (Saville *et al.*, 1996; British Psychological Society, 2016) and the associations between 53 OPQ psychometric measures and farm profitability are reported here using both correlation analysis and linear models. The findings, and their implications for farm management and farm management research, are then discussed.

2. Materials and Methods

Introduction

The objective of the study presented here was to assess the relationship between personality and farm profitability. A sample of dairy farmers in England and Wales had their personality assessed in conjunction with the financial performance of their farm businesses in 2015. In this section, the participants' characteristics, the profitability measure, the personality assessment, and the analysis methods used are introduced and described.

Sample characteristics

Over 180 dairy farm managers and farmers in England and Wales were asked to take part in our study; most were clients of Promar International, and a minority were contacted by DairyCo (now called AHDB Dairy). As such, the sample can be classed as a convenience sample; 59 dairy farm managers and farmers completed a personality assessment resulting in a response rate of 33%. Farmer workload was cited as the most common reason for not participating. Financial data was not forthcoming from three participants, so personality and financial data was only available for 56 of the 59 project participants.

Of the 59 respondents, 40 had independently created farm management accounts carried out by Promar International which provided the financial data for this study. Looking at this sub-sample of 40, it is not especially representative of England and Wales for farm size and system with smaller herds under-represented in particular (Table 1).

Whilst 16 farm managers completed spreadsheets by themselves to calculate their own 'comparable profit', this farmer calculated data was found to be less accurate than the independently calculated data as stronger statistical relationships emerged when using only the independently calculated profitability measures. For this reason, these farm businesses were not included in the profitability analysis resulting in a final sample of 40 for

Table 1: Participant farm businesses' **summary descriptive statistics (N=40)**

	Mean	Standard deviation	National average (2015)
Herd size	210	108	141[1]
CFP[3]/litre	5.3p	5p	4.35p[2]
CFP[3]/cow	£390	£353	N/A
Litres per cow	7,362	1,620	7,944[1]

[1] Herd size, England and Wales, litres per cow, UK (AHDB, 2016a)
[2] Mostly English reference sample (Vickery *et al*., 2015)
[3] Comparable Farm Profit

Table 2: Example OPQr forced choice question block

	Most like me	Least like me
I like helping people	X	
I enjoy competitive activities		
I view things positively		X

the correlation and linear model analysis. For our comparisons between farm managers and the UK population norm, all 59 completed personality assessments were used.

Comparable Farm Profit (CFP) is a measure of profitability used in benchmarking by the levy body that all UK dairy farms are required to belong to, AHDB Dairy. Here it focused solely on the dairy enterprise and involved calculating total profit for the dairy enterprise per litre, per cow and per hectare. In this study, only profit per litre and cow was available to the authors. CFP is derived as follows. From dairy income, variable costs and fixed costs are subtracted plus the profit/loss on any sale of assets to produce what is widely called Farm Business Income. When the value of family or unpaid manual and managerial labour is subtracted, CFP results - in some circles this is called Farm Corporate Income. Rent, whether real or imputed, and finance charges are not deducted to get this measure.

The Occupational Personality Questionnaire

The Occupational Personality Questionnaire TM (OPQ) is a personality inventory designed for use in occupational contexts for selection and training. The themes assessed include relationships with people, thinking style and feelings and emotions. It is based on prominent models from psychology and management (Saville *et al*., 1996). The OPQ has received an endorsement from the British Psychological Society having been tested for validity and reliability (Smith and Banerji, 2007). OPQ's incremental validity for predicting performance beyond ability measures has also been established (Bartram, 2013; Furnham *et al*., 2014). The OPQr was, thus, deemed a suitable tool for the study summarised here where farmer personality was the topic of interest.

Table 2 shows an example OPQr question block. In each block, three statements were presented. Participants then selected the statement most like them and the statement least like them - a forced choice format. This forced choice format helps counteract social desirability bias and is relatively efficient (Brown and Bartram, 2009). The OPQr version employed in this study was the latest version of the OPQ available at the time and takes 25 to 40 minutes to complete. It has a short, forced choice format, with normative properties (British Psychological Society, 2016). The OPQi (ipsative) is similar but with a forced choice between four options (rather than three) and the OPQn is a normative version. As they are mostly self-explanatory, for space reasons, and the fact that the OPQr instrument is proprietary, descriptions and definitions of every variable assessed are not included in this paper. Much information regarding the OPQ is, however, available from SHL/CEB publications on their website of published literature e.g. Saville *et al*., 1996; Brown and Bartram, 2009; Bartram, 2013.

The norm population

To calculate scores on these personality measures for the participant farmers, their responses were compared by SHL to a norm population that was a representative of the general working population of the UK's Commonwealth English speaking countries; this includes people from India and Australia (for example SHL Group Limited, 2011). People from all socio-economic, educational and occupational backgrounds were included in this norm population as detailed below:

> '*The OPQ32r international 'general population norm' is a work population norm, drawn from country-specific (or regional) work population norms (CEB, 2011-2012) that include people actively seeking employment and those in employment; it is therefore a generic norm of people who can be employed, including people not currently in employment, students, and graduates (with varying employment length and all education levels).*' (*SHL Group Limited, 2015*)

The characteristics of the norm population are detailed in the technical manuals available online from the SHL/CEB website (SHL Group Limited, 2015). The main population norm characteristics of note that contrast with average dairy farmers in England and Wales are as follows:

- A gender ratio of 61:39 male to female; farmers in England and Wales are 95% male (Wilson *et al*., 2013);
- 37% of the norm population were 29 or younger and only 6.7% of the norm group were over the age of 50; the average age of dairy farmers in England is 51 (Farm Business Survey Team, 2012);

Table 3: Likelihood of having a particular competence by STEN score

STEN score	1	2	3	4	5	6	7	8	9	10
Competence likelihood	Unlikely		Less likely		Average		Quite likely		Very likely	

- 32.6% of the norm population had postgraduate degrees; this is much higher than farmers in England and Wales at about 3% (Wilson *et al*., 2013); and
- only 40% of the norm population had managerial responsibilities; this can be compared to all the participants of this study having such responsibilities.

Though this may not be the most ideal comparison, it functions well as a reference. In addition, other population norm comparisons were not available for the study reported here. For example, a comparison with managers or sole proprietors would also have been informative.

A total of 53 psychological variables were extracted from the individual farm managers' assessments. These measures were calculated by SHL against the norm population and presented as STEN (standardised ten) 'scores' in reports for each of the participants (Table 3). Each score indicates how likely the respondent has a particular competence/trait compared with the norm population. Mean STEN scores for the norm population are, by definition, 5.5 and have a standard deviation of 2 for the norm population (Macnab *et al*., 2005). These STEN scores were extracted from the individual participants' reports and comprise the independent variables used in the study reported here.

Analysis methods used

To compare the participants' scores with the population norm mean of 5.5, one-sample t-tests were performed using R function 't-test' specifying 'two-sided' and mu of 5.5 (R Core Team, 2013). To assess the relationship between personality measures and profitability, a Spearman's rank correlation analysis was performed. To assess the relative importance of variables correlated with profitability, linear regression was also carried out. The 'cor' and 'lm' functions in R statistical software were used for this (R Core Team, 2013).

3. Results

Introduction

In this section, the results of three types of analysis are presented. First, the scores of the study farmers and farm managers are compared with the reference norm sample using one-sample t-tests. Second, correlation analyses between personality measure STEN scores with litres of milk produced and profitability measures are reported. Finally, two linear models predicting profitability are presented.

Comparison with norm population

As the OPQ reports measure participants as STEN scores, for comparison purposes, the mean of the norm population described above for each measure is, by definition, 5.5. Table 4 reports the contrasting mean scores for farm managers, the standard deviation of the farm manager sample, and the p-value indicating if farmers' scores were statistically distinct from the norm population (UK English speaking general working population). For 40 of the 53 measures, the farm managers' scores differed significantly ($p=<0.05$); 33 of 53 differed at the stricter threshold of <0.01 and 23 at <0.001.

For example, farm managers scored lower on Conscientiousness and Detail Conscious measures but higher on Modest and Independently Minded compared with the norm sample.

Correlations with profitability

Four personality variables had large and significant correlations with both profit of the dairy farm business per cow and profit per litre. As shown in Table 5, these were Detail Conscious, Leadership, Relaxed and Conscientiousness measures.

Profitability linear models

This study reported here set out to identify variables predictive of CFP per cow and per litre. To this end, linear models to predict variation in these two variables were developed using the personality measures most correlated to these profitability measures.

An initial model was created with these nine variables most correlated to profitability shown in Table 5. The least significant variable was then removed and the model re-run. This procedure was iterated until all the remaining variables were statistically significant, similar to the stepwise procedure used by Vandermersch and Mathijis (2004). Models with an adjusted R^2 of 0.41 for profit per litre of milk and 0.38 for profit per cow resulted. The same three variables emerged in predicting both outcomes: Detail Conscious; Leadership; and Relaxed (see Table 6 and Table 7).

A high scorer for Detail Conscious 'focuses on detail, likes being methodical, organised and systematic'. A low scorer can be described as 'unlikely to become preoccupied with detail, less organised and systematic, dislikes tasks involving detail'. High scorers were much more profitable. Scoring one STEN score higher on this measure (half a standard deviation) was associated with £72 per cow or 1p per litre of milk greater CFP per year.

A similar change in Leadership score was found from the modelling to result in a £55 per cow, or 0.8p per litre of milk, change in profit per year. Leadership is described as 'Inspiring and guiding individuals and the group. Leading by example and arousing enthusiasm for a shared vision'. Finally, Relaxed was negatively associated with profit with each STEN score increase associated with a negative change in profit of £49 per cow and 0.6p per litre of milk. A high scorer on this is likely to be described as: 'finds it easy to relax, rarely feels tense, is generally calm and untroubled'. A low scorer 'tends to feel tense, finds it difficult to relax, can find it hard to unwind after work'.

Only the personality measures derived from the OPQ were included in this analysis of financial performance, as that was the focus of the study.

Table 4: Comparison of farm managers with the population norm on personality scores[1], ordered by farm manager mean upwards (N=59)

	Farm managers mean	Farm managers Std Dev	p-value
Conscientiousness	3.4	2	<0.001
Detail Conscious	3.6	1.9	<0.001
Conscientious	3.6	2.1	<0.001
Service Orientation	3.8	1.8	<0.001
Building Bonds	4	2.1	<0.001
Achieving	4	1.8	<0.001
Rule Following	4.1	1.9	<0.001
Behavioural	4.2	1.9	<0.001
Understanding Others	4.3	2.1	<0.001
Persuasive	4.3	1.6	<0.001
Caring	4.3	2.1	<0.001
Emotional Awareness	4.4	2.1	<0.001
Communication	4.4	2.1	<0.001
Innovative	4.4	1.8	<0.001
Accurate Self Assessment	4.5	1.8	<0.001
Achievement Drive	4.5	1.8	<0.001
Organisational Awareness	4.5	2.1	0.001
Persistence	4.6	2.2	0.003
Influence	4.6	1.9	0.001
Change Catalyst	4.6	2.1	0.002
Developing Others	4.6	2	0.001
Teamwork and Collaboration	4.6	1.9	<0.001
Leadership	4.7	2.1	0.005
Affiliative	4.7	2.1	0.003
Socially Confident	4.7	2	0.003
Democratic	4.7	2.5	0.015
Evaluative	4.7	1.9	0.002
Conceptual	4.7	2.2	0.011
Variety Seeking	4.7	2.1	0.006
Adaptable	4.7	1.7	0.001
Initiative	4.8	2	0.009
Outspoken	4.8	2.1	0.017
Self Confidence	5	1.9	0.045
Data Rational	5	2	0.049
Conflict Management	5.1	1.7	0.083
Controlling	5.1	1.9	0.148
Outgoing	5.2	2.1	0.34
Optimistic	5.3	2.1	0.55
Decisive	5.3	2.1	0.41
Adaptability	5.4	2	0.675
Relaxed	5.4	2.5	0.732
Competitive	5.5	2	0.869
Forward Thinking	5.6	1.8	0.694
Tough Minded	5.7	2.3	0.515
Trusting	5.7	2	0.423
Vigorous	5.8	1.8	0.265
Conventional	5.9	2	0.105
Worrying	6	1.9	0.059
Self Control	6.1	2.1	0.024
Consistency	6.2	1.4	<0.001
Modest	6.5	1.9	<0.001
Emotionally Controlled	7	2.2	<0.001
Independent Minded	7.2	1.7	<0.001

[1] One sample t test, two tails, n=59; being STEN scores, the reference population has a mean of 5.5. Ordered by mean STEN score upwards

4. Discussion

Introduction

Farmers were found to be distinct psychologically from the population norm of people available to work in UK English speaking countries with 23 out of 53 variables being significantly different at the <0.001p-value threshold (see Table 4). This could well have been expected as farmers and farm managers are quite different in many regards from the general working population of UK English speaking countries used as the comparative population norm. Of note, however, is that participants, in general, scored lower than the comparative population norm used.

Farm managers scored a standard deviation lower on the Detail Conscious personality variable (mean =3.6) compared with the norm population (5.5). This indicates farmers and farm managers are much less likely to focus on detail, be methodical, organised and systematic compared with the population norm described in the Method section above and relative to many of the other measures assessed. Farmers are generally their own 'bosses', perhaps

Table 5: Profit of dairy farm businesses and farm manager personality correlation (n=40)

	Rho	p-value	Rho	p-value
	profit/litre		profit/cow	
Detail Conscious	0.48	0.00	0.45	0.00
Leadership	0.46	0.00	0.43	0.01
Relaxed	-0.35	0.03	-0.37	0.02
Conscientiousness	0.35	0.03	0.33	0.04
Controlling	0.30	0.06	0.29	0.07
Democratic	0.29	0.07	0.26	0.11
Social Skills	0.29	0.07	0.24	0.14
Conscientious	0.26	0.10	0.26	0.10
Self-Control	-0.21	0.19	-0.29	0.07

Table 6: Profit per litre on survey farms predicted by personality variables (N=40)

	β	Estimate	Standard error	t-value	p-value
(Intercept)		1.03p	2.16p	0.47	0.638
Detail Conscious	0.40	1.00p	0.31p	3.22	0.003
Leadership	0.34	0.79p	0.29p	2.72	0.001
Relaxed	-0.31	-0.61p	0.24p	-2.49	0.017

R^2=0.48, Adj R^2=0.41

Table 7: Profit per cow on survey farms predicted by personality variables (N=40)

	β	Estimate	Standard Error	t-value	p-value
(Intercept)		£137.66	0.477	-1.554	0.129
Detail Conscious	0.38	£71.84	0.069	2.994	0.005
Leadership	0.31	£54.67	0.064	2.449	0.019
Relaxed	-0.32	£-48.72	0.054	-2.596	0.014

R^2=0.43, Adj R^2=0.38

explaining this difference from the reference population who are generally, employees. A comparison with managers in other sectors would have been insightful in this regard. Leadership was the other positively related variable and those studied had a mean of 4.7, just less than half a standard deviation lower than the norm population.

Farmers and farm managers were found to have a similar mean score for Relaxed to the norm population (5.4), and this measure was negatively associated with profitability. High scorers on Relaxed are likely to be less proactive in preventing problems as they probably can tolerate problems when they arise. The more anxious and worried manager, scoring lower in the Self-Control and Relaxed personality variable, goes out of their way to prevent such occurrences.

The remainder of this section discusses these findings in more detail. First, each of the three variables included in the profitability models are discussed and interpreted in more detail. Observations regarding the data sources, possible future research and some weaknesses of the study described here are then discussed.

Detail conscious

The Detail Conscious measure relates positively to profitability. A high scorer 'focuses on detail, likes being methodical, organised and systematic'. A low scorer is 'unlikely to become preoccupied with detail, less organised and systematic, dislikes tasks involving detail'. However, the sample of dairy farmers assessed had relatively low scores compared to the other competences assessed and the comparative norm population used in this study. Half of the farmers and farm managers had STEN scores of three or below. The median dairy farmer in the sample was, thus, at least a standard deviation less Detail Conscious than the norm population.

Potential explanations include that many farmers may only have worked for family members before becoming managers themselves, and that family owned and managed farms provide a job security that is likely to reduce incentives for the Detail Conscious behaviour expected in other contexts. Further research, both quantitative and qualitative, may thus be required to understand this finding fully. However, farming does not preclude Detail Conscious behaviour as several high scorers were observed in this study. These farmers tended to have much more profitable farm businesses.

The correlation of rho=0.48 indicates that the Detail Conscious measure of farmers and farm managers co-varies with approximately 24% of the variation in profit. This is the largest correlation found in the study reported here. The regression model indicates that a change in STEN score of just one (half a standard deviation in the norm population) predicts a change in profit per cow of £71. Assuming a 150 cow herd, the UK average (Ashbridge, 2014), this implies over £10,000 profit differential a year for a single STEN point change in managers' scores. As a result, the relationship between Detail Conscious behaviour and profitability should be communicated to farmers and farm managers along with the finding that it is far from the norm found in the industry.

Starting from a low base of 3.7, and with the largest single correlation observed in the study, this offers the greatest potential return for achieving farm financial performance improvements. If farmers and farm managers could become more Detail Conscious, large improvements in performance may follow. The models suggest that effecting a two or three point change in this score could have large benefits. As a consequence, expending effort to achieve this is likely to represent a good return on investment for farmers and farm managers.

Conscientiousness and related measures

Here we outline the differences between Conscientiousness, Conscientious and Detail Conscientious measures discussed in this study. Conscientiousness is one of the five factors constituting the Five Factor Model (McCrae and Costa, 1985), also known as the Big Five or NEO five. The scores Conscientious and Detail Conscious exist within the 'Conscientiousness' factorial space (Brown and Bartram, 2009). Conscientious and Detail Conscious, therefore, measure specific aspects of 'Conscientiousness'.

The broader measure, Conscientiousness, is described as 'Taking responsibility for personal performance. Meeting commitments and adopting an organised approach to one's work'. Possessing this measure correlated with profit per litre, and per cow, significantly (0.35 and 0.33). In contrast, a high scorer for Conscientious, an aspect of Conscientiousness, is described as someone who 'focuses on getting things finished, persists until the job is done' and a low scorer as someone who 'sees deadlines as flexible, prepared to leave some tasks unfinished'. Conscientious correlated (0.26) to both profit measures but was not statistically significant (p=0.10). Having compared these three measures (Detail Conscientious, Conscientious and Conscientiousness) it appears that it is the attention to detail aspect, rather than completing and finishing that is most associated with profitability.

Leadership

Leadership is described as: 'Inspiring and guiding individuals and a group. Leading by example and arousing enthusiasm for a shared vision'. The important role of Leadership in farm profitability is, for the first time, supported empirically among farmers and farm managers by our findings. The regression models predict that, if two farmers only differed in their Leadership measure by one STEN score, half a standard deviation, the one that scored higher would achieve £55 more profit per cow or just under £8,000 more per year for a 150 cow herd.

Relaxed

The variable Relaxed had a large negative correlation with profitability, and was included in the final models. A high scorer on the Relaxed measure 'finds it easy to relax, rarely feels tense, is generally calm and untroubled' and a low scorer 'tends to feel tense, finds it difficult to relax, can find it hard to unwind after work'. A constant drive to succeed manifests as tenseness and an always-on approach appears beneficial in dairy farming, financially at least. This finding was somewhat contradictory to expectations. Relaxed exists in the factorial space of Emotional Stability (Bartram, 2013), which is thought to be an important positive predictor of performance, in general, while these results indicate that some aspects of emotional stability are not beneficial from a farm financial perspective.

Data quality and future research

Future research in this area should include the OPQr, or alternative psychological inventory, a reputable GCA measure and quality financial data with a larger fully representative sample and with varying populations of farmers. Controlling for business size may also be advisable. The OPQr instrument has been proven to be effective for use with farmers and farm managers. However, non-proprietary alternatives should be considered. The OPQs' opaqueness, due to its proprietary nature, is a significant impediment from a research perspective and it would be relatively expensive for farmers and farm managers to use the tool themselves. This is likely to reduce potential benefits from the application of the findings in practical contexts.

5. Conclusions

Three personality measures predicted around 40% of the variation in farm financial performance in a relatively small sample of 40 dairy farmers and farm managers in England and Wales over 2015. A wide range of scores on these variables existed among the farmers and farm managers, and the mean scores of some key attributes are distinct from the national norm population used for comparison in the study summarised here. Hiring and training of farm managers, and other farm staff, is likely to be improved by increased assessment of such personality measures in the process. Training providers, farm consultants and farm managers should also consider how to achieve this.

Increasing Detail Conscious behaviour is the most exciting opportunity arising, as there appears to be a need to increase this beneficial trait from a low base among dairy farmers and managers in England and Wales. The effectiveness of training at targeting Detail Conscious behaviour, and Leadership, at improving farm business financial performance also requires more investigation. Further research, with larger, more representative and diverse samples of farmers and managers from sectors other than dairying focusing on Detail Conscious, Leadership and Relaxed measures is required to verify the very promising, and rather innovative, findings of the study presented here.

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Socioeconomic drivers of land mobility in Irish agriculture

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ABSTRACT

Land mobility is becoming an increasingly important issue for European agriculture given the so-called ''greying'' of the farming population. This is especially the case in Ireland where meeting current and future policy goals will pose challenges to current agricultural land use and land structures. One of the most important of these policy goals is Food Harvest 2020 (FH2020), which envisages an increase in dairy milk volume of 50% by the year 2020. In order to facilitate this expansion, changes in Irish agricultural land use and land structures may be required.

Increased land mobility may be required to reach the FH2020 target. Currently, Ireland has the lowest rate of agricultural land rental in Europe and less than 1% of farmland is transferred by sale or inheritance annually. Although efforts have been made by policy makers to improve rates of land mobility, little improvement has occurred.

Given the current land structures, our analysis concludes that dairy farmers will require more land than is currently available to meet FH2020 targets. This extra land may come from non-dairy farmers. Cattle farmers are seen as most likely to transfer to dairy farming in the future but structural and demographic issues may mean that a far smaller amount of switching between cattle and dairy systems will occur than is expected by policy makers. This may impinge upon future growth in the Irish agri-food industry. In order to achieve policy objectives, better incentives may have to be developed to encourage the mobility of land between farmers.

KEYWORDS: Ireland: land use; land tenure: dairy: socio-economic determinants

1. Introduction

The removal of the milk quota for EU farmers in 2015 represents both a period of change but also opportunity for European farmers. Unlimited milk production allows EU countries that possess a comparative advantage in terms of dairy production to fully capitalise on that advantage for the first time in over 30 years. One such country is Ireland, where a combination of a grass-based feeding system and large amounts of productive land should allow great scope for increased dairy production. Despite continued milk price volatility in recent years, net margins for Irish dairy farms continue to outperform all other domestic farm systems (Dillon *et al*., 2017a). Irish public policy targets such as Food Harvest 2020 (FH2020) and Food Wise 2025 envisage an increase in dairy milk volume of 50% by the year 2020, followed by continued industry growth in subsequent years (DAFF, 2010a). This is based on an expected increase in demand for dairy products as a result of global population growth and rising per capita disposable incomes (DAFF, 2010b). This increased global demand is expected to lead to higher, albeit more volatile, prices for dairy products.

However, doubts have already been expressed concerning the likelihood of achieving FH2020 targets through increased herd size or increased milk yield without changes in Irish farm structures (Läpple and Hennessy, 2012). Meeting these targets, as well as fulfilling climate change and environmental obligations, will pose challenges to current land use and land structures. Land use change may require adjustments in what we formally consider agricultural land use change. Change may mean moving from agriculture to forestry, but may also mean a change in the mix of agricultural activities on a farm, for example, from cattle to dairy. Structural land change may involve changes in farm size and farm fragmentation.

Growth in the dairy sector will require changes to land use and land structures, which may prove difficult given Ireland's low level of land sales (O'Neill and Hanrahan, 2012) and land leasing (Ciaian *et al*., 2010). While there has been some increase in the average farm size over time, the rate of change is quite slow. Much of this increase has been via non-contiguous parcels, with the average land parcel number per farm increasing over time (Kearney, 2010). Measures to increase land mobility i.e. the transfer of agricultural land whether permanently or temporarily, have been introduced including incentivised land leasing, the removal of barriers associated with farm partnerships and farm consolidation stamp relief (Land Mobility Service, 2014).

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Nevertheless the pace of land mobility has been relatively slow. Recent work by Bogue (2013) has highlighted relatively limited understanding of the existence of these policies, as well as the existence of mistrust on the part of farmers in relation to these schemes. It is likely also that the interaction with other schemes such as the Basic Payment System and the Disadvantaged Area Payment may affect behaviour via the capitalisation of subsidies into land values (Latruffe and Le Mouël, 2009) and into reluctance to lease long term (Patton *et al.*, 2008). Low land mobility can impact on land price volatility (Roche and McQuinn, 2001), which can further reduce incentives to trade land. Ireland also shares many of the same issues facing other EU countries in terms of land mobility: increased concentration of land ownership (van der Ploeg, 2015); the inability of young farmers to access land (Hennessy, 2014; Zondag *et al.*, 2015) and increased competition for land use (Rounsevell *et al.*, 2006).

One consequence of this lack of land mobility is that it makes it difficult for those wishing to enter farming to acquire land. This is especially the case for young, aspiring farmers who are unlikely to have the financial means to compete for land even if it does become available. Despite the fact that Irish farmers are becoming older on average (Hennessy *et al.*, 2013), a renewed interest in farming amongst young people in Ireland is being observed. Enrolments in agricultural colleges have doubled between 2007 and 2014, with nearly 1,500 applications for Green Cert courses (the benchmark agricultural qualification in Ireland) (Healy, 2014). This is estimated to be three times the normal level of applications (Teagasc, 2015). This suggests that there is demand to enter the farming profession in Ireland. However, the increasing age profile of farmers suggests these prospective farmers are unable to access land. The inability to access land is particularly problematic in terms of dairy expansion as Irish dairy farmers tend to be younger on average than farmers in other systems (Hennessey & Moran, 2015).

The objective of this paper will be to utilise the Teagasc National Farm Survey (NFS) to describe the current land use structure and barriers for land use change in Ireland. From the perspective of meeting FH2020 and future strategic targets, it will look at the potential capacity for land use change and identify potential socio-economic barriers to change and restructuring. This will inform our understanding of what changes may be required to facilitate land use change to meet the ambitions of Irish agriculture. As Ireland shares many of the same land mobility challenges as many countries across the developed world, this paper will also give an insight into the issue of agricultural land mobility in general.

In terms of the structure of the paper, firstly we will look at the history and theory of land mobility and transfer. We will then consider the current pattern of land holdings in Ireland in terms of land use and land tenure and how the situation has changed over time. Following this, we will examine how agricultural land rents and values have evolved over time. The next section of the paper will describe the socio-economic drivers of land access and how these relate to the potential future expansion in dairy farming. Finally, the paper will examine the implications for land mobility policy and future dairy expansion.

2. Theory and background

Land markets are driven by supply and demand. Many factors can shift the supply of and demand for agricultural land, such as competing uses for land, changes in agricultural productivity, speculative forces, the potential of land to hedge against inflation and land's amenity values (Ciaian *et al.*, 2010; Ciaian *et al.*, 2012a). Individuals also hold land for many reasons besides agricultural production, such as prestige, lifestyle value and family traditions. Land may also be used as a store of wealth in times of high inflation or economic uncertainty.

Generally speaking, farmland is acquired either through attaining ownership (by purchase or inheritance) or through rental. In Western Europe, historical factors largely determine whether the majority of farmed land is owned or rented (Ciaian *et al.*, 2012b) Historically, European countries were dominated by large landlord-small tenant relations with poor tenure security and few tenant rights. In the early 20th century, policy strategies to improve the situation of tenants were enacted. In broad terms, one of two types of policy strategy was implemented. The first strategy was to improve the rental conditions for tenants through regulation and was followed in countries such as Belgium, France and the Netherlands. This led to a situation where farmers in these countries no longer wanted to purchase land because their tenure security was very high, and they could use their capital for other investments. In these countries, the rental share is relatively high.

The second strategy was to help tenants become landowners. This was the dominant strategy in countries like Denmark, Italy and Ireland. There, the government set up state funds to purchase farms for poor tenants or to subsidise the latter's purchase of land (or both). In all of these countries, the share of land rental is relatively low. The most dramatic impact occurred in Ireland, where almost all agricultural land was rented at the beginning of the 20th century, having since declined to around 17% in 2010 (CSO, 2012).

Agricultural land rental in Ireland is dominated by the conacre system, which involves land being rented on an 11-month basis. This type of short-term rental of agricultural land is unusual in the European context[1], with short-term or annual rental contracts being usually associated with developing countries (Deininger, 2009). The dominance of the conacre system goes back to the Land Commission, which was set up by the Land Act of 1881 to adjudicate on the fairness of rents and continued as a tool for implementing land policy following the setup of the Irish Free State in 1922. The leasing of land (excluding 11-month or conacre lettings) was subject to the express permission of the Land Commission, with land under longer leases being open to possible seizure by the Commission. Seized lands would be redistributed to local small farmers or migrants from 'congested' western counties. Landholders were reluctant to seek permission to let their land under leases longer than 11 months for fear of having such land taken over by the Land Commission (Conway, 1986). Long-term leases, common in

[1] Although there is a great deal of heterogeneity in the length of rental contracts across Europe, agreements generally last for multiple years with many countries regulating minimum contract length e.g. 9 years in France/Belgium, 5 years in Spain. See Ciaian et al. (2010) for further discussion.

European agriculture, have therefore remained relatively rare in Ireland (Ciaian *et al*., 2010).

In Ireland, only a limited amount of agricultural land comes on the market each year, typically arising from the retirement or death of the owner. As a result, only a tiny proportion of total agricultural land is sold in any given year. Bogue (2013) points to an aversion amongst Irish farmers to selling their farms (only 28% of farmers would consider doing so), as well as a strong desire to see their farm remain within their family (66% of farmers).

Agricultural land availability in Ireland is seen as increasingly important in the light of policy developments such as FH2020 and the removal of the milk quota system in 2015 (Dillon *et al*, 2008; Läpple & Hennessy, 2012). FH2020 seeks to increase the volume of milk output by 50% by the year 2020, with further expansion likely to be targeted beyond that time. Since Irish dairy farmers use a predominantly grass-based production system, this expansion will require a substantial amount of extra land on which dairy cows can graze. Gaining access to this extra land will be important in terms of meeting FH2020 targets as well as sustainable dairy expansion beyond 2020.

Soil and land quality is an important issue in this context. Productive soils are vital for successful dairy farms due to the high grass growth rates needed for intensive grazing systems (Lalor *et al*., 2013). In order for dairy output to increase by targeted levels, productive land will have to become available for use by expanding dairy farmers and new entrants to the sector. A related topic is the productivity of dairy farming compared with other farming systems. It has been shown that dairy farming in Ireland is consistently more profitable than other farming systems such as cattle rearing, tillage and sheep farming (Hennessey *et al*., 2013). A movement of land that is currently being used for other types of farming to dairy farming could see a huge productivity gain for Irish agriculture.

3. Methodology and data

This paper utilises data from the National Farm Survey (NFS) which is a national farm survey of approximately 1,000 farms conducted every year by Teagasc. The survey data is weighted so as to be nationally representative of Irish dairy, cattle, sheep and tillage farms. In 2011[2], the survey reported results from 1,077 different farms, of which 1,073 were divided into one of six farming systems: dairy; dairy other[3]; cattle; cattle other[4]; sheep and tillage (see Table 1). The NFS also provides data on soil quality with soil being rated on a scale from one to six (one being the highest quality soil, six being the lowest). Soils rated one or two are good quality, those rated three or four are medium quality while soils rated five or six are poor quality[5].

Cattle farming is currently the dominant form of agriculture in Ireland across all soil types, accounting for 57% of land on NFS farms. Dairy farming accounts for

Table 1: Farms by system in the National Farm Survey, 2011

Farm System	Number of Farms	Share
Dairy	272	25.3%
Dairy Other	90	8.4%
Cattle	202	18.76%
Cattle Other	274	25.44%
Sheep	132	12.3%
Tillage	103	9.6%
Total	1073	99.6%

14.9% of agricultural land, with sheep farming taking place on 12.3% of land. Tillage farming takes up 8.6% of agricultural area. Figure 1 shows how agricultural land is used on different types of soil. Land with good quality soil makes up the majority of Irish farmland, accounting for 55% of agricultural land. Cattle farming uses the most good quality soil (54.5%), followed by dairy farming (17.1%) and tillage (14.8%). Cattle farming also dominates the use of medium quality soil (64.1%), with dairy farming taking up 14.6% and sheep farming 10.8%. Poor quality soil comprises 11.4% of agricultural land with cattle (46.8%) and sheep (32.4%) farming taking up the vast majority of this type of land.

Although cattle farming uses the majority of agricultural land, Table 2 shows that cattle farms are not the largest on average. The NFS breaks down farms into one of six systems: dairy; dairy other; cattle; cattle other; sheep and tillage. Tillage farms are the largest on average, at just over 64 hectares per farm, followed by dairy farms at 54.8 hectares and dairy other farms at 48.9 hectares. Sheep farms are 40.8 hectares on average, with cattle other farms measuring 33.8 hectares and cattle farms being the smallest at 31 hectares per farm. In terms of soil quality, dairy and cattle farms tend to get smaller, on average, as soil quality worsens. The average size of sheep and tillage farms tends to increase as soil quality deteriorates.

Average farm sizes are now at their highest level in recent history. In 1996, the average farm size, according to NFS data, was 32.2 hectares. By 2011, this had risen to 40.3 hectares with increases in farm size evident across all systems. This farm size increase has resulted from a movement of land from small (under 25 hectares) to medium (50–75 hectares) and large farms (over 75 hectares). Land rental share has increased from 12.7% to 17.6% from 1996 to 2011 but the share of land rented out has dropped from 2.6% to 1.8% in that time. This suggests that active farmers are not the source of rented land.

4. Results I. Patterns of land access and transfers

The increase in farm size has been enabled by an increase in renting by farmers. The average amount of land rented per farm has been increasing steadily over the last number of years, reaching 16.3 hectares per farm in 2011. Farms with good soil have the highest amount of rented land per farm at an average of 19.8 hectares per farm. Farms with poor soil rent 16.4 hectares on average, while those on medium soil rent an average of 12 hectares of land (see Table 3).

Table 3 also shows the disparity between the amount of land rented in and rented out by farmers. It demonstrates

[2] Although this paper uses data from 2011 and before, more recent data shows similar results to those mentioned here (see Dillon et al., 2017b).
[3] Mainly dairy farming with beef cattle/tillage also on farm
[4] Mainly cattle fattening/finishing. The 'cattle' system refers to cattle rearing, usually up to one year of age.
[5] Soil quality is based on the use range of the land with the highest rated soil having the widest use and lowest rated soil the narrowest. Soil quality is measured in person by the survey recorder.

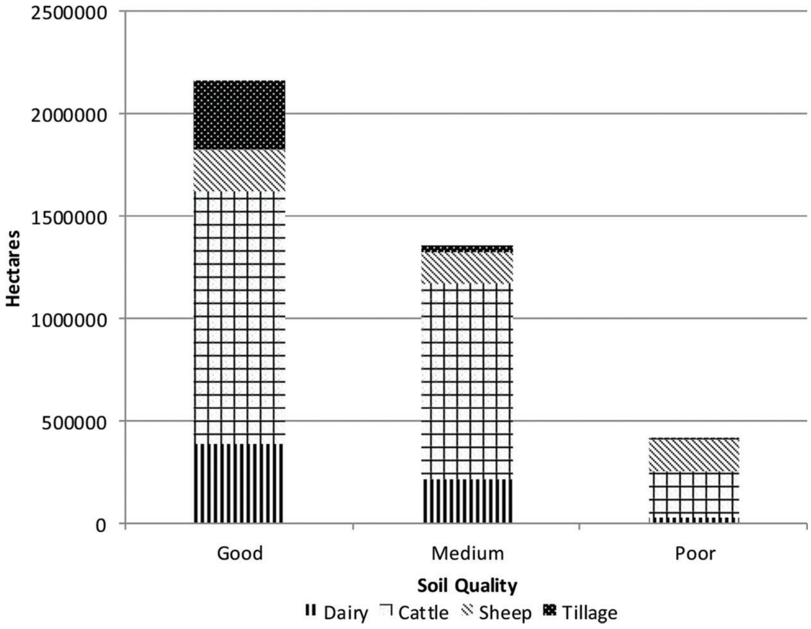

Figure 1: Land use on Irish farms by soil type (in hectares), 2011

Table 2: Average farm size by farm system and soil type (in hectares), 2011

Farm System	Dairy	Dairy Other	Cattle	Cattle Other	Sheep	Tillage	Total
Soil							
Good	55.4	59.9	32.4	35.9	38.0	64.3	44.0
Medium	54.1	42.2	28.9	31.3	37.9	68.6	35.6
Poor	52.8	31.4	35.3	33.7	47.6	0.0	40.4
Total	54.8	48.9	31.0	33.8	40.8	64.8	40.3

Table 3: Owned/rented share of agricultural land, 2011

	Land Owned	Land Rented In	Land Rented Out	Land Owned (per farm) (Ha)	Land Rented (per farm) (Ha)
Soil					
Good	82.5%	20.0%	2.5%	37.7	19.8
Medium	85.5%	15.4%	0.8%	31.9	12.0
Poor	87.6%	13.6%	1.2%	37.1	16.4
Total	84.1%	17.6%	1.8%	35.3	16.3

that the vast majority of land rented in by farmers is not rented from other active farmers. This land may be rented out by landowners, usually the non-farming offspring of farmers who inherit land upon their parent's death, who are not interested in farming the land themselves but wish to retain ownership of the land. The improved economic conditions in Ireland in the late 1990's and 2000's may have facilitated this as the offspring of farmers found non-agricultural employment rather than take over the family farm (Meredith & Gilmartin, 2014).

Average rent per hectare (in nominal terms) has stayed relatively stable over the last number of years (see Table 4). The average rent paid in 1996 was €230.24[6] per hectare while by 2011 this had only risen to €241.10 per hectare in nominal terms. On land with good soil, nominal average rent per hectare decreased steadily from 1996 to 2005, falling from €280.82/ha to €253.96/ha. However, nominal rents then started to rise again and stood at €279.15/ha in 2012. Nominal rents on land with medium quality soil stayed constant at just over €200/ha over the time period between 1996 and 2011. Nominal rents on land with poor quality soil rose steadily from 1997 onwards,

Table 4: Average rent per hectare by soil type (in €/ha), 1996 & 2011

Year	1996	2011
Soil		
Good	€280.82	€279.15
Medium	€203.52	€213.91
Poor	€136.96	€154.62
Total	€230.24	€241.10

[6] At the time of writing (December 2016), €1 was approximately equivalent to $1.05 and £0.84.

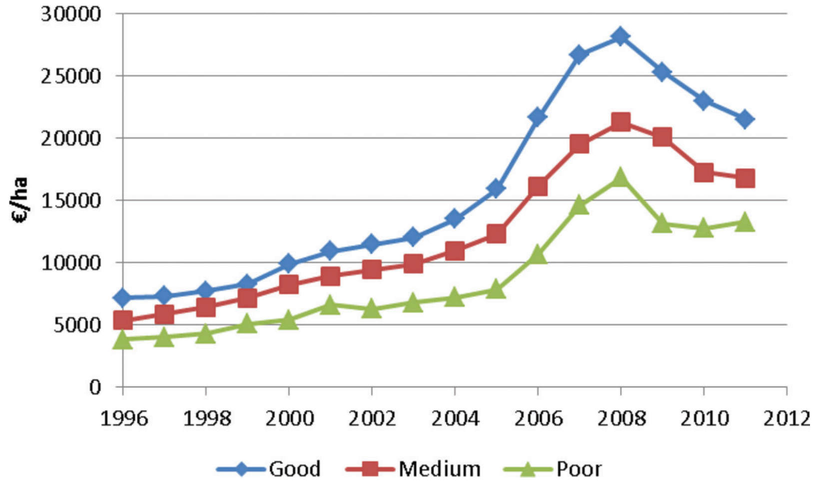

Figure 2: Average self-reported agricultural land values by soil type (in €/ha), 1995–2012

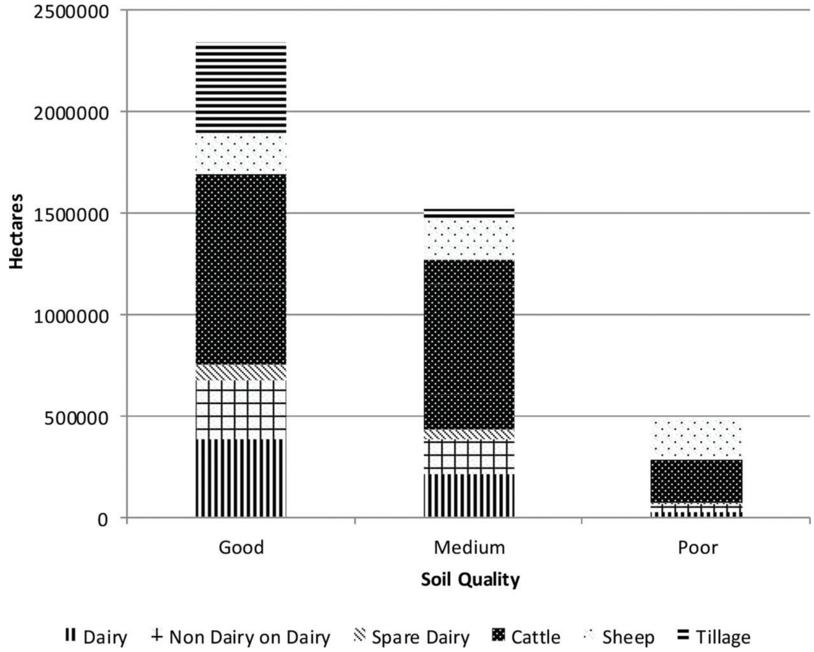

Figure 3: Land use on Irish farms by soil type (in hectares), 2011

peaking at €179.52 in 2007 but have since slipped to €154.62/ha in 2011.

The amount of agricultural land sold in Ireland each year is very small, accounting for less than 1% of Irish farmland (Busteed, 2014). Supply of land for sale is inhibited by the traditional model of agricultural land mobility where land is inherited rather than sold. Agricultural land values are shown in Figure 2. These values are based on NFS data which are self-reported estimates of the value of farmland in the dataset. Values rose through the 1990's and most of the 2000's as Ireland experienced rapid economic growth and the development of a property bubble. As demand for residential and commercial land increased, agricultural land values also spiked as purchasers hoped to have the land rezoned for alternative uses. The disconnect between stable land rental prices and increasing agricultural land values shows that the increase in land values was not due to agricultural factors. As Figure 2 shows, values peaked in 2008 and fell rapidly afterwards as the property bubble collapsed and recession took hold.

5. Results II: Socio-economic drivers of land access

Dairy farming represents the second biggest share of agricultural land in Ireland but it remains far behind that of cattle farming. However, since public policy targets such as FH2020 envisage an expansion of dairy production, it may be necessary to increase the amount of land dairy farmers can access. Figure 3 shows that there is already a pre-existing share of land on dairy farms that is either spare dairy platform[7] or is being used for non-dairy purposes. Land used for non-dairy purposes is overwhelmingly used for cattle farming, with a small amount of sheep farming or tillage crops. These are likely to be farmers who are constrained by quota in the amount of milk they can produce so use some of their land for other types of production. The land on dairy

[7] Spare dairy platform refers to land on dairy farms that is within walking distance of the milking parlour and is not currently being used by the dairy herd for any other farming purpose.

Table 5: Description of yield scenarios

Yield	Description
No Increase	Yield per cow stays constant at 2010 levels (5,000l/cow)
50% Long-Term Rate	Yield per cow increases at 50% of long-term rate (0.65%)
Long-Term Rate	Yield per cow increases at long-term rate (1.3%)
150% Long-Term Rate	Yield per cow increases at 150% of long-term rate (1.95%)

Table 6: Milk production required to reach Food Harvest 2020 target (000,000's litres)

	Stocking Rate			
Yield Increase	1.8 LU/ha	2 LU/ha	2.5 LU/ha	3 LU/ha
No Increase	5007.8	5564.3	6955.3	8346.4
50% Long-Term Rate	5343	5936.7	7420.9	8905.1
Long-Term Rate	5698.3	6331.4	7914.3	9497.2
150% Long-Term Rate	6074.6	6749.6	8437.1	10124.5

Table 7: Distance from Food Harvest 2020 target

	Stocking Rate			
Yield Increase	1.8 LU/ha	2 LU/ha	2.5 LU/ha	3 LU/ha
No Increase	-32%	-25%	-6%	+13%
50% Long-Term Rate	-28%	-20%	0%	+20%
Long-Term Rate	-23%	-14%	+7%	+28%
150% Long-Term Rate	-18%	-9%	+14%	+37%

farms currently being used for non-dairy purposes corresponds to 44.4% of land on dairy farms (11.9% of all agricultural land), while spare dairy platform corresponds to 11% of land on dairy farms (2.9% of all land). Therefore, there is quite significant land within dairy farms currently being used for other purposes, which will be the easiest on which to expand.

Milk expansion scenarios

The policy aim accompanying dairy expansion is the achievement of a 50% milk production increase by 2020. Table 5 presents a number of potential scenarios of how milk production can be increased given the current land use and milk yield structure. This gives an insight into how much land will be required to reach the target of increasing milk production by 50%. Given that the baseline milk production on which the target is based is an average of production from 2008 to 2010, a 50% increase amounts to a milk production target of 7.4 billion litres by 2020. This target can be met in four ways: increasing yield; increasing stocking rate; increasing available land area or a combination of the three. Table 6 shows to what extent the FH2020 target is achievable with only yield and/or stocking rate increasing and no extra land becoming available.

Four yield and stocking rate levels are modelled. The yield scenarios are based on the long-term trend of milk yields since the introduction of quota in 1984 (see Table 5). From 1984 to 2010, there has been an average yearly increase of 1.3% in milk yields per cow based on CSO data. The first yield scenario has yield per cow remaining constant at 2010 levels of 5,000 litres per cow. The second scenario has yield per cow increasing yearly at half the long-term rate (0.65%) up to 2020. The third scenario has yield continuing to increase yearly at the long-term rate (1.3%) while the fourth scenario has yield increasing yearly at 50% above the long-term rate (1.95%) up to 2020. The four stocking rates that are modelled are 1.8 livestock units (LU) per hectare (the average stocking rate of dairy farms in 2010), 2 LU/ha, 2.5 LU/ha and 3 LU/ha.

The results show that without a large increase in stocking rate, extra land will be required to meet the FH2020 milk production target (see Tables 6 & 7). At both the current stocking rate of 1.8 LU/ha and the increased rate of 2 LU/ha, none of the modelled yield rates produces enough milk to reach the target of 7.4 billion litres. When the stocking rate is raised to 2.5 LU/ha, yield growth is still required although growth at 50% of the long-term rate is sufficient to reach the target. When the stocking rate is set at 3 LU/ha, the FH2020 target is achieved, even without any increase in yield over 2010 levels.

In reality, reaching the FH2020 target only through increased yield and/or stocking rate is unrealistic. Although Irish dairy farmers are constantly improving efficiency in terms of increased grazing through grassland management, increased stocking rates usually have the effect of slowing per cow yield growth or even causing yields per cow to fall (Baudracco *et al.*, 2010; MacDonald *et al.*, 2008). Additionally, increased stocking rates may conflict with the European Union Nitrates Directive. The Nitrates Directive aims to address water pollution by nitrates from agriculture by capping the amount of livestock manure that can be applied to land at 170 kg of nitrogen per hectare. This has the effect of limiting the stocking rate a farmer can maintain on their farm. Currently, Ireland has a derogation that allows a 250 kg nitrogen limit but this derogation runs out in 2021. There are no guarantees that such derogations will be available again after 2021, which poses a risk to expanding dairy farmers who aim to maintain high stocking rates going forward. Given these difficulties around yield and stocking rates, it seems likely that extra land will be required to reach FH2020 target.

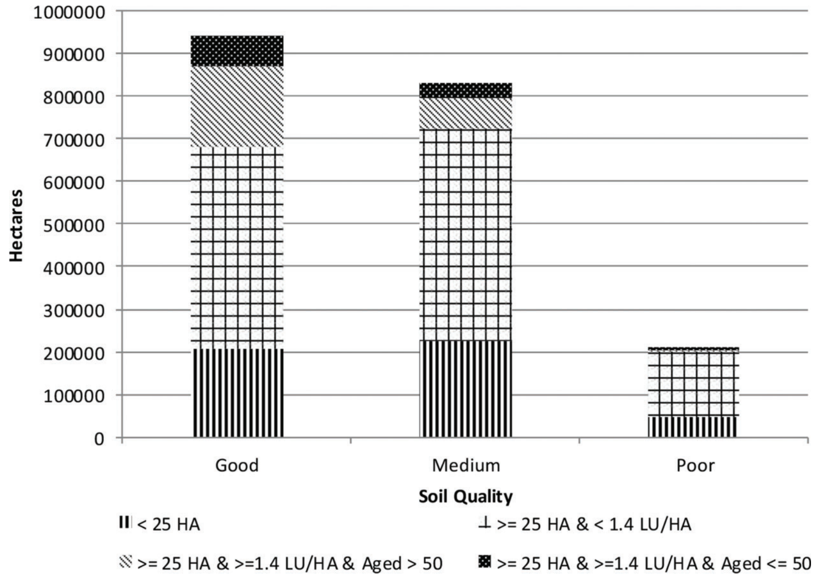

Figure 4: Land structure of cattle farms (in hectares), 2011

Socio-economic scenarios by land use type

Accessing extra land for dairy farming would require structural change in Irish agriculture. This could occur through existing dairy farmers acquiring land via land markets, collaborative farming arrangements or through current land owners becoming new entrant dairy farmers. Given, the static nature of the Irish land market, as well as the low uptake of collaborative farming arrangements in Ireland, current land owners becoming new entrant dairy farmers seems the most likely future scenario. Looking at current land use, 19.4% all agricultural land with good quality soil is used for tillage farming. While these farms have sufficient quality land and are generally large in size, they are unlikely to have facilities or experience for handling dairy animals. They would thus require quite significant investment and re-skilling and/or change of management to move into dairy farming. Additionally, conversion of tillage land to dairy may reduce Ireland's level of self-sufficiency in relation to cereal crops, as well as having environmental implications in terms of birds and wildlife (DAFM, 2014). In terms of land with good and medium soils, 11% of this land is used by sheep enterprises, which again are likely to face issues in terms of investment and specific dairy management skills.

Of the alternative farming systems, cattle managing systems are the most complementary for moving into dairy. Nearly half of the land on farms with good or medium soils is used for cattle farming. However, several issues may inhibit the movement of cattle farmers into the dairy sector (see Figure 4). Firstly, 24% of cattle farms with sufficient soil quality are less than 25 hectares and would thus require consolidation before moving into dairy. This consolidation is required as dairy transition would not be economically viable on such a small grazing land base. Secondly, of the farms larger than 25 hectares, 55% have stocking rates of less than 1.4 LU/ha. The stocking rate is low largely due to either age (31% aged 65+) or due to other work commitments (33% with an off-farm job). These farmers are unlikely to want to move into a more intense system such as dairy. Those most likely therefore to consider moving into dairy are those with stocking rates of 1.4 LU/ha or higher and a farm of at least 25 hectares, which amount to 21% of cattle farmland in the good/medium soil range and to 10% of all farmland with these soils. Of the farmers with the necessary land and stocking rate, 25% have off-farm employment. Age is also likely to be an issue with 19% over 65 in 2011, and only 29% 50 years of age or younger. When all these factors are taken into account, just over 100,000 hectares of cattle land are likely to become available for dairy purposes, corresponding to 2.5% of total agricultural land. Roughly speaking, if stocking rates remained unchanged and milk yields continued to grow at the long-term rate of 1.3%, around 166,000 extra hectares of land would be required to meet the FH2020 target.

6. Conclusions and policy recommendations

The agricultural land market in Ireland is characterised by stasis. Cattle farming is the dominant use of farmland, with over half of the total agricultural land in the country being devoted to it. The share of farmland that is rented in rather than owned has increased to over 17% of all agricultural land but this figure still rests well below the European average of approximately 55% (European Commission, 2018). This increase in land rented in by farmers is not matched by the amount of land farmers are renting out (1.8% of total UAA), suggesting that farmers are renting land from non-farmers rather than from other farmers. Nominal rent prices have remained stable over time, regardless of the quality of the land. Agricultural land values underwent a boom in concert with residential and commercial property prices from the late 1990's until the economic crash of 2008 caused prices to fall precipitously. A very small amount of farmland is bought and sold each year, a pattern that predates the rise in agricultural land values during the economic boom (Kelly, 1983; Roche & McQuinn, 2001). Much of the land sold is of a very small size (less than one hectare), with these plots of land likely used to build one-off houses.

In terms of dairy expansion, there is a not insignificant amount of land that dairy farmers can immediately expand onto following the removal of quota restrictions. This land consists of land on dairy farms currently used for non-dairy farming purposes. Given the increased stocking rates and/or increased milk yield that would be necessary to reach FH2020 targets, it is almost certain that additional land will be required in the future by dairy farmers. This corresponds with the findings of Läpple and Hennessy (2012) who found that achieving the FH2020 target of a 50% increase in milk output on current dairy farms' land base is unlikely. Cattle farmers are likely to be in the best position in terms of skills and land quality to transfer to dairy farming but multiple hurdles may prevent this from happening. Small farm size, low stocking rates and age-related concerns mean that in actuality, only a small number of cattle farmers may be likely to switch to dairy farming. The farmland accounted for by these farmers corresponds to 2.5% of total agricultural land.

The environmental effect of increasing dairy production must also be considered. Ireland has international obligations in terms of greenhouse gas (GHG) emissions reduction and water quality maintenance through the Nitrates Directive. Dillon *et al.* (2016) report that although the economically top-performing dairy farms emit less GHG emissions than their less intensive counterparts, the same top performing farms have a higher nitrogen surplus per hectare on average. Given that the most economically productive farmers are also the most intensive and therefore the most likely to expand following quota removal, achieving environmentally sustainable dairy production may prove difficult. Changing land use from other forms of farming to dairy may also have other environmental implications including increasing overall GHG emissions from agriculture (Donnelan *et al.*, 2014), increasing the risk of flood generation at the local scale (Williams *et al.*, 2012), and reducing farmland biodiversity (Sheridan *et al.*, 2011).

While immediate and significant dairy expansion following quota removal seems feasible given current land structures, medium and long-term growth in milk production will require more land to become available than currently seems likely. In order to achieve policy targets, increased land mobility will have to be facilitated. The low levels of renting and thin transaction market show a bias amongst Irish farmers toward owning the land that they farm. This is despite increased government interest in the area and a land market found to be the least regulated in the EU (Swinnen *et al.*, 2014). However, relatively little is known about the attitudes of Irish farmers to land mobility. It must also be noted that policies leading to effective changes in tenure systems are very politically sensitive and difficult to achieve (Swinnen *et al.*, 2016). More work is required to determine why Irish farmers are more averse to entering the land market than their European counterparts and to identify new policy options that can make land mobility more attractive to farmers.

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