

**EXPLORING THE ROLE OF AGRICULTURAL
INNOVATIONS IN THE SCOTTISH BEEF SECTOR:
PATHWAYS TOWARDS MORE SUSTAINABLE
PRODUCTION**

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Abstract

It is widely recognised that innovation is essential for the development of the agricultural sector. To address this challenge, this thesis has focused on how sustainable agricultural innovation may be delivered at farm-level in Scottish beef production systems. Fostering innovation requires an improved understanding of farmers' innovative behaviour. Accordingly, farmers' intentions towards farming in Scotland and their reliability were assessed. A segmentation behavioural model was developed and three classes of farmers were identified (n=213): Profit-seekers (42.1%), Satisfiers (35.7%) and Expansionists (22.1%). This model was subsequently linked to a farm-level economic model to estimate the effects of a set of innovations across the distribution of beef farms, under two alternative agricultural support policy scenarios.

The findings suggest that Profit-seekers with more labour, livestock and land in crops and grass; heavier dependence on subsidies and levels of borrowing; and performing better as measured by Net Farm Income and Management and Investment Income are more likely to adopt innovations. Results of the reliability analysis of farmers' intentions showed that 58.4% of farmers overestimated their future production plans and economic factors have the strongest influence on these farmers' behaviour. Furthermore, the outcomes of the modelling exercise indicate that all innovations considered could provide some benefit, especially when used in combination (£5.1k-£22.1k). The farm-level analysis showed the potential benefits of innovation; however, when direct support was removed the heavy reliance of farms on subsidies was revealed, with 54.8% of farms becoming loss making under the baseline scenario. While this study has made best use of Farm Business Survey data, it has only captured part of the overall farm innovation activity. The collection of complementary data on the actual level of innovations adopted in Scottish beef systems would enable a better assessment of the degree of farm 'innovativeness', an interesting area for future research.

List of Acronyms and Abbreviations

ADAS	Agricultural Development and Advisory Service
AECS	Agri-Environment Climate Scheme
AFBI	Agri-food and Biosciences Institute
AHDB	Agriculture and Horticulture Development Board
AHP	Animal Health Planning
AIC	Akaike Information Criterion
ANOVA	Analysis of Variance
AUA	area used for agriculture
BIC	Bayesian Information Criterion
BPS	Basic Payment Scheme
BSE	Bovine Spongiform Encephalopathy
BVD	Bovine Viral Diarrhoea
CAP	Common Agricultural Policy
CT	Combined Technologies
DA	Disadvantaged Area
DEFRA	Department of the Environment Food Rural Affairs (UK)
DM	Dry Matter
DMI	Dry Matter Intake
EBV	Estimated Breeding Value
EC	European Community
EID	Electronic Identification
EM	Expectation-Maximum
EU	European Union
FADN	Farm Accountancy Data Network
FAPRI	Food and Agriculture Policy Research Institute of Missouri
FBI	Farm Business Income
FBS	Farm Business Survey
FGS	Forestry Grant Scheme
FTA	Free Trade Agreement
GAMS	Generic Algebraic Modeling System
GHG	Greenhouse Gas
GI	Genetic Improvement
INRA	Institut National de la Recherche Agronomique
LCA	Latent Class Analysis
LFA	Less Favoured Area
LFASS	Less Favoured Area Support Scheme
LP	Linear Programing
LU	Livestock Units
MII	Management and Investment Income
NFI	Net Farm Income
OECD	Organisation for Economic Co-operation and Development
P	Probability
PMP	Positive Mathematical Programing
QMS	Quality Meat Scotland
R&D	Research and Development
RDP	Rural Development Programmes
RRR	Relative Risk Ratios
SACC	Scottish Agricultural College Consulting

SAHPS	Sheep and Suckler Cow Animal Health Planning System
SBCS	Scottish Beef Calf Scheme
SBES	Scottish Beef Efficiency Scheme
SD	Standard Deviation
SDA	Severely Disadvantaged Area
SFP	Single Farm Payment
SLR	Standard Labour Requirement
SRUC	Scotland's Rural College
SSBSS	Scottish Suckler Beef Support Scheme
SUSSS	Scottish Upland Sheep Support Scheme
TFP	Total Factor Productivity
UTL	Unilateral Trade Liberalisation
UK	United Kingdom
WTO	World Trade Organisation

1. Chapter 1: General Introduction

1.1. Context of the thesis

Livestock production is an important element of Scottish agriculture, reflecting the wide range of grazing resources. In particular, beef production is a significant agricultural sector in Scotland. With a direct output of around £830.6 million in 2018, beef production accounted for 26.1% of Scottish agricultural output and by this measure is the largest single sector of Scottish agriculture (Quality Meat Scotland [QMS], 2019; Scottish Government, 2019a). Around 12,000 agricultural holdings make some income from a beef enterprise (Scottish Government, 2017a, 2018a). Even though a marginal decline in total beef production was verified in 2018¹, beef production has remained fairly constant over the past ten years (Scottish Government, 2018a, 2019b). Comparatively speaking, the beef sector continues to have a greater significance to the Scottish agriculture than it has either in the whole UK (15.2%) or, on average, in the EU (7.8%), as a contributor to agricultural output. Furthermore, the sector is also an important contributor to the country's rural economy, providing jobs in farming, processing sectors and agricultural supply, especially, rural jobs in areas with low population density and fewer employment opportunities (Moxey and Thomson, 2018).

Despite its importance, over the past few decades, the Scottish livestock sector has been facing some crucial challenges. For instance, the number of all cattle in Scotland has been in constant decline since the 1970s, falling from 2.7 million in 1974 to about 1.8 million in 2016, and is currently at, or near to, its lowest levels since EU accession in 1973 (QMS, 2016; Ge et al., 2018). Such declines in livestock numbers over the past decade are not only a response to market pressures, but also the result of the Common Agricultural Policy (CAP) reform implemented in 2005 that saw the shift from coupled 'headage' payments to decoupled support payments and its continued adjustments. In spite of producing a premium product, Scottish cattle farms have been struggling to break-even. A number of factors contribute to this: a fall in total factor productivity (Barnes, Bevan and Revoredo-Giha, 2011a); increased competition in export markets (Leat and Revoredo-Giha, 2017; QMS, 2017, 2018a); and the need to tackle consumer

¹ Total beef production fell marginally in 2018 to 167,000 tonnes, in contrast with 174,000 tonnes and 167,250 tonnes in 2016 and 2017, respectively (Scottish Government, 2018a; 2019a).

concerns over health and safety, animal welfare and environmental sustainability (Simm, 2009; Wall, 2011), all of which play a major role in enterprise profitability.

More recently, the prevailing uncertainty about the impact of 'Brexit' has dominated discussions. It is very clear that, whatever the UK's future trading arrangements are, they are very likely to deeply influence not only future agricultural and rural policy in Scotland, but also the supply and movement of labour requirements for both the agricultural industry and food processing sectors (Swales et al., 2017). Changes in agricultural policy and market prices are estimated to have a major impact on the structure and resilience of the Scottish agricultural sector 'post-Brexit', especially the beef and sheep sectors. Given the magnitude of estimated income reductions, particularly from the removal of support payments, a significant pressure for structural change is expected, meaning that any adjustment period would give farmers time to plan strategies for future changes to their farm systems. Farm profits, stocking densities, herd sizes, as well as animal health and welfare are projected to be affected by these potential changes. Hubbard et al. (2019) report on the potential effects of UK agricultural and trade policy scenarios following 'Brexit', and estimate that the immediate effects of removing direct payments on farm profit are such that farm businesses are predicted to respond by trying to improve on-farm efficiency and/or search for other sources of income, which in some cases means leaving farming. Farm profitability is therefore a major concern. While future agreements are expected to reshape the environment for Scottish beef farmers, they may also act as a stimulus for evolving farm management practices and structure. This uncertainty surrounding 'post-Brexit' agriculture requires a detailed assessment of the impacts of potential alternative policy arrangements.

Historically, gains in productivity and profitability due to e.g. farm efficiency improvements and diversification have, in some cases, offset the effects of changing both trade relations and farm support payments on farm incomes, by providing an alternative income stream to the farm business (Ash et al., 2015; Department for Environment, Food and Affairs [Defra], 2018a). This raises the question of whether innovative improvements can remain an important pathway for increasing farm profitability sufficient to guarantee that the Scottish beef industry stays economically viable over the longer term. In this light, the challenges outlined earlier can be met, in

part, through the adoption of agricultural innovations that are able to improve productivity, sustainability and resilience at the farm level. Agricultural innovation is often considered an essential aspect in the transition towards more sustainable and resilient farm systems, highlighting both the capacity to adapt to changing circumstances and cope with unexpected events, and by doing so, generate a range of new potential opportunities for the farm (Carpenter et al., 2001; Holling, 2001).

At the same time, European Rural development policy and national policy have been progressing to foster not only the competitiveness and sustainability of farm systems, but also knowledge transfer and innovation. Research has been focusing on identifying practices to improve Scottish beef farms' sustainability, for instance, by investigating the impact of farm management activities in specific agronomic conditions (Borthwick et al., 2014; Boden et al., 2015, 2017). From a policy perspective, there is an increasing demand for farm-level analysis of the management decisions, technologies and practices, and associated financial performance, which can take account of the distribution of performance across the range of heterogeneous beef farms (O'Donoghue et al., 2016). Such analysis can contribute to meeting the ambitious sectoral growth targets of Scottish Government.

The aim of this thesis is to develop an integrated approach capable of such assessment and to demonstrate its use in policy assessment scenarios relevant to beef production in Scotland. To achieve this objective, first, a segmentation model is developed based on farmers' intentions (as assessed by farmers' objectives and attitudes) towards both economic and environmental aspects of farming in Scotland, which is then connected to the Farm Business Survey (FBS) returns for Scotland. To promote adoption and use of new technologies, there is a need to identify the drivers of farmers' decision-making. The identification of such drivers requires a full understanding of the potential targets for technology. Thus, the focus was set on recognising and explaining the variation in farm and farm business performance in respect to Scottish beef farmers' intentions and actual behaviours. This segmentation model is subsequently linked to a farm-level economic model to describe the impacts of technological innovations on the Scottish beef sector, under two alternative agricultural policy scenarios ('with' and 'without direct support'), due to the possibility of change in support payments in the UK following 'Brexit'. This integrated approach provides an important tool to evaluate the

range of technological innovations applied at farm-level and associated performance across the distribution of heterogeneous Scottish beef farms. This tool can help both individual farmers and policy makers in planning farm and sector strategies in the face of alternative agricultural support policy options. To date, there is little evidence about the direct impact of innovation on the economic vulnerability and resilience of individual farms, in particular beef farms, with most existing studies focusing on the macro-level (e.g. Alston, 2010; Kimura and Le Thi, 2013). The assessment of the financial impacts of such innovation and policy scenarios at the individual farm-level is therefore necessary from a future policy planning perspective, in order to make informed decisions and design efficient policies.

1.2. Objectives and structure of the thesis

The objectives of this thesis are as follows.

1. Explore whether Scottish beef farmers can be classified into specific behavioural segments and identify the underlying drivers that shape these segments.
2. Analyse the relationship between farmers' segmentation classes and a range of farm characteristics, including physical, financial and managerial characteristics.
3. Compare farmers' intentions to actual production decisions and identify factors explaining a potential intention–realisation gap at the individual farm-level.
4. Investigate farm economic performance under alternative innovation and agricultural policy support scenarios (with and without direct payments retained as currently under the CAP).
5. Provide recommendations and information to enhance innovation policy design and delivery across Scottish beef production systems, given the uncertainties in relation to future support payments of the agricultural sector.

To support the integrated approach taken, several theoretical frameworks have been used in each analytic chapter (chapters 3 - 5). The rationale for three different studies reflects the complexity of the innovation adoption process. Data on the full distribution of FBS farms producing beef cattle has been used in the applied analysis, even if the beef enterprise is not the sole enterprise, hence 'beef farms' and 'beef and sheep farms'

are used as synonyms throughout this thesis. Unlike previous farm systems models applied to Scottish agriculture that modelled ‘representative’ farms, this thesis uses data from actual individual farms, taking account of the variability that exists between different farms and respective farm types. By including farm variability, results are representative of the national population of beef farms and extrapolations can be made on the distribution of performance, reflecting farm specific conditions. Furthermore, results are scalable to the national level thus enabling an integrated assessment of the impacts of innovation scenarios and potential policy shocks (e.g. policy reforms) on farm economic vulnerability across the national beef sector.

The remainder of this chapter presents the primary data source used in this thesis, the Scottish FBS. Chapter 1 also briefly describes both the structure of the Scottish beef sector and the evolving policy context to inform the development of a conceptual framework addressing the research objectives previously identified. The conceptual framework is designed to support an integrated analysis of the Scottish beef sector, focusing on the impacts of implementing different technological innovations and/or agricultural support policy measures on economic farm-level outcomes and animal dynamics.

1.3. Data – Scottish Farm Business Survey (FBS)

Data used in this thesis are drawn from the Scottish FBS relating to the farming years of 2012/13 and 2015/16 (chapters 3 – 5). The FBS is the most comprehensive survey of farm businesses performed across the UK annually. It started in the 1930s and forms part of the Farm Accountancy Data Network (FADN), which evaluates farm incomes on a consistent basis across the EU².

The main objective of FBS data is to inform policy decisions and to help monitor and assess current policies, in particular their effect on different agricultural sectors. The data is also used to model the effect of potential future policy options. The use of FBS data in policy issues relates not only to the specificity of the information collected, but

² The FADN is the only source of microeconomic data that is harmonised across all European Commission (EC) countries and is used for the formulation and evaluation of agricultural policy, being also employed to monitor the farm income levels in each Member State as established by the Council Regulation (EC) No. 1217/2009 and subsequent amendments (EC, 2013a).

also to the lack of other sources (Scottish Government, 2014a). In addition, the FBS delivers information on average levels of income and costs incurred by farmers, which are used to measure the viability of farm businesses. FBS data can also be used for benchmarking business performance across the UK and, in particular Scotland, and for academic research (Scottish Government, 2018b). The full dataset is made available for several research projects, including this thesis, in an anonymous form and under strict confidentiality conditions, as data collected through the FBS can be highly sensitive.

The FBS is an annual survey of around 500 farms performed by SAC Consulting³ (SACC) on behalf of the Scottish Government. The number of agricultural holdings surveyed in the FBS in 2017/18 was 492, which accounts for approximately five per cent of the total agricultural holdings in Scotland (Scottish Government, 2019c). Weightings are applied to the data to account for potentially unrepresentative nature of the sample. In 2017/2018, a new calibration weighting method was suggested, making the weighted averages more representative of the population (Scottish Government, 2018b, 2019c). The survey is carried out on an accounting year basis with a year-end in early March. FBS data includes a variety of physical and financial variables that allow not only the development of comprehensive profiles of farm characteristics and overall performance, but also the comparison across and between different regions and years. As it represents the most detailed farm database available, it was selected as the basis for configuring the modelling frameworks for this thesis. The specific FBS variables of interest required are summarised and discussed in the data sections of chapters 3 – 5, after having first established the context for the respective research questions.

FBS results are obtained from a stratified simple random sample, where farms are chosen randomly from the Scottish Agricultural Census to be representative of their economic size and farm type. At present, the survey does not include farms mainly engaged in horticulture, poultry, egg or pig production. The coverage of the survey is limited to farms presenting considerable economic activity (at least 25,000€ of output equivalent to £21,315) and that are not considered as spare-time farms, with a Standard

³ SAC Consulting is a division of Scotland's Rural College (SRUC).

Labour Requirement⁴ (SLR) of more than 0.5. Around 10,802 holdings are represented presently (Scottish Government, 2019c).

The method of classifying farms into farm types by the FBS is based on detailed sub-types as defined in the European Commission (EC) farm typology set out in the Commission Delegated Regulation (EU) No. 1198/2014 (EC, 2014). The methodology is centred on the relative significance of the various crop and livestock enterprises on each farm assessed in terms of standard output⁵, with the largest source of output determining the farm type. Accordingly, a farm is classified as belonging to a particular farm type if the highest proportion of their activity (more than two-thirds of the total standard output) comes under the classification of that type, even if a percentage of their production would be relevant to one or more of the other classifications (EC, 2014; Scottish Government, 2018b). In Scotland, farms are classified into one of eight main farm types. Within the original FBS databases, only beef and sheep systems classified according to this methodology were selected for this study, i.e. Less Favoured Areas (LFAs) cattle and sheep, LFA beef, lowland cattle and sheep and mixed farms (cropping, cattle and sheep).

The FBS offers a prominent source of information for the assessment of economic performance since farms, once recruited, can remain in the survey for an unlimited period of time (Scottish Government, 2014a). However, given the voluntary nature of participation, a small number of farms join and leave the survey each year. For instance, between 2015/16 and 2016/17, 31 farms left and 20 new farms entered the survey (Scottish Government, 2018b). These are replaced by farms with a similar outline (farm type and size) trying to achieve and maintain a sample representative of Scottish farms. Additionally, the characteristics of farms which remain within the sample can vary between sample years, e.g. a mixed farm may invest in livestock, which may result in a change to the classification of the farm type, e.g. from mixed to cattle and sheep. Furthermore, the FBS is periodically resampled to ensure that an entirely new panel is

⁴ Standard Labour Requirements (SLRs) represent the approximate average labour requirement for a livestock or crop enterprise.

⁵ Up until 2010, the classification of farms was based on standard gross margins, which have been replaced by standard outputs according to the Commission Delegated Regulation (EU) No. 1198/2014 (EC, 2014). The difference between standard outputs and standard gross margins is that the variable costs are not taken into account in the calculation of standard outputs (Defra, 2014).

selected from the sample frame, although the same farms can be sampled again allowing to collect data from a consistent sample over multiple years.

1.4. Background to the beef sector

This section analyses the structure of the Scottish beef sector from both farm-level and market perspectives, providing a concise socio-demographic and economic profile of the farm systems analysed in this thesis, and a detailed discussion of the evolving policy framework. Section 1.4.1. investigates the range of beef production systems in more detail, providing important information on the shape and scale of Scotland's beef industry. Economic performance of the sector and its continued importance to Scotland's economy are highlighted. Section 1.4.2. overviews important policy shaping the sector, from the inception of the European Economic Community (EEC) and establishment of the CAP, through subsequent major CAP reforms. Section 1.4.2. also discusses the implications and pressures resulting from changing trade relations as well as other potential impacts of 'Brexit' at the farm level.

1.4.1. Structure of beef production

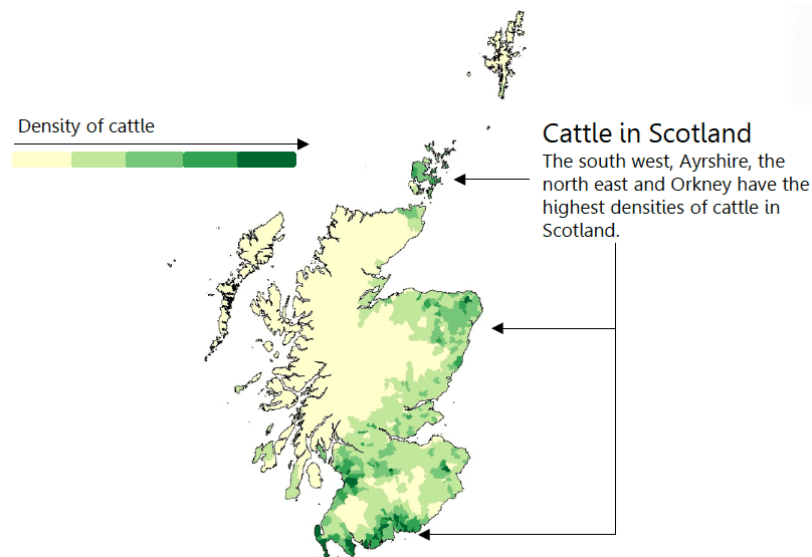
In Scotland, livestock production is strongly determined by land type; consequently, in the North West, Tayside, the Borders and Argyll and Bute, the cattle population tends towards the beef herd. In contrast, in the South West, there is a significant focus on finishing store cattle⁶ and dairy production. In the North East, the Lothians and Fife, beef calves production and finishing beef cattle are relatively equally important (QMS, 2019). Though beef cattle are farmed widely across Scotland, on a regional basis, beef farming is considered mainly located in the South West and North East of the country (Figure 1.1). This stratification of the beef sector illustrates that calves are not always kept on the holding of birth, thus the regional distribution of non-breeding animals differs from that of breeding animals⁷. For instance, the proportion of non-breeding cattle in the North West is significantly lower than breeding animals, whereas the proportion of non-breeding animals, especially, in the North East is higher, which

⁶ Store cattle consist of young stock that is purchased and subsequently resold at heavier weights. These beef finishing systems can be intensive (12-15 month finishing time), semi-intensive (15-20 months) and extensive (more than 20 months).

⁷ Breeding cows are considered female beef cattle over two years of age with offspring.

reveals that store cattle is usually moved away from the North West for finishing. A similar pattern is verified for sheep (QMS, 2016, 2018a).

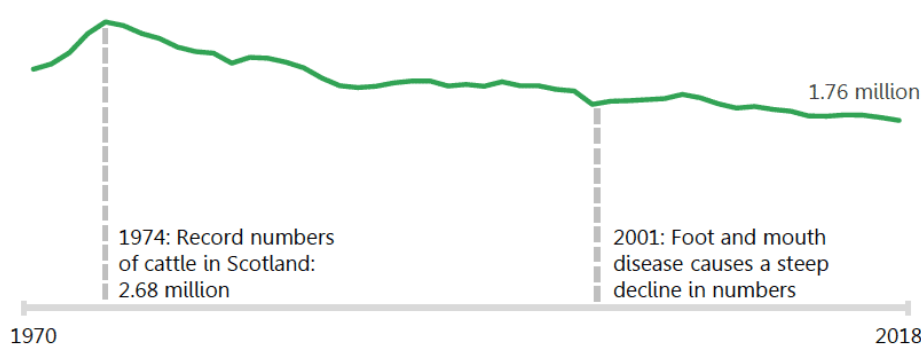
Figure 1.1. Distribution of cattle in Scotland (Scottish Government, 2018c). Beef farming is mainly located in the South West and North East of the country.



The Scottish beef sector is represented by small to medium-sized farms and the majority of beef cattle are concentrated on specialist beef farms, although some can be found on a variety of other farm types, typically in smaller numbers (QMS, 2018a), reflecting the co-existence of different activities on many farms. Specialist cattle farms are also not necessarily limited to their specialism being able to keep other animal and crop enterprises as well. The structural distribution of livestock by farm type is therefore uneven, where ‘farm type’ is a function of the predominant rather than an exclusive enterprise (QMS, 2016), as discussed in the previous section. For instance, Scotland’s hill livestock farmers typically farm both cattle and sheep, a mixed grazing system, on all year round grazing, which benefits biodiversity, landscape management and grazing quality. Mixed livestock grazing systems also contribute to reduce worm burdens for cattle and sheep and should not be viewed in isolation. There is also a strong link to the dairy sector and hence there are a large number of dairy-crossbred animals in the population (Amer et al., 2007; Scottish Government, 2017a). This relationship between different activities, or ‘enterprise-mix’, is important, allowing these farms to share resources such as labour and machinery without creating undue pressure on the resources at any time. Furthermore, multiple enterprises can share risk and improve cash flow, having, for instance, additional and multiple sale dates (SAC, 2015, 2017).

The size distribution of breeding herds is positively skewed, i.e. the majority of herds are small and as a group correspond to a small proportion of total animals, compared to the relatively few larger herds that account for the majority of animals (QMS, 2016; Scottish Government, 2017b). In 2018, the 14% of holdings with 100 or more animals constituted half of the beef herd and averaged 175 cows each. Furthermore, 17% of holdings which presented at least 100 cattle under 12 months of age kept 55.4% of the Scottish total, averaging 180 each (QMS, 2019; Scottish Government, 2019b). However, holdings with more than 100 cows have reported reductions in numbers in 2018 (1.3%-2.7%). Overall, average herd sizes have been dropping across Scotland after the decoupling of subsidy payments in 2005 (QMS, 2017; Scottish Government, 2017b). Total cattle numbers fell from an estimated 2 million in 2005 to almost 1.7 million in December 2018⁸, and have steadily declined to a 60 year low (Scottish Government, 2019d; Figure 1.2). Decoupling had a disproportionate effect on beef production, as compared to other agricultural enterprises, the shift from payments per animal, to payments per hectare of land, reduced the predicted performance of suckler beef enterprises, as measured by Gross Margin per cow, by almost half, from £247 to £133 – despite higher calf prices at the time of decoupling (Nix, 2001, 2004; figures reflect high performing herds). However, by 2016, the average size of a Scottish suckler-cow herd increased to 48 cows and has remained consistent, which was above that reported for the United Kingdom (31 in both 2016 and 2017; AHDB, 2018a, 2019a).

Figure 1.2. Cattle numbers in Scotland, June 1970-2018 (Scottish Government, 2018c). Total cattle numbers fell from an estimated 2 million in 2005 to almost 1.76 million in June 2018, and have steadily declined to a 60 year low.

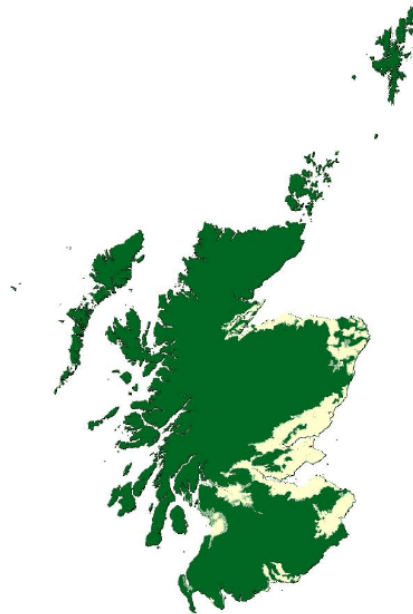


⁸This is five percent lower than the ten-year average and a drop of two per cent from the previous year.

Scotland's beef and sheep sectors are mostly dedicated to the production of meat rather than livestock products based on milk and wool, unlike many European countries (Vosough Ahmadi et al., 2015). The vast majority of prime cattle are marketed deadweight (80%); however, a large number is traded at some stage in their lives through the auction system, which provides an important service within rural communities. The livestock auction market is considered a trusted free-market system to settle on a price (SAC, 2015).

As mentioned, there is a variety of types of beef and sheep farm systems, which are usually determined by the availability of resources, climatic conditions, topography and management system. The vast majority of Scotland's agricultural land is classified as LFA (85%) under European legislation (LFA Article 2 of EU Council Directive No.75/268/EEC; European Communities Council, 1975), and suffers from natural handicaps including poor climate, mountainous or hilly topography, short growing seasons and tendency of depopulation (Morgan-Davies, Waterhouse and Wilson, 2012; Scottish Government, 2019c,d; Figure 1.3). Specifically, almost 70% of the registered agricultural holdings in Scotland are in LFAs, which reflects the large areas of upland farmland in Scotland (Scottish Government, 2018a). In 2018, there were 51,138 registered agricultural holdings in Scotland, with 29.4% (15,049 holdings) being classified by the Scottish Government as LFA cattle and sheep, and only 5.7% (2,914 holdings) classified as non-LFA cattle and sheep. Most of these LFA cattle and sheep holdings are situated in the North West and South West of the country. Furthermore, 79.6% of beef cows, and 90.3% of breeding ewes are in the LFAs (Scottish Government, 2018a).

Figure 1.3. Less Favoured Areas (LFAs) in Scotland. The dark green areas on the map show naturally disadvantaged land in Scotland (Scottish Government, 2018c).



Livestock farming, in particular for those classified as LFA cattle and sheep, is thus the main land use in the hills and upland areas (Morgan-Davies et al., 2012). As a result, beef and sheep farming play a significant role in supporting local economies and the environment as alternative agricultural uses for much of the land are usually lacking (Vosough Ahmadi et al., 2015). Some of these farms are able to produce efficiently, however many others depend heavily on CAP support payments to sustain their farming activities. For instance, according to the figures reported in Farm Management Handbook in recent years (SAC, 2015, 2017), an average Scottish beef farm would have made a loss without direct support. Barnes et al. (2011b) estimated that if direct support payments were to be removed or reduced, as is possible in the future, a large number of cattle farms in Scotland would become unprofitable.

Economic performance of the beef sector

The financial contribution of cattle to farm profitability is inevitably determined by the sales price. However, there is only limited opportunity to influence prices and much greater potential exists through improving output per hectare and cost control (SAC, 2017). The most profitable farm businesses are able to return a positive net income without support payments. Top performing beef systems regularly rear more calves per cow, to heavier weights, using less purchased feed. Grassland management also tends

to be better. While fixed costs may be lower among these farms, they are diluted further by higher outputs (SAC, 2015). Unfortunately, this is not always the reality.

As a result of diverse physical and business circumstances, the Farm Business Income (FBI) can fluctuate from year to year with subsidy support providing a financial buffer for many of these farm systems. For example, in 2014/15 FBI was on average £23,000 per farm, falling to £12,615 in 2015/16 (Scottish Government, 2016; 2017c). In 2016/17, the average FBI for businesses in the survey was £26,400, whereas in 2017/18 incomes from commercial farms in Scotland increased, with the average FBI rising 19% to £35,400, the highest level over the last six years (Scottish Government, 2018d, 2019b). However, without direct support the average Scottish farm business would not have been profitable in any of these years.

The average FBI of the farm types analysed in this study is presented in Table 1.1. Overall, average FBI is largely consistent over the represented years, with the largest variation being verified among mixed farms. All farm types experienced a decrease in overall FBI between 2014/15 and 2015/16, due to a rise in spending on livestock inputs combined with a declining average value of subsidy payments, as the Basic Payment Scheme (BPS) replaced the Single Farm Payment (SFP) in 2015 as the method of assigning subsidy support through direct payments (Scottish Government, 2017c). Conversely, increases in revenue from crop outputs, diversification and subsidies resulted in an overall increase in FBI in 2016/17 (Scottish Government, 2018d).

Table 1.1. Average Farm Business Income (FBI) by farm type over the years.

	2014/15	2015/16	2016/17
LFA cattle and sheep	£26,000	£20,893	£35,284
LFA beef	£26,000	£22,482	£25,565
Lowland cattle and sheep	£26,000	£12,302	£18,252
Mixed farming	£12,000	£2,264	£24,168

Furthermore, the analysis of farm business profitability over the years, at either enterprise or farm-level (via QMS enterprise profitability surveys and the FBS returns for Scotland, respectively) also confirms that without CAP support payments, many cattle-based farms would be uneconomic. The results presented in the most recent QMS

enterprise profitability survey (QMS, 2018b) show some recovery in net incomes, with 44% of suckler herds in the survey achieving a positive net income, an improvement on previous years. In addition, net incomes among store finishers also improved considerably in 2017/2018, with 43% of the businesses surveyed achieving a positive net income, up from 30% of businesses in the previous year. This variation in economic performance suggests that there is an opportunity for farmers to make technical performance improvements, perhaps through innovation, thus increasing business profitability. A further potential benefit would be a reduction in dependence on CAP support and an increase in business resilience.

1.4.2. Agriculture policy context

An overview of the Common Agricultural Policy (CAP)

The CAP of the EU was developed under Article 33 of the Treaty of Rome that established the EEC, being created with the primary objective of progressing in establishing a common European market (OECD, 2004; Janse, 2017). It is arguably one of the most significant policies in the EU, being a system of income and market support programmes for the agricultural sector. It was first conceived as a common policy, with objectives that have gradually evolved to respond to EU society changes and needs, including guaranteeing a stable supply of affordable food by supporting farmers and improving agricultural productivity, while encouraging the sustainable management of natural resources. Furthermore, the CAP has been further developed to help tackle climate change, preserving rural areas and landscapes across the EU, and to support the rural economy by promoting jobs in farming, agri-food industries and associated sectors (Kuhmonen, 2018; Recanati et al., 2019). Business uncertainties and the environmental impacts of farming emphasize the substantial role that the public sector support plays in this area (EC, 2017a; Houses of the Oireachtas, 2018). The CAP was one of the first integrated EU policies and it is the largest area of expenditure of the overall EU budget (accounting for nearly 40% of the budget; World Bank, 2017; EC, 2018a,b), being particularly important to rural Scotland and the agri-food sector.

To meet the aforementioned objectives, the CAP takes action by providing income supports such as direct payments, market-support and rural development measures. Direct payments ensure income stability in a market subject to volatility, for instance, by compensating farmers for implementing environmentally friendly practices and for

delivering public goods. Market measures are measures the EU can apply to handle challenging market situations such as a fall in prices due to a temporary oversupply on the market. Finally, rural development measures consist of national and regional programmes focusing on the particular needs and challenges facing rural areas (EC, 2018b).

At present, the CAP delivers direct financial support to farmers in the UK through the BPS, also known as Pillar I or direct payments, and to the rural economy through Pillar II funding for rural development programmes (RDPs). Pillar I support comprises payments made directly to farmers, which are usually determined in the form of an area-based income support decoupled from agricultural production. Pillar II funding, or RDPs, supports agri-environment schemes and rural growth, being co-financed by national governments. At least 30% of Member State rural development funding must be used on measures associated to climate change and land management. Each of the UK nations establishes its priorities in terms of targeted support under six economic, environmental and social programmes delineated in the EU rural development regulation for 2014–2020 (House of Commons Library, 2016; Matthews, 2018).

In the UK, there are varying levels of funding across the four nations under the current CAP. There are also different programmes, as mentioned, that operate across each of these nations, which reveal specifically tailored policy measures determined by underlying differences in socio-economic, environmental and demographic conditions. Scotland receives a lower level of CAP support per hectare of farmland than the rest of the UK and other EU Member States. The largest part of Scotland's pre-allocated EU funds originate from Pillar I, with support to farmers' incomes delivered via direct payments and market-support measures, which are proportionately more significant to Scotland than the rest of the UK. It has been estimated that CAP support makes up between 50%-80% of farm income in the UK. In particular, it is projected that three quarters of total income from farming in Scotland is supported by CAP payments (House of Commons Library, 2018). As mentioned in the previous section, Scotland's natural capital is a constraining factor on the levels of agricultural productivity compared to the rest of the UK. Thus, CAP support plays a key role in supporting farm incomes to guarantee the continuity of farming in upland areas, avoiding the risk of land abandonment (Baldock and Mottershead, 2017; Swales et al., 2017).

Major CAP reforms

The CAP has undergone periodic reforms since its inception, frequently described as a historical evolutionary process where old policy instruments are replaced by new measures, with the aim of reducing market distortions or making them more acceptable at the international level (House of Commons, 2011; Medina and Potter, 2017). There has been a move from a ‘coupled’ support (i.e. support given per unit of output) to a more ‘decoupled’ support (not associated to production, but given on an area or as income support) over the years (Latruffe and Desjeux, 2016), as described below.

The 1984 CAP reform

Following on from the preliminary implementation of the original CAP in 1962, and the introduction of price supports, productivity among EU farmers increased dramatically. As a result of EU production outstripping demand (creating the notorious ‘butter mountains’ and ‘wine lakes’) and of global trade becoming distorted, supply management easily became a problem. It was against this background that in 1984 the first major CAP reform took place (Fouilleux, 2004). This reform is considered historic as it presented several measures to better coordinate production with market demand (Baldwin and Wyplosz, 2015). One of these measures was the implementation of milk quotas that introduced a cap on milk production, and had a significant impact on countries with a relatively large dairy sector (Kempen et al., 2011).

The 1992 ‘MacSharry’ CAP reform

The second major CAP reform occurred less than a decade later, in 1992. This reform is often described as the ‘MacSharry’ reform, after the Irish agricultural commissioner at that time, Ray MacSharry; it came into operation on the 3 January 1993. The MacSharry reforms reduced the levels of market price support and introduced direct support, with the first crop area and livestock direct payments being implemented (Latruffe and Desjeux, 2016). This was the first decisive move towards decoupling support from production and trade. In addition to direct payments, mandatory land set-aside and rural development measures with an environmental focus were introduced (Ackrill et al., 2008). The first agri-environment payments were provided to farmers who complied with environmental commitments on a voluntary basis. These measures comprised reducing inputs, changing to extensive pasture, keeping abandoned land in good condition and reducing livestock density. For instance, extensification premium

payments were implemented for beef cattle, which were determined by the overall stocking density on the farm (of both beef and sheep), being particularly important in the LFA areas. Following the MacSharry reform, there have been other major reforms of the CAP, all pushing the same mechanisms even further.

The Agenda 2000 agreement

From an international perspective, the CAP continued to be seen as too protectionist, with direct payments still linked to production decisions, as these payments supported land sown with specific crops or particular livestock types (Brassley and Lobley, 2003; Latruffe and Desjeux, 2016). Accordingly, in March 1999 a reformulation of agricultural policy was agreed at the Berlin European Council in order to give greater emphasis to environmental policy objectives and, in particular, to the multifunctional role of European agriculture. The Agenda 2000 agreement saw market price support further reduced and direct payments increased, in addition to the establishment of a rural development programme. This rural development regulation required that all Member States introduced agri-environmental measures. While some of these measures resulted from the previous reform, new measures such as cross-compliance and modulation were also introduced (Schmid, Sinabell and Hofreither, 2007). Even though this CAP reform made a small further reduction in market distortions, the measures continued to distort production in relation to production coupled subsidy support. Concerns over production and trade distorting effects, and the associated forthcoming enlargement of the EU led to the mid-term review of the CAP in 2003 (Osterburg and von Horn, 2006).

The Fischler reform and the Luxembourg Agreement

In June 2003, the EU Council of Agricultural Ministers reached agreement on a radical change in the CAP, the Fischler reform. This new CAP reform introduced ‘decoupling’ with the ultimate aim of breaking the link between direct payments and production, giving clearer market signals to farmers. As mentioned, the payments structure at the time strongly incentivised farmers to increase livestock numbers and therefore production. Conversely, the new measures aimed to reduce this production linkage by introducing a support instrument known as the Single Farm Payment (SFP). The SFP assigned income support on a per hectare basis under any type of production, or even for land not in production, provided farmers adhered to a set of cross-compliance

measures (Brady et al., 2009; Swinnen, 2010; Latruffe and Desjeux, 2016). The rationale behind the introduction of decoupled payments within Pillar I was therefore to move towards a more market-orientated agricultural sector by eliminating the distorting effects of payments linked to output. While initially proposed as a mid-term review of the Agenda 2000 agreement, the changes suggested by the finalised agreement can be seen as the most radical and far reaching of any CAP reforms thus far (Binfield et al., 2003).

Under the Luxembourg Agreement, Member States had the option of either opting for full decoupling of subsidies from production, or for a range of partial decoupling measures. This CAP reform brought key changes to the subsidy system for Scottish farming. While some Member States remained with partially decoupled payments, Scotland opted for full decoupling. The reform introduced the aforementioned decoupling of direct payments, a replacement of production based subsidies by the SFP associated with the compulsory modulation of funds from direct payments (5% reduction in direct payments) to measures in the Scottish rural development plan (Scottish Government, 2010).

The Scottish Government opted for SFP based on historic subsidy receipts (from 2000 to 2002), instead of an area based flat rate payment system, to reduce the redistribution effects of the CAP reform (Scottish Government, 2004; Greer, 2005; Gelan and Schwarz, 2008). Given the importance of beef cattle in Scottish uplands, the Scottish Government chose to supplement the SFP with a beef national incentive, a new, coupled, Scottish Beef Calf Scheme (SBCS). However, given the vulnerability of LFA agriculture to policy change, decoupling of direct payments was likely to have a substantial effect on the direction of agriculture in LFAs regardless of any other measures (Moss et al., 2002). As argued by Gelan and Schwarz (2008), while decoupling of direct payments has reduced production linkages and, to some extent, the sectoral linkage, both SFP and SBCS were uniformly implemented throughout Scotland and had no direct spatial or regional targeting.

The 'Greening of CAP' 2013 Reform

In 2013, the latest reform took place aimed at improving competitiveness, promoting sustainable practices, innovation and growth of rural areas, linking financial resources to the productive use of land more efficiently (EC, 2013c). This reform delineates the current framework for CAP, which was agreed from 2014-2020. The latest CAP reform (European Parliament and Council of the EU, 2013) set two important changes in Pillar I payments that are considered to have major effects on Scottish farms. The main aspect of the 2013 reform was the introduction of a mandatory 'greening' payment to ensure sustainable farming and help contribute to the EU's efforts to tackle climate change, biodiversity loss and soil quality (EC, 2017a,b). This has arguably been one of the most debated aspects of CAP reform since its announcement in October 2011 (EC, 2011a, 2017a; Vosough Ahmadi et al., 2015). Under this framework, 30% of direct payments, paid per hectare, is associated to three 'environmentally friendly' farming practices: crop diversification, maintaining permanent grassland and dedicating 5% of arable land to environmentally friendly measures (so-called 'ecological focus areas'; EC, 2013b,c, 2017b). The purpose of these measures is to increasingly introduce environmental protection issues into the realm of Pillar I support payments. In the past, Pillar I has been mostly associated with production, rather than environmental goals. However, these greening measures are targeted towards arable farming, and may have very little effect on livestock farming (Shrestha et al., 2013).

The second main change in this CAP reform is a shift from historical payments to a regionalized payment system. Scottish farms, which have been receiving historically based farm payment support, are estimated to experience a considerable redistribution in direct support payments when the regionalization and convergence processes are fully implemented (Vosough Ahmadi et al., 2015). Scotland applies a BPS paid on an area basis to reflect the variation in land quality across Scotland, therefore based on different types of land (arable cropping, temporary or permanent grass, and rough grazing LFA and non-LFA), although this will become a flat rate payment in 2019, i.e. farms with similar land quality will receive equal payments per hectare if they undertake a minimum level of activity (Scottish Government, 2019e).

In addition, different parts of the UK have implemented the CAP in different ways to reflect variation in local conditions and political inclinations (Moxey and Thomson, 2018). For instance, the UK has opted to assign 1.7% of the direct payments allocation (in 2016) for voluntary coupled support, associating payments not only to the number of hectares but also to maintaining production levels in certain sectors in difficulty such as beef and veal, as well as sheep meat and goat meat (EC, 2016, 2017b). This is particularly relevant to Scotland, where such coupled support payments are in place for beef and sheep production since 2015, through the Scottish Suckler Beef Support Scheme (SSBSS) and coupled Scottish Upland Sheep Support Scheme (SUSSS), which reflect the greater relative importance of these sectors in Scotland than on average across the UK.

Regarding the Pillar II of the CAP, the Scottish Government has decided to apply a higher proportion of the rural development budget for funding based on topography, i.e. LFA and Higher Nature Value classifications. Furthermore, there is also significant support for programmes related to climate change established to reduce greenhouse gas emissions (GHG), carbon conservation and sequestration through the Agri-Environment Climate Scheme (AECS) and Forestry Grant Scheme (FGS; Scottish Government, 2019f). Just over a quarter of the funding programme is targeted at improving agricultural and supply chain competitiveness, including farm viability and sustainable management. Conversely, the majority of RDP funding in England, where only a small proportion of land is considered LFA, is targeted at better environmental land management, with very little funding being used to support agricultural competitiveness or climate change and resilience (Swales et al., 2017).

Brexit and the future of farming

On 29 March 2017 the UK government, triggering a two-year countdown to the exit of the UK from the EU, invoked the EU's Article 50 exit clause. That deadline has since been extended to 31 October 2019 (unless the Withdrawal Agreement is ratified in the interim). Even though the date for 'Brexit' may seem clear, there remains substantial uncertainty concerning many other aspects of 'Brexit', including the nature of the economic relationship between the UK and the remaining EU27. The prospect of a 'no deal Brexit' cannot be ignored, which reflects a rapidly changing political environment. A 'no deal' scenario could have a significant impact on UK trade in agricultural

products and, consequently, major implications for all of the agricultural sectors in the UK (Swales et al., 2017; Hantzsche, Kara and Young, 2018). Thus, there is little doubt that leaving the EU would have significant consequences for the UK agriculture, a sector highly dependent on trade relations with both the EU and the rest of the world, strong reliance on CAP income support, and dependent on migrant labour (Hubbard et al., 2019).

The EU is the UK's largest trade partner, meaning that about half of the UK's trade occurs with the EU (House of Commons Library, 2019). Membership of the EU has reduced trade costs between the UK and the rest of Europe. Specifically, a customs union between EU members ensures that all tariff barriers are removed within the EU, enabling free trade in goods and services. Just as important in reducing trade costs has been the reduction of non-tariff barriers⁹, which results from the EU's constant efforts to build a 'single market' within Europe (Reenen, 2016; Haverty, 2019). In this sense, leaving the EU would most likely lower trade between the UK and the EU as a result of higher tariff and non-tariff barriers to trade. At the same time, the main economic benefit of leaving the EU would be a lower net contribution to the EU budget, as the UK is currently the second largest net contributor to the EU budget (Matthews, 2016).

Regarding exports, the UK has exported an average of over 156,000 tonnes of beef and other bovine products per year between 2013 and 2017, which equates to an average total of £456 million (Defra, 2019). Over this period, exports to the EU comprised an average of 82% of all exports, which emphasizes the aforementioned significance of the EU market, in this case, to the UK beef industry. Ireland and the Netherlands are the main export destinations for UK beef, accounting for just over 50% of total exports. Hong Kong has been developing as an important export target in recent years, with exports having increased from 4,300 tonnes in 2013 to 14,500 tonnes in 2017 (AHDB, 2019b; Haverty, 2019).

In general, imports have stayed above export levels, a lasting effect of the BSE-related ban that was lifted in 2006 (AHDB, 2019b). The UK is a net importer of beef and around 75% self-sufficient in beef production. Just over an average of 360,000 tonnes

⁹ Non-tariff barriers consist of an extensive range of measures that raise the costs of trade including sanitary and phytosanitary (SPS) rules relating to plant and animal health (van Berkum et al., 2016).

of beef and beef products have been imported by the UK between 2013 and 2017 (Defra, 2019). On average, the value of imports is close to £1.3 billion per year, a figure that has remained fairly stable in recent years (Defra, 2019). Imports from the EU included an average of 86% of the total (2013–2017), with Ireland being the leading supplier, presenting an average of 63% market share (AHDB, 2019b; Haverty, 2019).

In Scotland, abattoirs produce around 170,000 tonnes of beef and 26,500 tonnes of sheep meat annually (QMS, 2017). As reported by Quality Meat Scotland (QMS, 2019), in 2018, only about 24% of Scottish abattoir annual turnover resulted from meat sales within Scotland (£157m). The volume of meat processed by Scottish abattoirs surpassed the domestic demand for beef and sheep meat, which resulted in significant trade with the rest of the UK and internationally. Two-thirds of the turnover was derived from sales made to the rest of the UK (£455m). England and Wales remained the usual first point of sale for the Scottish processing sector. Scottish processors continued to send less of their produce overseas than the UK as a whole, which could be further exacerbated in the event of ‘Brexit’. The lower scale of production in Scotland compared to the rest of the UK coupled with higher beef producer prices, make it difficult for the Scottish processing sector to compete in price-sensitive export markets, hence leading to a focus on lower volume but higher value markets (QMS, 2018a, 2019). In fact, 7% of turnover (around £48m per annum) originates from sales performed internationally; however, around 90% of these are with the EU. France, Italy and the Netherlands are the largest EU overall markets in terms of export revenue (£12.8m, £9.2m and £8.6m, respectively). Norway, Switzerland and Iceland are the main non-EU destinations for beef products, whereas Hong Kong and Macau are the main non-EU markets for beef offal, which play a key role in terms of the whole carcass value, allowing processors to discover markets for products that are not easily sold in the UK (Swales et al., 2017).

Trade in livestock and meat outside Scotland is considered essential to the long-term sustainability of the Scottish red meat industry. Potential changes to the trade arrangements associated with ‘Brexit’ will have a significant impact on the Scottish red meat supply chain, and access to EU and non-EU markets together with the management of imports, are all key areas that could affect farm profitability (QMS, 2017). As a result of the lower level of EU exports, Scottish agriculture appears to be

less exposed to this risk when compared to other parts of the UK. However, it is clear that a new policy environment could still highly affect the industry. Furthermore, new trade relations could also affect the strong interdependence with the agri-food sector elsewhere in the UK, which is important to maintain Scottish farm incomes (Swales et al., 2017).

As argued by Hanrahan, Donnellan and Thorne (2017), to date no trade deal that has been established by the EU has treated agri-food trade merely as another element of trade. Furthermore, agriculture in the EU has reserved levels of protection in excess of the zero tariff rates envisaged by some. Thus, there is more than a possibility that there could be some tariffs on trade, and there could almost definitely be non-tariff barriers to trade. The level of these tariff and non-tariff barriers would determine the relative competitiveness of beef and sheep meat exports (Matthews, 2018; Haverty, 2019). Brexit is therefore very likely to create price differentials between the UK and EU27 prices. The trade rules that will govern EU-UK trade are at this point unknown, and there is a great deal of speculation about the trading relationship that the UK will seek with the EU, a complex negotiation area where each party will pursue their own interests.

To address this uncertainty, there has been a considerable amount of quantitative modelling analysis being delivered on various ‘Brexit’ scenarios and assumptions (e.g. Van Berkum et al., 2016; Davis et al., 2017; Bradley and Hill, 2019). A range of feasible options has been chosen to represent: (i) trade relations with the EU and the rest of world; and (ii) domestic UK policy for direct payments to farmers. These all cover a variety of scenarios in the optimistic-pessimistic spectrum, including a selection of trade scenarios such as Free Trade Agreement (FTA), World Trade Organisation (WTO) and Unilateral Trade Liberalisation (UTL).

According to Hubbard et al. (2019), the trade scenario impacts appear to be determined by the net trade position and/or world prices. Under a FTA with the EU, the impacts on the agricultural sector are fairly modest. Implementation of the current EU’s WTO tariff agreement for all imports (including those from the EU) benefits net importer sectors (e.g. beef), while having a harmful effect on net exporter sectors (e.g. sheep). Conversely, unilateral removal of import tariffs (i.e. UTL) is predicted to have major

negative effects on prices, production and incomes, particularly for the UK beef and sheep sectors, which is more evident in Scotland in comparison to elsewhere in the UK. This is due to the differences in the number of beef animals obtained from the dairy herd across the UK, with a higher number of animals being supplied from the dairy herd in England, Wales and Northern Ireland compared to Scotland.

Similarly, Shrestha et al. (2018a) analysis of the impacts of 'Brexit' scenarios on Scottish farm systems report that the FTA trade agreement scenario has the least impact, whereas the WTO trade scenario is estimated to be financially beneficial for most of the Scottish dairy and beef farm systems, considering direct support payments remain, as a result of import substitution. Nevertheless, even with existing levels of direct support, the WTO scenario is estimated to lead to a significant fall in Scotland's ewe flock ($\leq 50\%$ in size). With Scottish lamb exports to the EU being disadvantaged due to the new tariff barriers for Scottish lamb entering the EU market, coupled with a protected UK beef market (high levels of tariff on imports), lead to a more attractive beef sector. Conversely, the UTL trade scenario has a very substantial negative impact on Scottish farm profitability, which is particularly high for LFA specialist beef, LFA beef and sheep, and LFA specialist sheep producers as tariff protection is lost, even with continued direct support.

UK farmers are guaranteed to receive similar levels of support as under the CAP until the end of 2022. Given the reliance of many UK farms on support payments, their withdrawal certainly aggravates the negative effects of new trade arrangements and offsets potential positive effects. The removal of direct payments is indeed expected to affect most farm businesses, with the magnitude varying significantly by enterprise (Harvety, 2019; Hubbard et al., 2019). Overall, the viability of many farms, particularly beef and sheep, is uncertain when direct payments are removed under any trade scenario. In particular, the removal of direct support payments under the UTL scenario has a further downward impact on suckler cow and ewe numbers. This scenario is estimated to lead to a significant decrease in the viability of the Scottish beef and sheep sector (Swales et al., 2017), with two-thirds of specialist beef producers and almost 90% of specialist sheep farms expected to be loss making (Shrestha et al., 2018a). Furthermore, cuts to farm subsidies would have a knock-on effect not only on farmers,

but also on supplementary rural economic activities dependent on farming, including slaughterhouses and machinery supply.

Uncertainty during negotiations regarding the Withdrawal Agreement has been (and continues to be) a major issue, making this period particularly challenging for farm business planning. The impacts of 'Brexit' will manifest in practice as farmers adjust and adapt their farm businesses to the new policy context and subsequent effects (Hubbard et al., 2019). The aforementioned scenarios' analysis emphasizes that significant change could result from 'Brexit', which is likely to aggravate existing differences in the beef sector performance across countries and, in particular, among Scottish individual beef farms. Given potential reductions in support levels, farmers need to adapt farming methods to be resilient to the evolving market and policy context. Within this context, innovation is often considered a significant part of achieving improved productivity growth and resilience to policy uncertainties and market developments (OECD, 2013; Läpple and Thorne, 2019). Following this line of thought, the next chapter reviews the literature on innovation and agriculture systems models to develop a conceptual systems framework to address the research objectives previously outlined, in the light of this review of Scottish beef production systems and policy context.

Chapter 2: Development of a Conceptual Framework

As many have argued, innovation is essential to promote output growth, productivity and rural development (see e.g. OECD and Eurostat, 2005; Spielman and Birner, 2008). Although our understanding of innovation activities and their economic impact has greatly increased over the years, there is still opportunity for improvement (OECD and Eurostat, 2005; OECD, 2013). Most studies of innovation adoption examine the pattern of diffusion of one particular innovation. In this thesis a different path is taken, one that involves the analysis of a range of innovations in the context of beef production in Scotland. Some of these innovations are reasonably new, being in an early phase of their diffusion process on beef farms (e.g. Electronic Identification [EID]) while others are further down their diffusion curve (e.g. grassland reseeding). As most studies of adoption deal with technological innovations, technology and innovation have been usually applied as synonyms (Rogers, 2003). Similarly, in this thesis innovation and technology are also used interchangeably.

The literature on innovation incorporates a plethora of different streams of topics, frameworks and particular models. This chapter briefly reviews relevant concepts and theories from the literature to establish an effective conceptual framework to answer the underlying research questions. In the following sections, the strengths and limitations of the selected theories and concepts referring to the adoption of agricultural innovations in general and more specifically with respect to beef cattle farms are presented. The emphasis is on how these innovations may be relevant to beef production in Scotland. As the volume of such published research is extensive, this chapter will focus on representative works in the field, rather than present an exhaustive discussion of all work to date.

In Section 2.1., the theoretical concepts underpinning innovation adoption and diffusion are outlined with appropriate reference to methodologies subsequently detailed. Section 2.2. provides an historical overview of the innovation adoption and diffusion literature, followed by an assessment of previous empirical studies relevant to this thesis. In Section 2.3. discussion is directed towards systems modelling and its applications on the analysis of agricultural innovations and policy scenarios, with both recent

developments in the area and state of the art in the literature being addressed. Finally, Section 2.4. shows some examples of agricultural innovations that may be suitable to increase the productivity and profitability of the Scottish beef sector. This discussion is framed within the context of the current study's focus and reference is made throughout to appropriate model developments in order to frame the modelling approach suggested for the integrated assessment of these production systems.

2.1. Innovation in agriculture: a theoretical framework

What is innovation? From an economic perspective, the concept of an innovation stems from the ideas of Joseph Schumpeter (1883-1950). Schumpeter defined technological innovation as 'an economic decision comprising a new combination of ways of production', i.e. a change in the way factors of production (land, labour, capital) are converted into products (Schumpeter, 1939). More specifically, this new combination may arise from new methods of production, or from inventions that lead to a general increase in all methods of production (Koutsoyiannis, 1979).

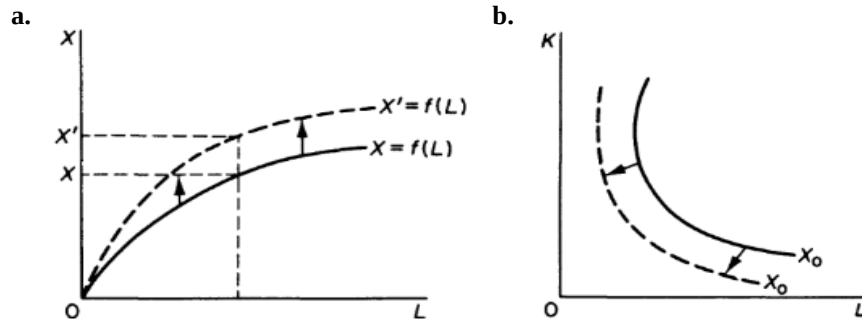
Over the years, a number of innovation theories have been published with a wide range of views on the process of innovation. The literature on innovation is therefore diverse and has developed its own vocabulary, with several definitions of innovation being used across different fields (Sunding and Zilberman, 2001; Rogers, 2005). For instance, the Oslo Manual (OECD and Eurostat, 2005) presents a broader definition of innovation as follows: 'the implementation of a new or significantly improved process, product, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations'. In this sense, an innovation can represent either one change, or a series of small incremental changes, which originate the introduction of a novel component in the business (OECD, 2013).

In this thesis, the reviewed technologies can be classified as *process* and *product innovations*. An agricultural example of a new method of production is the adoption of zero-grazing systems for cattle. In contrast to these *process innovations*, *product innovation* arises where the product itself is improved – e.g. the adoption of high-yielding wheat and rice varieties in the 'Green Revolution' – most closely associated with the Agronomist, Norman Borlaug (see Hesser, 2006, for an overview of Borlaug's

achievements). As adoption of new process and product innovations takes place, and as old methods and products are retired, technological progress occurs. It is worth noting that this progress relies on both adoption of the new – and letting go of the old.

Technological progress or *change* is the main driver of productivity growth: technological change leads to an improvement in the efficiency of production, which ultimately increases overall economic growth (Link and Siegel, 2003). From an economic perspective, it corresponds to a change in the production function (Rosenberg, 1963; Korres, 2016), i.e. more can be produced from a given combination of inputs; alternatively, a given output can be achieved with fewer inputs. Graphically the effect of innovation is illustrated with an upward shift of the production function (Figure 2.1a), or a downward movement of the production isoquant (Figure 2.1b; Koutsoyiannis, 1979; Korres, 2016).

Figure 2.1. The effect of innovation on the production function (a), and the production isoquant (b; Koutsoyiannis, 1979).



In agriculture, as in other sectors, technological change has been the starting point for increasing productivity and promoting economic development and therefore innovation is an important area for research. In the examples above, the word ‘adoption’ was deliberately used to show that change only occurs if innovations are adopted by end users, in this case farmers. Lionberger (1960) described adoption as the full-scale incorporation of a new idea, product or practice (hence encompassing both process and product innovation) into a farmer’s on-going operation, through repeated and continuous use, usually through an individual decision (Jones, 1963; Rogers, 2003). Diffusion, on the other hand, consists of a cumulative and gradual process resulting from a sequence of individual decisions. As the number of adopters increases, the new

technology diffuses and its economic impact grows (Hall and Khan, 2003). In this thesis, innovation is considered as the application of new or existing knowledge that is integrated in innovative ways (Kiers et al., 2008; Spielman et al., 2008). That is, innovation is defined as the application of managerial, technical and/or other forms (or sources) of knowledge to introduce positive innovative changes in a specific context, in this case, at the farm level (Conroy, 2008). As mentioned, this includes knowledge that may be new, or that depend on the new use of existing knowledge.

An innovation may be new, or indeed, ‘innovative’ but fail through lack of adoption and hence diffusion. Thus, understanding the factors influencing adoption and diffusion is clearly of great importance, for instance, to inform and refine agricultural policy interventions, in particular those aimed at promoting knowledge exchange and innovation adoption (Pannell et al., 2006).

2.2. Approaches to measure innovation adoption and diffusion in agriculture

Innovation is a complex process that is challenging to measure (Van Galen and Poppe, 2013). This complexity is further compounded by the fact that there is no universal definition of what can be regarded as an agricultural innovation. Understandably, distinct approaches have been applied to measure innovation. The following sections attempt to provide a comparative overview of these different approaches, linking the theoretical concepts and methodologies to the range of empirical and historical evidence.

2.2.1 Innovation adoption and diffusion: an historical overview

Technological adoption and diffusion have produced a voluminous and diverse theoretical and empirical literature that sprawls over several disciplinary boundaries. Innovation adoption and diffusion theories emerged in the traditions of rural and medical sociology (often as ‘epidemic’ models), anthropology and education, in the 1920s, 1930s and 1940s (Rogers, 2003; Ruttan, 1996). Schumpeter’s (1934) path-breaking work provided the first systematic analysis of diffusion: a linear progression from invention to innovation to imitation and diffusion. By the late 1950s and mid-1960s, other economists started contributing to the literature. In fact, the seminal

contribution of economics to the adoption and diffusion literature was in agriculture (Griliches, 1957, 1960). Griliches (1957) wrote his first paper on the diffusion of hybrid corn, based on epidemic models first presented in the field of sociology. Some years later, Mansfield (1963a,b) dedicated himself to the study of industrial innovations' diffusion, by integrating economics into the epidemic models. This approach considers the process of diffusion as a disequilibrium process, where innovation adoption is a function of the spread of information (Sarkar, 1998; Diederer et al., 2003).

Griliches (1957), by fitting data to a 'logistic curve', demonstrated that differences in the time and rates of adoption in a region could be described by economic variables, e.g. profitability of entry into production of hybrids by seed producers, and profitability of adoption by farmers. Mansfield (1961) applied more complex models of diffusion, also using an S-shaped diffusion curve, but including variables relating to uncertainty surrounding the innovation, together with profitability.

The epidemic diffusion model has been widely used in research, mostly due to its convenient analytical properties. However, its disadvantages are well recognised. These models are centred on several restrictive assumptions that are somewhat unrealistic such as the assumption that innovation diffusion is driven only by information diffusion. Apart from that, several other limitations can be mentioned, including the assumption of a constant and homogeneous population of adopters (with similar needs), an unchanging innovation, a constant profitability of adoption, and no active information search (Karshenas and Stoneman, 1992; Geroski, 2000; reviewed by Diederer et al., 2003).

Several other approaches to the process of diffusion arose over time. 'Equilibrium approaches' (David, 1975; Davies, 1979) focus on the decision-making process of adopters such as farmers, emphasizing the characteristics of early adopters in contrast to late adopters (more recently this approach has been taken by Karshenas and Stoneman, 1992). The 'probit model' (pioneered by Davies, 1979) is the main empirical model that links innovation adoption and diffusion to variation in characteristics and in benefits. Equilibrium models can include multiple variables that describe the variation in adoption benefits over the potential adopters of an innovation, but as these models assume a transparent market for innovations, they do not consider the impacts of the

generation and the spread of information (Diederer et al., 2003). However, there are a few studies that modelled adoption decisions based on uncertainty of the true value of the innovation, therefore considering information diffusion (Karshenas and Stoneman, 1992).

While some recognise the value of this approach, they argue that it does not consider the full complexity of the economic environment (Sarkar, 1998). Criticisms are essentially focused at the three fundamental assumptions of these models (Sarkar, 1998): (i) the assumptions of perfect to almost complete information, and infinite rationality (Nelson, 1995); (ii) the view of the diffusion process as an equilibrium process (Metcalf, 1994); (iii) and the idea of diffusion as a continuous, quantitative process (Zeeman, 1976). Over the years, the frontiers between the several disciplines that study adoption and diffusion began to fade, and concepts and methods started to be shared by different disciplines, leading to a more interdisciplinary approach, as presented below.

2.2.2 Empirical studies of innovation adoption and diffusion in agriculture

The studies in the literature that have attempted to investigate agricultural innovation usually use proxies to infer its impacts and have been mostly performed in a developing-country context. A range of indicators related to innovation efforts (e.g. national R&D expenditure), outcomes (e.g. number of patents and publications) and impacts (e.g. total factor productivity [TFP] growth) are typically applied to evaluate the aggregate national impact of agricultural innovation (OECD, 2013; Lapple and Thorne, 2019). Conversely, at the individual farm-level, the adoption of new technologies is often used as a proxy for innovation, while a few authors apply more complex approaches to measure innovation (e.g. Sauer and Zilberman, 2012).

Considering the macro-level, Spielman and Birner (2008) have identified a framework for the design and construction of national agricultural innovation indicators and have discussed its use in developing-country agriculture. A particular indicator frequently applied to measure innovation efforts at the macro-level is the national expenditure on agricultural R&D, which is often considered an important driver of TFP growth and competitiveness in agriculture (Alston, 2010; Fuglie, 2012). Other studies regard farm performance as an indicator of innovation within countries as well as across countries,

and identify the specific characteristics of high and low performing farms such as farm size, age, education and subsidy reliance (e.g. Kimura and Le Thi, 2013).

At the individual farm-level, considerable emphasis has been placed on explaining the adoption and diffusion of new technologies, and on measuring their effect on farm profitability. However, while measuring agricultural innovation at the individual farm-level is an important topic that has received substantial interest and attention in the literature, most of these studies assess factors that influence innovation adoption, for instance, applying the aforementioned probit model.

Lindner (1987) categorised the agricultural economics' literature into empirical studies, focused on adopter characteristics (adoption studies) and those centred on innovation characteristics (diffusion studies), with each of these categories also having both cross-sectional and temporal aspects (as noted, for example, by Abadi Ghadim and Pannell, 1999). Cross-sectional studies aim to identify why some farmers adopt an innovation, whereas others reject it: the bulk of empirical studies of adoption are in this area (e.g. Marra, Hubbell and Carlson, 2001; Khanal and Gillespie, 2013, Ghimire and Huang, 2016). Temporal studies are mostly based on the determinants of the timing of adoption, i.e. why some farmers are early adopters whereas others are laggards (e.g. Foster and Rosenzweig, 1995; McWilliams et al., 1998; Cameron, 1999). The literature has expanded considerably throughout the years, however this dichotomy still applies, though supported by an increasingly sophisticated number of mathematical and statistical approaches (Marsh, Pannell and Lindner, 2000).

In general, while models of individual adoption in the past were founded on a static framework, more recent approaches have tried to include dynamic aspects of the adoption decision process such as the learning effect or the reduction of uncertainty, enabling the estimation of adoption patterns over time (e.g. Abadi Ghadim, Pannell and Burton, 2005; Holden and Quiggin, 2017). Nevertheless, the identification of general explanatory factors to estimate adoption in agriculture has been difficult to accomplish (Knowler and Bradshaw, 2007).

Similarly, in the past, aggregate models of technology diffusion were mostly based on logistic models of the type referred to earlier in the case of hybrid corn (Griliches,

1957). Over time, many authors have tried to extend the basic logistic model in an attempt to adjust for its limiting assumptions, including a fixed adoption ceiling, and a fixed and homogenous population of potential adopters (e.g. Marsh et al., 2000; McRoberts and Franke, 2008). As a result, diffusion has been modelled to describe changing equilibrium populations, changing technologies, changing rates of adoption, spatial differences and rate of abandonment (Feder and Umali, 1993; Pannell et al., 2006).

Most studies examine the pattern of diffusion of one particular innovation, though farmers may consider adoption of multiple innovations. Some authors argue that considering one technology as a proxy for innovation may not fully represent innovation behaviour, as innovation is more complex than the adoption of a new technology (Läpple and Thorne, 2019). As stated by Goldsmith and Hofacker (1991), a farmer may implement one technology early and therefore be categorised as an innovator, whereas the same farmer may require more time to adopt a different technology, or to participate in other innovative activities. Thus, considering one specific technology as an innovation proxy may lead to misleading conclusions.

Conversely, some studies use a range of technologies to proxy for innovation. For instance, Mutenje et al.'s (2016) study among farmers in Malawi relied on farm practices such as maize variety, soil and water conservation, and improved storage to assess innovation, reporting that adoption of these technologies increases productivity. Using the FADN dataset in the Netherlands, Diederer et al.'s (2003) study identified a set of innovations, including the use of ultrasound to exterminate insects, or a system for drying chicken manure, to distinguish between 'innovators', 'early adopters' and 'laggards'. The adopter classifications were determined by the position of these innovations' adoption on the diffusion curve as specified by the farmer. Van Galen and Poppe (2013) also used FADN data in the Netherlands to measure innovation. This study reported that in 2010, three per cent of Dutch farmers were classified as innovators, introducing innovative changes in both product and production processes new to Dutch agriculture, although direct measures of farm-level innovation are rarely provided by the available datasets. However it should be noted that, in general, innovation adoption is determined by the heterogeneity among potential adopters (e.g. attitude to profit, risk, information; Diederer, van Meijl and Wolters, 2002; Young,

2009; van Grieken et al., 2019), and usually occurs when farmers perceive that a specific technology – or technologies - have the potential to help them achieve their objectives (economic, social and environmental; Pannell et al., 2006).

As mentioned, a few authors have used more complex approaches to measure innovation. Some studies derive a single measure of adoption of multiple innovations, i.e. an innovation index, either by:

- performing a summation of ‘dummy variables’ as a proxy of technical progress and implementing it in their TFP score (Karafillis and Papanagiotou, 2011);
- designing an innovation matrix that classifies innovations based on their technological advancement which is then used to calculate the innovation index (Ariza et al., 2013);
- or combining expert-weighted farm-level innovation indicators such as innovation adoption, acquisition of knowledge and continuous innovation (Läpple, Renwick and Thorne, 2015).

More recently, Läpple and Thorne (2019) assessed the impact of innovation on Irish dairy farm economic sustainability applying a generalised propensity score method. The study focused on profitability, productivity of land and market orientation, revealing that innovation can increase economic sustainability, however not in a linear way. Given a specific level of innovation, relatively small innovative efforts can lead to significant profitability gains, whereas no economic gains seem to be achieved at low levels of innovation.

From this overview, the major factors that influence the adoption of agricultural innovations and their hypothesized effect on innovation behaviour are summarised in Table 2.1. However, it is clear that no general approach perfectly describes all circumstances and that in some cases different models are able to represent a single event effectively. Accordingly, a different approach to measuring agricultural innovation is presented in the following section.

Table 2.1. Major factors influencing the adoption of agricultural innovations and their hypothesized effect (positive/ negative).

Factors	Hypothesized effect	References
<i>Farmer's characteristics</i>		
Age	+/-	Diederen et al., 2003 (-); Ariza et al., 2013 (-); Khanal and Gillespie, 2013 (-); L��pple et al., 2015 (-); Ghimire and Huang, 2017(-)
Marital status	+/-	L��pple et al., 2015 (+)
Experience	+	Foster and Rosenzweig, 1995; Marsh et al., 2000; Marra et al., 2001; Abadi Ghadim et al., 2005; Sauer and Zilberman, 2012
Education level	+	McWilliams et al., 1998; Marra et al., 2001; Ariza et al., 2013; Khanal and Gillespie, 2013; Ghimire and Huang, 2017
Agricultural education	+	L��pple et al., 2015, 2017; Toma et al., 2018
Off-farm job	+/-	Khanal and Gillespie, 2013 (-); L��pple et al., 2015(-); Ghimire and Huang, 2017 (-)
Farm-related business	+	McWilliams et al., 1998
Risk aversion	-	Abadi Ghadim et al., 2005; Sauer and Zilberman, 2012
Attitude regarding innovation	+	Diederen et al., 2003; Sauer and Zilberman, 2012
<i>Farm resources</i>		
Farm size	+	McWilliams et al., 1998; Marra et al., 2001; Diederen et al., 2003; Sauer and Zilberman, 2012; Khanal and Gillespie, 2013; L��pple et al., 2015, 2017; Ghimire and Huang, 2017; Toma et al., 2018
Market position	+	Diederen et al., 2003; L��pple and Thorne, 2019
Solvency	+/-	Diederen et al., 2003 (-); L��pple et al., 2015 (+)
Credit/Loan	+	L��pple et al., 2015
Farm profitability	+	Mariano, Villano and Fleming, 2012; Kimura and Le Thi, 2013; Toma et al., 2018; L��pple and Thorne, 2019
Extra farm labour	+/-	Abadi Ghadim et al., 2005 (+)
Extra hired labour	-	Abadi Ghadim et al., 2005
<i>Institutional characteristics</i>		
Participation in Agricultural Innovation Networks	+	Sauer and Zilberman, 2012; Ariza et al., 2013; Mutenje et al., 2016
Number of market actors the farm is involved with in innovation activities (suppliers, clients, other farms and consultants)	+/-	Ariza et al., 2013 (+)

2.3. Systems Modelling

So far, analysis has been mostly centred on econometric approaches to measure agricultural innovation. Discussion will now be directed towards systems modelling and its applications on the assessment of alternative technological innovations and policy scenarios. Systems are abstractions of the real world that are developed for particular purposes, consisting of components, their interactions with each other and with their environment to determine overall system behaviour (Bywater, 1990; Jones et al., 2017). They are extremely useful in science across all fields, including engineering, economics, and particularly, agriculture.

In agriculture, an agricultural system can be defined as an arrangement of interacting components with the primary purpose of producing crops and livestock to deliver food, fibre, energy and non-market goods, and services from natural resources. Such systems may also produce undesired effects on the environment (Woodward et al., 2008; Jones et al., 2017). In this thesis, the farm ‘system’ is the decision unit to be analysed, which can be described as a range of interlinked fixed causal relationships that operate within an established boundary. Thus, the response of the ‘system’ is endogenously determined by the interactions between components, rather than exogenously determined and dependent on the interpretation of the model, as for instance, in budgeting models (Cacho, 1997). The farm system facilitates understanding of the functioning of the decision unit, and the interactions between production activities and the environment. Accordingly, systems research provides a framework for detailed analysis of farm-level resource use decisions, which can help explaining both the identification of resource constraints and the basis of technology choice, allowing drawing inferences on the profitability of alternative management decisions (Asuming-Brempong et al., 2016).

Agricultural system models offer therefore a simplified description of important system components and their connections. Even though they can be considered as imperfect abstractions, system models can deliver a valuable economic representation of the farm and a way of testing concepts and policy measures (Hazell and Norton, 1986). Agricultural system modelling attempts to integrate, interpret and apply information from several disciplines in a manner that the scientific information can be directly

applied to farm decision-making. Thus, agricultural systems modelling can be considerably important for farm planning and extension, research planning and evaluation, and policy analysis (Klein and Narayanan, 1992).

Agricultural systems models comprise a broad range of methods and levels such as statistical crop yield models, process-based crop simulation, economic optimisation and bio-economic models at farm, regional and supra-national levels. The selection of a particular way of modelling and a specific model depends on the study design. According to the study design, systems models can be categorised within the literature (Cacho, 1997). These general classifications and modelling approaches are briefly introduced in the following section.

2.3.1. Types of agricultural systems models

Agricultural systems are diverse. Before examining how agricultural systems can be modelled, it is important to consider the classification of agricultural systems models in space and time as defined by Swinton and Black (2000). In space, agricultural systems models range in level from micro-level plant and tissue growth models to the individual organism, to the field (Messina et al., 2006), to the whole-farm, to multiple farm businesses (Keating et al., 2003) and to larger levels such as policy models at the wider macro-level of environmental zone, or at national and regional levels (Louhichi et al., 2015). In parallel with the physical boundaries, there are also social boundaries, including models describing macroeconomic links to the rural economy and social systems of rural communities (van Calker et al., 2006).

In time, agricultural systems models can be defined as ‘static’ or ‘dynamic’. Static models do not contain time as a variable, generally simulating equilibrium conditions. Conversely, a dynamic model takes account of time, specifically describing the change in the system variables over time. A dynamic model can be applied to delineate the path and the length needed for adjustment when an equilibrium is disturbed, or to predict whether a new equilibrium will be reached (Cacho, 1997).

Distinctions between ‘mechanistic’ and ‘empirical’ models, and ‘normative’ and ‘positive’ approaches, respectively, are also suggested in the literature (van Calker et al., 2004; Janssen and van Ittersum, 2007). Mechanistic models are developed based on

existing theory and knowledge of the processes actually occurring on farms (Pandey and Hardaker, 1995; Austin et al., 1998), whereas empirical models are established based on data that is incorporated in the model, attempting to define associations in the data that are not known ex-ante (Austin et al., 1998). Different modelling approaches are generally associated with specific types of analysis. In particular, farm systems models can be modelled according to a positive or a normative approach. Accordingly, positive approaches try to model farmers' behaviour by offering insight into the farm responses and trying to fully understand and describe them (Janssen and van Ittersum, 2007), while normative approaches attempt to determine the optimal resource management and allocation solutions, and alternatives (van Calker et al., 2004), which are the focus of this thesis.

It is apparent that the literature includes different approaches to classifying agricultural systems models. Several studies have delivered comprehensive overviews of the agricultural systems modelling literature encompassing mathematical programming, simulation and econometric models (Janssen and van Ittersum, 2007; Jones et al., 2017). Under these broad classifications, a few methods have been developed to model the economic implications of technology and different policy interventions on farmers' decisions for a range of levels and purposes. The most relevant methods and their capabilities and limitations are summarised below, to support the development of a modelling approach for the integrated assessment of the adoption of technological innovations in Scottish beef and sheep farms.

2.3.2. Agricultural systems modelling and innovation

Several studies have attempted to assess the implementation of agricultural technologies using a wide variety of modelling approaches, with the majority of this studies being performed in poor rural farming communities (e.g. Ruben, Kruseman and Kuyvenhoven, 2006; Berkhouta et al., 2010). As mentioned, these models generally comprise econometric models (e.g. multi-market models, continuous production functions and efficiency measures, general equilibrium models), simulation and mathematical programming models, including linear and positive mathematical programming.

A few of these models either simulate farmers' resource management decisions such as technological (non) adoption and input choices, or biophysical processes separately. However, to effectively assess potential impacts of technological innovations, models that link formulations representing farmers' management decisions to formulations that define current and alternative production options, are required (Ruben, Menk and Kuyvenhoven, 1998; Janssen and van Ittersum, 2007; Asuming-Brempong et al., 2016). These models are generally referred to as 'bio-economic' models, as they typically integrate both economic and biophysical components (Knowler, 2002; Flichman, 2011). Combining both components into an analytical framework can greatly assist policy making, for instance, by allowing the ex-ante assessment of the impacts of technological innovations and policy measures on farm business resilience, which is particularly relevant in the context of this thesis. Furthermore, bio-economic models can also help identify potential trade-offs between economic and environmental objectives (Ruben et al., 1998). Many descriptions and applications of bio-economic models have been published in the literature. A review of selected studies from the international research literature with particular relevance to this thesis is presented in view of the aforementioned classifications.

Mathematical Programming/ Optimisation models

Several bio-economic farm-level models use mathematical programming or optimisation models, which are usually based on Linear Programming (LP). Established in the 1950–60s, linear economic optimisation models of farm systems offer a framework for farm management advice (Heady and Dillon, 1964). These models are defined by a set of linear inequality constraints that describe the available production options, representing the farm as a linear combination of 'activities'. An activity is a set of operations with associated inputs and outputs, which result, for instance, in the production of feed for the farm (Ten Berge et al., 2000). Accordingly, an activity is expressed by a set of coefficients (technical coefficients or input–output coefficients) that define the contribution of the activity to achieve the stipulated objectives (Ten Berge et al., 2000; reviewed by Janssen and van Ittersum, 2007). As inputs are limited resources, constraints to the activities need to be specified, representing the minimum, or maximum, amount of a specific input that can be applied. This system of activities and constraints is then optimised for an objective function, which describes a defined goal, for example, profit-maximisation (see e.g. Hazell and

Norton, 1986; Rae, 1994 for standard mathematical formulations of different kinds of LP models).

This approach has been used in assessments of alternative farm configurations and technological innovations, including evaluations of the long-term effects of innovations and respective policy contexts, based on the assumption that the innovation only needs to be marginally profitable to be adopted. Examples of such bio-economic models include Abadi Ghadim (2000), Benoit and Veysset (2003), Alford, Griffith and Cacho (2004) and Crosson et al. (2006).

Abadi Ghadim (2000) used a whole-farm LP bio-economic model known as Model of Integrated Dryland Agricultural System (MIDAS; Abadi Ghadim, 1991; Pannell, 1999) to evaluate the profitability of innovations aimed at increasing production on the non-wetting sands of wheat belt farms of Western Australia. The model represents the biological processes and economics of the farm systems of several regions in Western Australia, assuming that the goal of the farmer is to maximise farm profit. Using this LP framework, it was shown that amelioration of water repellency was an economic possibility for some of these farms.

Benoit and Veysset (2003) analysed the transition of a French cattle and sheep suckler system to organic farming constructing a static LP bio-economic model named Opt'INRA. The model maximises the global gross profit margin by optimising the farm system with several constraints, both internal and external, to the farm (Veysset et al., 2000). After conversion, the optimal balance resulted in fewer cows with fattened products and larger areas for cereals, with gross margins increasing significantly, whereas maintenance of previous earnings from sheep production required a rise in selling prices.

Alford, Griffith and Cacho (2004) using multi-period linear programming, developed the Northern Tablelands Whole-Farm linear programming model (NTLP) to assess the potential economic gains associated with improved net feed efficiency in beef cattle. The NTLP model represents a typical beef and sheep farm on the Northern Tablelands of New South Wales in Australia using a similar approach to MIDAS (Kingwell and Pannell, 1987). The farm system is based upon a single year in equilibrium and the

objective function seeks to maximise farm gross margin to identify the optimal beef production system and associated range of activities. Results show that there are regions where these feed efficiencies may provide greater benefits due to seasonal variations in grass growth rates, which is the case of the Northern Tablelands with its recognised winter feed deficit.

Crosson et al. (2006) developed the Grange Beef Model (GBM), a static, deterministic, budgeting, whole-farm, optimisation model that maximises farm gross margin to identify optimal beef production systems in Ireland. The model employs a single year steady-state design and uses an empirical approach to define biological relationships based on production research. The model has been used by Crosson et al. (2006) to examine optimal adjustment strategies in light of price changes (concentrate and beef prices), and the impacts of varying herbage utilisation and integrating maize silage into beef production systems on gross margins. The value of rural environment protection schemes on both farm gross margins and nitrogen usage was also investigated. Another application of the GBM model consisted on the identification of optimal solutions for calf-to-stocker and calf-to-finish beef cattle production in high- and low-price market scenarios, and the associated impacts of these production systems on environmental indicators through farm simulation, i.e. by integrating a module to simulate ‘residual’ outputs (Crosson et al., 2007).

In terms of Scottish agricultural production systems, ScotFarm (Stott et al., 2012; Shrestha et al., 2018a,b), a ‘pseudo-dynamic’ LP bio-economic model that maximises farm net income within a number of limiting farm resources, has been used extensively in policy change impact studies. These include, for instance, the assessment of impacts of greening measures and flat rate regional payments of the CAP on Scottish beef and sheep farms (Vosough Ahmadi et al., 2015), and the analysis of farm gross margin effects of selected soil organic carbon management measures for arable farms (Glenk et al., 2017). More recently, studies focused on estimating both the effects of alternative ‘post-Brexit’ trade and agricultural support policy scenarios on Scottish farm systems (Shrestha et al., 2018a), and the financial vulnerability of dairy farms challenged by Johne’s disease to changes in farm payment support (Shrestha et al., 2018b). However, to date, none of the available studies using ScotFarm has estimated the impacts of technological innovations.

A few issues with LP based models have been reported in the literature over the years. For instance, one limitation of these models is that the solutions are limited to extreme points in the multidimensional decision variable space, hence this approach is not capable of investigating intermediate solutions. Complex constraint structures are required to calibrate the base data, which limits alternative solutions (Jones et al., 2017). Furthermore, optimisation studies assume the existence of perfect markets and a lack of a detailed specification of producers' decision-making procedures. As mentioned, optimisation approaches generally employ a LP framework to mathematically obtain the best solution given a certain objective, for example, optimise farm profit. In this sense, mathematical programming models are often classified as a normative approach, given that economic agents, in this case farmers, must follow the restricted assumption of optimising an objective function subject to a set of constraints (Buysse, Guido and Lauwers, 2007). However, farmers are not always able to optimise profits, or may not wish to manage the farm according to model outcomes as a result of risk aversion, imperfect information, management quality and skills, among others (Falconer and Hodge, 2000; van Calker et al., 2004; cited by Janssen and van Ittersum, 2007). This highlights the limitations of normative neoclassical assumptions of profit-maximisation often used in the development of LP models, which may not fully represent farmers' behaviour.

Following this line of thought, Barnes et al. (2014a) explored the ability of the LP framework to fully address the complexity of Scottish beef farmers' production decisions, by comparing estimations of an LP based policy model with results of a farmer production intentions survey under hypothetical CAP reform payment scenarios. That is, the ScotFarm model was used to predict the impacts of two potential CAP reform scenarios (full decoupling and partial decoupling) on beef farms in Scotland post 2015. Comparing the results of both exercises, shows that the model projections are in line with intentions, and that the imposition of economic rationality on farm decision-making is thus deemed appropriate, supporting the application of mathematical programming models on these production systems. In addition, by using mathematical programming models it is possible to model straightforwardly the link between economic, biophysical and ecological aspects of the farm. Although other approaches may also allow including the combined non-commodity output production, mathematical programming models offer several advantages when compared to other

methods, as a result of being able to tackle the multi-variant and extremely interlinked nature of agriculture (Hazell and Norton, 1986; Buysse et al. 2007). Specifically, the popularity of LP based optimisation stems from its relative simplicity compared to other techniques such as mixed-integer linear programming (MILP).

Simulation models

Complex simulation models have been applied for the past 45 years to describe agricultural systems (Jones et al., 2017). Simulation models are ‘flexible’ models that consider the interaction of factors of a production system such as the effects of biological, technical and physical processes to produce observed events. The key difference between simulation models and mechanistic research models, is that the former are not intended to make recommendations as to how the farm system should be managed, focusing instead on conducting ‘what if?’ analyses to study the consequences of a range of hypothetical investigations (Woodward, 2008).

Van Wijk et al. (2014) review the variety of models that have been created to simulate the economic behaviour of agricultural systems, and relate behaviour to environmental processes and economic sustainability indicators. These include several kinds of linear and non-linear programming models (e.g. Cittadini et al., 2008; García-Vila and Fereres, 2012), household models (models combining production systems with household behaviour; e.g. Cabrera et al., 2005; Pfister et al., 2005), agent-based models incorporating spatial and temporal interactions amongst households (e.g. Heckbert, 2011; Schreinemachers and Berger, 2011), and integrated models linking economic models with biophysical crop, livestock and environmental models (e.g. Antle and Capalbo, 2001; Stoorvogel, Antle and Crissman, 2004).

Antle, Stoorvogel and Valdivia (2014) propose a conceptual framework linking economic simulation models to biophysical models to assess the effects of technology, policy and environmental changes on sustainability. Adequate biophysical and economic data can be a limiting factor in modelling such complex systems, in particular for the representation of out-of-sample counterfactuals in ex-ante analyses. Therefore, the use of parsimonious, population-based simulation methods is described as a way to meet these challenges and represent agricultural system heterogeneity.

The Moorepark Dairy Systems Model (MDSM; Shalloo et al. 2004a), a stochastic budgetary simulation model for dairy production systems, was used to examine the economic benefits of reseeded by simulating the impacts of reseeded different proportions of the farm annually (Shalloo et al., 2011). The MDSM provided a comprehensive framework for integrating the biophysical and economic components of a dairy farm. Results showed that increasing the level of reseeded had a positive impact on profitability, with the highest gain being achieved at the highest milk price. This model has also been applied to assess mitigation strategies for lower carbon dairy production (Lovett et al., 2008), analyse alternative calving patterns on input use, farm output and profitability (Shalloo et al., 2004a), and to compare a pasture-based system of milk production on high rainfall, heavy-clay soil sites with a lower rainfall, free-draining soils system (Shalloo et al., 2004b).

Another example of a simulation model is the Northern Australia Beef Systems Analyser (NABSA) model, which is a whole-farm dynamic simulation model that simulates the response over time of a beef cattle farm operating under a range of development scenarios (Lisson et al., 2010). Ash et al. (2015) used this model to evaluate the impacts of a range of technologies such as genetic improvement in cattle, nutrient supplementation, and alteration of the feed base (i.e. improved pastures and forage crops), across three regions representing different beef production systems in northern Australia. Model results showed that the implementation of individual technologies could significantly improve productivity and profitability, particularly when used in combination.

Ashfield et al. (2014) applied the Grange Dairy Beef Systems Model (GDBSM; Ashfield, Crosson, and Wallace, 2013), a whole farm, single year, static, deterministic simulation model to perform an economic comparison of pasture based dairy calf-to-beef production systems after a wide range of production system options, including animal breed, gender and age at slaughter combinations, were investigated. The GDBSM was modified to analyse the effects of compensatory growth and, hence, the energy demand of beef cattle. Sensitivity analysis showed that these systems were particularly sensitive to beef and concentrate price changes, and less sensitive to

variations in calf and fertiliser prices. Furthermore, there was no benefit in combining systems regarding utilisation of grass grown or net margin¹⁰.

Econometric models

When used for farm-level analysis, econometric methods are applied to statistically represent the farm systems. Single-equation and simultaneous system models that describe input demand and output supply behaviour have been reported in the literature, as well as static and dynamic models (Jones et al., 2017). Early work was based on primal representations and statistical estimation (Mundlak, 1961), but efforts shifted gradually to a dual approach.

While in many cases a quadratic or Cobb Douglas functional form for the production functions is specified (Heady and Dillon, 1964), implying restrictive assumptions on the production technology, later studies highlight more flexible technology representations (e.g. Translog flexible and Generalised Leontief profit/cost functions; Carter, 1984). A ground-breaking study in this area was performed by Just et al. (1983). This study emphasizes that multi-crop farms react to changes in prices or technology by adapting both the intensity of input use per hectare (the intensive margin), as well as the allocation of land to crops (the extensive margin), which is highly pertinent when attempting to model optimal input allocation in multi-crop farms. This finding was a considerable breakthrough in realistic economic modelling of farm systems. However, the study did not consider linkage to biophysical models. As reported by Antle and Capalbo (2001), in their study describing the development of an integrated assessment linking econometric and simulation models, limitations of the econometric approach include the lack of ability to extrapolate results on biophysical processes and economic conditions outside the sample of observed behaviour, or that use systems not represented in the data sample (Jones et al., 2017).

While econometric models can be used for farm-level agricultural policy analysis, it is difficult to sort the interactions into sets of incentives and behaviour (the economic structure needed for the assessment) and changed policy or technology (the effects of a policy measure or technology needed to evaluate change) using this approach (Preckel,

¹⁰ Both MDSM and GDBSM were developed in Ireland.

2002). The main criticisms presented in the literature therefore include their deterministic nature, the associated difficulty of incorporating alternative technological and policy options, the fact that these models are data intensive and, as mentioned, limited in extrapolating responses beyond the estimation sample (Ruben et al., 1998).

Positive Mathematical Programming (PMP)

Bio-economic models can also be modelled following a positive approach (Deybe and Flichman, 1991, Vatn et al., 2006), for instance, using Positive Mathematical Programming (PMP; Howitt, 1995). Positive Mathematical Programming provides a more flexible specification than traditional linear constraints, with the application of econometric techniques to calibrate mathematical programming models precisely to observed activity levels, therefore exploiting the advantages of both mathematical programming and econometric modelling (de Frahan et al., 2007). Accordingly, PMP ensures that the base year model outcomes are calibrated to reflect reality by adding non-linear terms to the objective function, in contrast with the tendency for over-specialisation of LP models (Howitt, 1995; Janssen and van Ittersum, 2007). These models are also free to respond to changes in competitive equilibrium induced by e.g. policy changes (Oñate et al., 2007).

This positive approach has been extensively applied in the area of agriculture and, in particular, in land use policy evaluation, with the objective of formulating policy recommendations. Heckelevi et al. (2012) in their review of PMP based models and respective applications propose three categories of PMP models. The first category corresponds to bio-economic farm models usually including detailed technology description and many different activity variants for producing one output such as The Farm System Simulator Mathematical Programming model (FFSIM-MP; Louhichi et al., 2010). The second group are price exogenous models for aggregate agents, either farm type groups as in *Programación Matemática para el Análisis de Políticas Agrarias* model (PROMAPA; Júdez et al., 2008) and an extension of Common Agricultural Policy Regionalised Impact model by farm type (CAPRI-FT; Gocht and Britz, 2011), or regional models as in CAPRI (Britz and Witzke, 2008) and the Dutch Regionalized Agricultural Model (DRAM; Helming, 2005). Finally, the third strand of models includes two North-American systems which incorporate price endogeneity for outputs, the Canadian Regionalized Agricultural Model (CRAM; Horner et al., 1992)

and the US Regional Environment and Agriculture Programming model (REAP; Johansson et al., 2007), both combining PMP with a spatial equilibrium setup.

While PMP tries to address the limitations of both econometric modelling and mathematical programming, it also has well recognised limitations (de Frahan et al., 2007). For instance, it is not possible to incorporate new technologies to those actually observed for the sample, though several studies attempted to fill this gap (Röhm and Dabbert, 2003; reviewed by Arfini et al., 2016). Furthermore, in studies where only limited data is available, the PMP approach may not be robust enough, resulting in an assessment that may be unreliable (de Frahan et al., 2007). However, this issue can be partially overcome when larger representative datasets are available (e.g. FADN), making PMP more suitable in comparison to other calibration approaches.

Developing an optimising farm-level model for policy analysis

Surveying the body of past research, it appears that mathematical programming techniques have been applied mostly to dairy systems and, to a lesser extent, beef production systems. In addition, the majority of these systems models (both mathematical programming and simulation models) are typically designed to either model hypothetical or representative farm types (e.g. Wallace and Moss, 2002; Shalloo et al., 2004a,b; Crosson et al., 2006). There are remarkable examples such as the MIDAS model (Pannell, 1999), the FSSIM model (Louhichi et al., 2010) and the CAPRI-FT model (Gocht and Britz, 2011). However, these models are defined by a combination of variables that deliver a geographical and biophysical representation of farms (e.g. farm size, production system, stocking rates) to particularly assess grouped farms with similar characteristics in given areas. Examples of Scottish studies using mathematical programming, more specifically LP, on individual farms include Vosough Ahmad et al. (2015) and Shrestha et al. (2018a,b). Individual farm modelling presents advantages over the representative farm approach, as it can better describe the heterogeneity among farms, providing the most possible disaggregation in terms of farms and activities, and reducing aggregation bias in response to policy and market signals (Richardson, Hennessy and O'Donoghue, 2014; Gocht et al., 2017).

To date, none of the studies presented in the literature estimated the impacts of agricultural technological innovations on Scottish beef and sheep farms under different

policy scenarios, using a whole-farm system approach. The integration of economic criteria and biophysical processes offers important opportunities, including the assessment of the trade-offs associated with different technological options and the identification of incentives to make their adoption feasible. To adequately test the implementation of innovations at farm-level, the modelling approach selected needs to be able to integrate findings from several disciplines such as economics, farm management, grassland science, animal genetics and nutrition, etc., to draw conclusions about the further profitability and productivity gains that can be achieved from alternative modelling scenarios.

In the context of this thesis, a farm systems model that has the potential to express farm-level economic performance, farm management practices, fluctuations in grass availability, animal dynamics and resulting nutritional demand, therefore offering farm management recommendations, is needed. Furthermore, in the light of current market and policy uncertainties, the challenge is to optimise the use of farm resources and to identify the best combination of alternative management strategies. A bio-economic LP based optimisation model offers the potential to identify optimal systems, being selected as the most appropriate modelling system to capture the impacts of alternative technologies, management practices and policy measures at the farm level, in order to relate financial outcomes to biophysical processes across the range of heterogeneous Scottish beef and sheep farms. A form of cost–benefit analysis, through valuation of inputs and outputs, can then be used to estimate the minimum conditions for technology change (e.g. profit), which can be applied to inform policy analysis at a wider national-level.

The bio-economic modelling framework proposed in this chapter requires accurate description not only of the beef and sheep production systems, but also of the technological improvements considered. Accordingly, a consideration of the suitability – or ‘adoptability’ - of specific technologies that have been suggested for Scottish beef production systems is the focus of the following section.

2.4. Selection of agricultural innovations

Farmers are faced with complex choices: there is a wide array of available technologies and they must deal not only with the uncertainties of their effects, but also with the policy and market context (OECD, 2004, 2013). Thus, farmers need innovations that will help improve efficiency and provide competitive edge while simultaneously producing environmental and social benefits, a process that needs to be continuous (Läpple et al., 2015). In the current policy context of the reconfiguration of UK agricultural policy following ‘Brexit’, sustainable production combining increased productivity with environmental improvement is likely to be a policy goal (Bateman and Balmford, 2018; Defra, 2018a). The recent report entitled ‘Beef 2020’ (Scottish Government, 2014) has also emphasized the key role of innovation in supporting a more sustainable and productive beef sector in Scotland. Different kinds of technological improvements focus on different areas of animal production such as animal feeding, health and breeding, among others. A few examples of the reviewed innovations that could be targeted to promote ‘sustainable intensification’ relatively easily in Scottish beef farms, and their relevance for these farm systems will be further discussed in this section, following Dicks et al. (2018). The aim was to identify technologies that were considered feasible, commercially viable, with clear environmental or social benefits, and with the potential to increase productivity or profitability in these farm systems. These specific technologies were also selected taking into account the current policy context and potential requirements to comply with future legislation.

2.4.1. Grassland management

Grazed grass has been reported in the literature as the largest proportional constituent of the ruminant feed budget, regardless of farm system or business (O’Donovan and Kennedy, 2007; Drennan and McGee, 2009; Keady, Hanrahan and Flanagan, 2009). Grass is therefore one of the most important resources for all ruminant systems, providing the most economic feed throughout the year, either as grazing or conserved forage (Finneran et al., 2010). In fact, according to Shalloo (2009), the quantity of herbage harvested per hectare (i.e. the variation in herbage utilisation) can describe about 44% of the variation in total profit per hectare. Grass and rough grazing make up almost 80% of Scotland’s agricultural area, it is essential that this resource be fully utilised (Scottish Government, 2018d).

Several studies have emphasized the need for optimising feed sources to improve farm profits (O'Kiely et al., 1997; Shalloo et al., 2004a, 2011). In particular, Ramsey et al. (2005) described an inverse relationship between feed cost and farm profitability on beef rearing farms in the US. McCall and Clark (1999) using data from dairy farms in the US and New Zealand reported similar findings. As feed costs consist of such a large share of total variable costs, it is clear that judicious management of feed costs can have a significant effect on the profitability and sustainability of ruminant production systems (Finneran et al., 2010).

The main goal of grass-based systems is to achieve a balance between the supply of feed and feed demand, at the lowest cost. This guarantees that the farm system can handle both input and output price volatility by reducing bought-in inputs and at the same time still return a profit. Increasing the quantity of grass produced when demand exceeds supply reduces reliance on bought-in feed. As feed is subject to substantial price volatility, the purchase of feed exposes the farm to risk. Reducing exposure to this form of volatility, by increasing grassland productivity and reducing concentrate feed requirement, can increase the resilience of the farm business (Shalloo et al., 2011), particularly in this period of 'unique unknowns'. Resilient farm systems have the capacity to absorb shocks and maintain essential function and outcomes within changing and uncertain production contexts. To this end, technological solutions that can improve grassland productivity are likely to add significant value to grass-based production systems, in particular, if associated with improved cattle performance (Shalloo et al., 2018). These should deliver real benefits in terms of profitability, sustainability and resilience by reducing costs, increasing efficiencies and adding value to products.

Within this context, reseeding is a significant part of grassland management on any farm, being important for maintaining productive grassland (AHDB, 2017). Studies have reported that increasing the proportion of the farm reseeded annually increases the amount of grass grown and utilised as feed, resulting in increased farm net profit (Creighton et al. 2011a; Shalloo et al., 2011). Particularly, newly reseeded swards can produce an extra three to five tonnes of dry matter (DM) per hectare (Creighton et al. 2011b), which can help boost profits. Thus, reseeding pasture can improve yield and quality, leading to higher farm output and reducing bought-in feed requirements.

However, the cost of the reseeding method employed should also be considered. A full reseed is not always a practical option, for instance, due to cash flow constraints, stony land that may be difficult to cultivate, or the fact that fields may need to be taken out of production. ‘Overseeding’ can then be regarded as a cost-effective alternative, involving around half the financial costs of a full reseed, but still being able to improve pasture productivity (by 30% to 40%, depending on pasture quality), and potentially prolong the life of a ley (SAC, 2015, 2017; AHDB, 2017). Opting to ‘overseed’ some pastures, rather than carrying out a full reseed, can thus help beef farmers minimise production costs, while still improving the production of the cheapest feed for ruminants, that is, well-managed grass.

2.4.2. Herd health, welfare and animal biosecurity plans

Failures to reach or maintain good levels of health amongst farm animals can cause the industry significant costs, as recently verified by BSE and Foot and Mouth Disease outbreaks in the UK (Islam et al., 2013a). The targeting of the causes of animal health problems – rather than treatment of symptoms - through preventive measures and improved planning and management practices may improve the health status and enhance the productivity and animal welfare of herds at both the farm and, if adopted by sufficient farmers, sector level, although to an extent this depends on what happens in England, the neighbouring country.

Since 2005/06 the Scottish Government has offered support to improve the adoption rate of animal health planning in Scotland, including the development of an online health planning system – the Scottish ‘Sheep and Suckler Cow Animal Health Planning System (SAHPS)’. This web-based health system allows farmers and veterinarians to manage flock/herd health and production in real time (SRUC, 2012). Over 2,000 farm holdings registered on the SAHPS during 2013/2014 (SRUC, 2014). Additionally, some companies offer health-planning services; however, the adoption of all these systems is relatively low. As reported by Islam et al. (2013a), one reason for this is a certain lack of clarity about the purpose and specific definition of health planning. Other problems include the absence of coordination and collective action amongst stakeholders, the complexity of existing planning systems and the lack of reliable data on farm animal health/disease and production performance. Thus, an improvement across these areas should facilitate adoption; however, it may well be that for many

farmers the rational decision is not to adopt, as the benefit-to-cost ratio may be quite low. This is an area that has been insufficiently addressed in the literature on herd health management.

One study that does address potential benefits more directly (Boden et al., 2015) conducted a scenario planning exercise that showed the potential for technological innovation to enhance efficiency through better animal health data sharing, which can improve a farmer's capacity to evaluate risks and prevent, detect and control animal disease. Furthermore, greater industry self-sufficiency, through incentives to improve farm health management and biosecurity, is important to improve long-term farming resilience to shocks such as major disease outbreaks. From this perspective, in a hypothetical scenario¹¹ where the livestock sector is not a priority for the government, regulation is low and technological R&D has stagnated, there would be a high likelihood of disease incursion, as suggested by the existing evidence from many developing countries (Roth et al., 2003; Zinsstag et al., 2009). Incursion – the rapid and sudden spread of disease – often results from poor veterinary infrastructure, lack of resources for animal surveillance and limited financial support for on-farm biosecurity and other health measures (Zinsstag et al. 2009; Narrod et al., 2012).

Animal health is therefore also subject to market failures and there is a role for the government to intervene in their correction, e.g. by providing goods and services, establishing and monitoring regulations, and through taxes and subsidy support (Rushton and Leonard, 2009; Bennett, 2012). Additionally, other policies relating to education and infrastructure are also important measures for livestock disease prevention, control and eradication. Reliable data and information on the sector will help identify the significance of different measures, and the areas where more government action is required to improve the profitability and sustainability of the beef industry. Within this context, the Scottish Government has been supporting an industry-led scheme aiming to eradicate Bovine Viral Diarrhoea (BVD) from Scotland. Bovine Viral Diarrhoea has been, and remains, a cause of significant economic loss to cattle farmers across the world. In breeding herds, the key aspects of Bovine Viral Diarrhoea virus (BVDV) epidemics are reproductive impairment and reproductive failure.

¹¹ This scenario was defined as the 'Opportunist' scenario in the Boden et al. (2015) study.

Barbudo, Gunn and Stott (2008) modelled these reproductive aspects based on a survey of reproductive performance and management in commercial Scottish beef suckler (cow-calf) herds. This study has confirmed that hidden losses due to impacts of BVDV on reproduction, though highly variable, are likely to be significant, perhaps doubling previous estimates of the total costs of BVD in these herds. Furthermore, disease impacts were also masked by long breeding seasons, which suggests that the continued presence of BVDV in Scotland could prevent programmes of sustainable intensification (aiming to improve the efficiency of beef production while reducing the environmental impact) from succeeding (Stott and Gunn, 2017). Thus, studies assessing the financial benefits and costs of BVD prevention in Scottish beef farms can provide important considerations to help reduce the incidence of this disease.

2.4.3. Electronic Identification (EID)

Proposals for introducing bovine electronic identification (EID) within the EU are currently progressing, hence justifying the need to estimate its economic impact at farm-level. Animals are individually identified with a microchip in either ceramic bolus, ear or pastern tags, enabling individual performance measurement. By the use of an EID system, the efficiency of data recording and sharing can be improved, as the system accelerates and simplifies data collection and transmission, contributing significantly to improved management of the herd (e.g. immediate access to animal data that can help with management decisions; AHDB, 2015).

However, the lack of popularity of the compulsory sheep EID scheme, implemented in 2010 in the UK sheep industry for breeding animals over 12 months old of age¹², appears to have discouraged voluntary adoption of cattle EID, and there is a widespread belief that cattle EID is an extra layer of bureaucracy with no benefits for the farmer. Similarly, several other factors appear to deter Scottish farmers from investing in EID, including the lack of association between cattle EID and positive economic returns (e.g. profit that can be made through healthier stock) or labour saving opportunities, and the perception that existing technology is not ‘future proof’ (Duckett, 2014).

¹² For younger slaughter animals, regulations vary between Scotland and the rest of the UK.

According to Kyle, Duckett and Sutherland (2017), the low adoption rates of cattle EID in Scotland could be improved by addressing farmers' concerns about the increasing complexity of information demands associated with cattle (e.g. statutory requirements) and the significant administrative burden this brings to farms. New information demands could be incorporated into systems that are already in place to balance the existing and growing information demands made on farmers. Additionally, measures could be taken to reassure farmers that early adoption will not be a wasted investment. Finally - and following the discussion of herd health management above - messages emphasizing the benefits and epidemiological objectives of EID could be reinforced (Duckett, 2014).

2.4.4. Genetic improvement

Historically, the uptake of breeding technologies by beef cattle producers in the UK has been reported as slow and variable (Bruce, 2012). These low adoption rates suggest either that the technique is less attractive to beef producers (than, e.g. dairy producers) or that there is a failure by farmers to fully grasp the potential benefits of metrics such as Estimated Breeding Values (EBVs). It has been argued that this is not only damaging the competitiveness of the beef industry, but also its sustainability (Islam et al., 2013b). A detailed cost-benefit analysis for the UK beef and sheep genetic improvement industries (Amer et al., 2007) found significant returns from beef industry genetic progress up until 2006/2007, with a Net Present Value of £23 million resulting from 10 years of genetic improvement. A recent report provided an update of these results (Amer et al., 2015): by applying new and more recent genetic trend information, it was shown that genetic progress continues to deliver significant benefits to the beef industry in the UK. There are some traits which are always likely to be important as they are fundamental to animal productivity, and hence to the profitability of the farm (e.g. selection for efficiency and growth). However, caution among farmers may be warranted, as rates of genetic progress are now dominated by progress in growth and carcass traits, which in turn, have a negative effect on the genetic merit of suckler cows for maternal production efficiency.

As well as an improved carcass, selective breeding also has the potential to improve other product qualities including animal health and welfare and to reduce GHG emissions (Simm, 2009; Wall, 2011). In relation to the latter, EBVs score animals'

genetic merit on certain selection traits; conventionally these have been production-based, but in the future EBVs could also reflect GHG intensity per litre - an innovation that would have increasing relevance to the industry if the Scottish Government were to continue to pursue 'green' policies. Given the importance of genetic improvement for the sustainability of the beef herd, it would be useful to explicitly explore the production and financial implications of selective breeding among these farm systems.

The adoption of EBVs in selective breeding programmes is increasing in Scotland. However, there is concern that this adoption has been slower in the beef and sheep sectors when compared to dairy, pig and poultry sectors (Simm, 2009; Vipond, 2010). Such concerns have generated studies that have addressed 'barriers' to the uptake of EBVs on beef farms. Borthwick et al. (2014) found that beef farmers tended to have a negative perception of EBVs, place a greater emphasis on prize-winning animals and the 'showmanship' aspects of farming, in addition to negative perceptions of trait recording and their potential benefits for small herds. As discussed earlier, there have also been some negative developments arising from existing breeding programmes. Many of the barriers to the adoption of EBVs in beef cattle appear to be associated with the increased management burden - or at least the perception of increased burden - that artificial insemination and EBV recording bring to the farmer.

Even though adoption of EBVs has been slower in the beef sector, those involved in EBV development and promotion believe that its uptake is on the increase (Islam et al., 2013b). Commercial beef farmers for beef-bull selection are increasingly using EBVs and there is potential to expand the pool of data if more information is gathered from these herds. In light of this, the Scottish Beef Efficiency Scheme (SBES)¹³ has recently encouraged producers to collect genetic and herd management information to develop a national integrated livestock breeding database to inform future breeding decisions.

¹³ The Beef Efficiency Scheme is a five-year climate change scheme that aims to help Scottish beef breeders improve the efficiency, sustainability and quality of their beef herd, by increasing the genetic value from 2016 and reducing greenhouse gas emissions. Recognising the additional work involved in collecting and entering data, the Scottish Government provides a payment equivalent to £32 per calf each year for the first three years to each farmer, which is done on an area basis. Farmers also receive free advisory service to assist them (Scottish Government, 2017d).

A variety of complementary advances may also encourage adoption: trialling of video image analysis (VIA), improved traceability through the use of EID tags, refinements in data handling systems and a positive shift in attitudes of breed societies towards EBVs (Islam et al., 2013b). However, it is worth noting that a reluctance to adopt may in part be connected with some of the value added, ‘natural’ aspects of production – something that allows the Scottish beef industry to differentiate its products in the global marketplace.

In the following section, an outline of the conceptual framework is presented describing the specific components of the integrated approach developed to meet the objectives previously set out. This overarching conceptual framework provides an integrated assessment of Scottish beef production systems, which links a behavioural segmentation model focusing on characteristics and determinants of farming to a farm-level model incorporating the discussed innovations and policy context. While farm-level analysis of Scottish beef production systems under different policy scenarios has been performed in the past, no such analysis has been conducted using a similar approach.

2.5. Towards a Conceptual Framework

Here a conceptual framework is developed to support the integrated analysis of Scottish beef production systems with a particular emphasis on the impacts of changing farm management technologies/practices on farm-level outcomes and profitability under an evolving policy context. An important aspect of this framework is that actual farms are modelled, meaning that the response to alternative policy scenarios is scalable to be representative of the national beef sector, thus making it more appropriate for ex-ante policy assessment. Furthermore, this conceptual modelling approach takes account of the inherent heterogeneity of Scottish beef production systems, including farmers’ underlying objectives and attitudes, which lead to different farming styles.

A number of models are specified in the following three analytic chapters. Each chapter contributes to the development of the integrated approach, which links information (farmers’ intentions, farm characteristics, technological interventions and policy context) to explore the response of farms to change. Combining and interpreting

knowledge from diverse scientific domains will provide a better understanding of these production systems.

Chapter 3 analyses the relationship between farmers' segmentation classes and their related physical, financial and managerial characteristics, testing the segmentation concept. In this chapter, a latent class analysis is applied to the sample of Scottish beef and sheep farmers. The latent class model developed is then linked to FBS information for the same sample of farms and a detailed description of each class of farmers is delivered. Identifying the characteristics of each farmers' class is essential to predict more accurately the effects of different technologies and policy initiatives on these systems, and the ways in which adoption might be more effectively supported, therefore enhancing policy design and delivery.

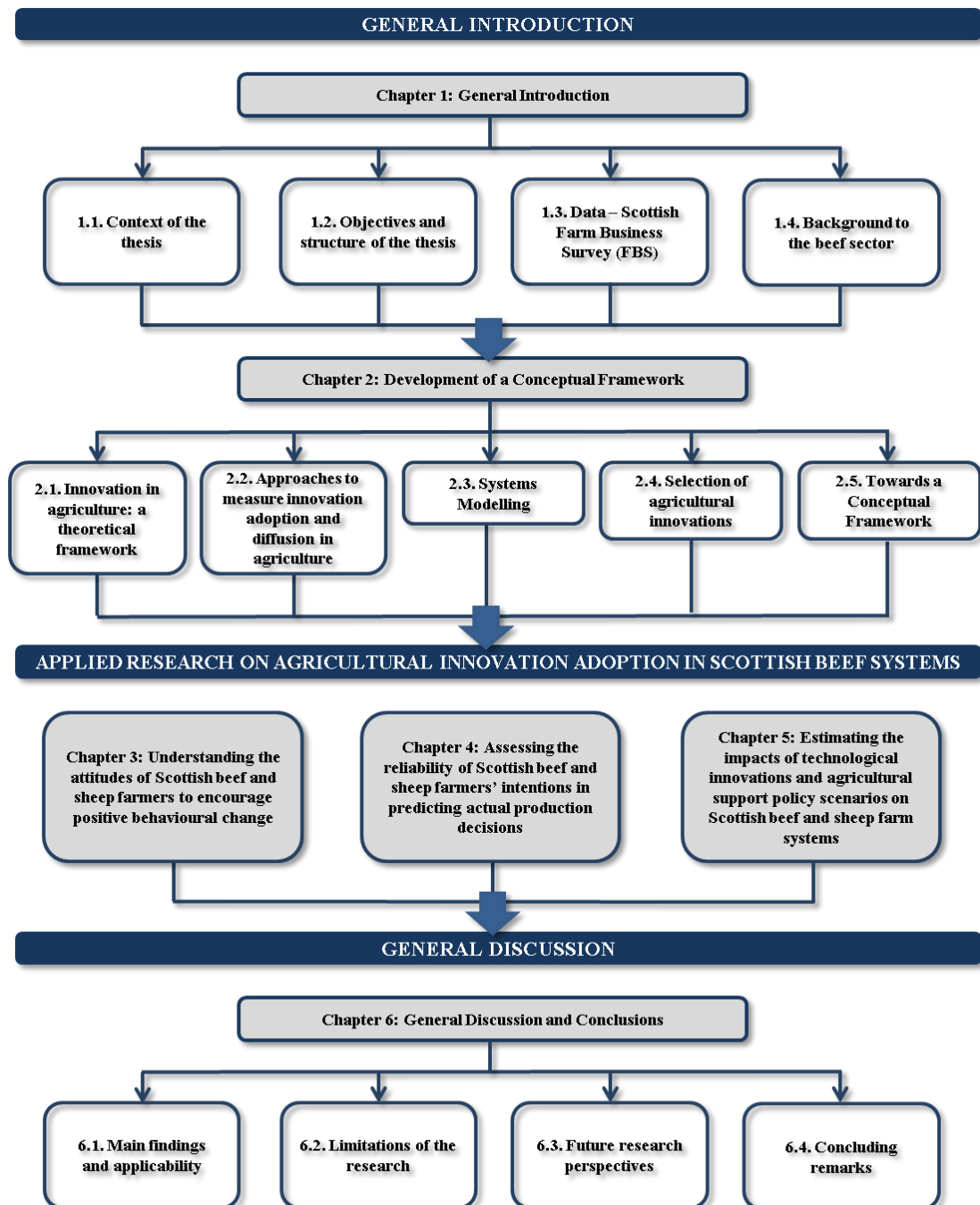
Chapter 4 assesses the reliability of Scottish beef and sheep farmers' intentions with respect to their primary objectives for the business. A comparison between farmers' intentions and actual behaviour is performed using FBS farm data to record their actual financial position and performance. Two multinomial logit models are estimated to assess the main factors behind farmers' intentions and behaviour, and to explain a potential intention–realisation gap at the individual farm-level. Recommendations on the use of intentions surveys to analyse the agricultural sector are also provided.

In Chapter 5, a farm-level analysis of the impacts of alternative technological innovations and agricultural support policy scenarios is performed taking account of farm variability. By including farm variability, all the physical and financial characteristics, and interactions between different activities of the farm systems can be used to estimate the effects of these scenarios. This chapter draws directly on previous work into segmentation analysis (presented in Chapter 3) and tests farm vulnerability and resilience using a farm-level bio-economic model, ScotFarm.

The final chapter provides a general discussion of the work developed in this thesis, integrating information to address how a movement towards innovation can be facilitated in Scottish beef and sheep systems. This chapter also discusses the limitations of the study and further research perspectives. The key components of the

integrated approach developed in this thesis are represented in the schematic diagram (Figure 2.2) below.

Figure 2.2. Schematic diagram of the thesis.



3. Chapter 3: Understanding the attitudes of Scottish beef and sheep farmers to encourage positive behavioural change

3.1. Introduction

In the UK, from Gasson's seminal 1973 work on the 'goals and values' of farmers onwards, it has been argued that improving our understanding of what drives farmer behaviour – how they choose to produce – is essential for the design of effective agricultural policies. The subject has been widely studied, from both sociological and economic perspectives; understandably, the focus of the former has been on attitudes, subjective norms and intentions (Garforth and Rehman, 2006); whereas in the latter, individualistic profit seeking or risk aversion motivations predominate (Burton and Wilson, 2006).

One of main motivating factors behind this type of research is illustrated by Perkin and Rehman (1994), who showed that personal, family and farm business objectives are inter-dependent. A number of authors (Brandth and Haugen, 2011; Defra, 2011; Moon and Cocklin, 2011) have argued that behaviour can act as a constraint to change – certain farmers have behaviours that are seen to be a barrier to the wider adoption of some form of desired farm practice or new technology. Taking a logical step from this, Dwyer and Blackstock (2007) explore how policy advice could be delivered to alter farmer behaviour to 'encourage and enable long-term positive behavioural change'. More generally, policy makers in the UK have sought to be better informed about farmer objectives and behaviours, with several studies bringing together available theoretical and applied evidence (Defra, 2008, 2011; Barnes et al., 2010). As Morris et al. (2000) argue, this type of approach should enable more targeted policy delivery and hence more efficient outcomes from policy mechanisms, a relevant topic in the context of this thesis.

Variation in farmer actions (e.g. technology adoption), behaviours (e.g. profit seeking), characteristics (e.g. education level), and many other dimensions (e.g. preferences) are possible drivers for differences in farm physical and economic performance. The analysis of the physical, financial and managerial characteristics (e.g. debt levels, reliance on subsidy, succession planning) associated with each segment presents

potential areas for policy development, not only in promoting awareness and understanding, but also by providing more cost-effective strategies for tailoring policies to meet the objectives of different groups (Barnes et al., 2010; Blackstock et al., 2010). Identifying the characteristics of each segment is also important to predict more accurately the uptake of policy initiatives and the ways to effectively encourage further uptake, hence preventing the development and implementation of policies that drive unwanted ('perverse') outcomes (Moon and Cocklin, 2011; Wilson et al., 2013).

There is strong evidence from the literature, from different countries, that distinct farmer behavioural segments exist and are useful from a policy perspective (e.g. Karali et al., 2013; Daloglu et al., 2014; Weltin et al., 2017). There has also been an increasing recognition at the policy level that to be more effective, advice and information should be adapted to reflect the differences between these segments (Cummins and Gurjeet, 2007; Defra, 2008a). This is particularly important where the objective is to *change* farmer behaviour directly, rather than the more traditional approach – such as under the CAP – where the policy mechanism has been to encourage behavioural change indirectly, through mechanisms such as price support or production of input quotas (see Chapter 1, Section 1.4.2.). Much debate in this area has centred around the concept of 'sustainable intensification': originally conceived in the context of developing country agriculture (Pretty, 1997; Reardon et al., 1999), sustainable intensification - the idea that agriculture should produce more food per hectare, less pollution and more environmental and wider societal benefits - has received considerable attention recently, both in the literature (Dicks et al., 2018; Firbank et al., 2018) and in government (Defra, 2018b).

Sustainable intensification suggests that through technology adoption and appropriate management, agricultural systems can be managed more intensively to increase production and at the same time minimise negative impacts (e.g. reducing GHG emissions per unit of agricultural output). Communication with farmers on how to move towards sustainable intensification – for example, through the adoption of innovative practices and technologies identified by Dicks et al. (2018), as discussed in Chapter 2 (Section 2.4.) – will be facilitated by a better understanding of different farming styles, and potentially lead to 'win-win' - 'profit-environment' scenarios that are very much of interest to policy making (Foley et al., 2005). As rural economic and land use policy

becomes less centred on production and productivity, it is important that policy analysis is informed by models reflecting the range of factors affecting farmers' decisions (Wilson, 2014).

In this chapter, a segmentation model is developed based on the role of objectives and attitudes in the decision-making process of farmers operating in Scotland. Scotland is an example of a developed country with several targets for agriculture, and where the policy framework presents some of the most ambitious targets in the World (e.g. GHG emission reduction targets¹⁴; Barnes et al., 2015). However, as detailed in Chapter 1 (Section 1.4.1.), in Scotland, agricultural possibilities are also widely understood to be severely limited by the biophysical environment (e.g. climate, topography and soils) and, in some areas, by geographical remoteness from input and output markets compared to other parts of the UK. These permanent disadvantages are formally recognised to the extent that around 85% of Scottish agricultural land (and 64% of agricultural holdings) has LFA status. Of this, 98% is classified as Severely Disadvantaged Areas (SDAs). This contrasts, for instance, with England where only 17% of the total farmed area is classified LFA (Defra, 2008b). Scotland is therefore a model example of a European region where farming conditions are challenging. Further challenges are expected as a result of the 2016 UK referendum on EU membership (i.e. 'Brexit'), and its implications for UK rural and farm development policy, including the effects of changes in tariffs and trade on agricultural outputs, as emphasized in the review of the agricultural policy context in Chapter 1.

Previous segmentation analysis has been conducted to understand Scottish dairy farmers' motivations for undertaking specific farming practices and the differences between different farmer segments (Barnes et al., 2009, 2013; Barnes and Toma, 2012). Similar approaches have been used to characterise Scottish beef and sheep farmers' perceptions of climate change (Hyland et al., 2015). However, to date, analysis of whether Scottish beef and sheep farmers' behaviours can be captured as different segments; and if so, whether these behaviours are associated with different economic indicators, particularly performance indicators, has not been tested. In order to fill this

¹⁴ The Climate Change (Scotland) Act 2009 established targets to reduce Scotland's emissions of GHG by at least 42% by 2020, and 80% by 2050 (Scottish Government, 2018f).

knowledge gap, a novel methodology was developed linking Latent Class Analysis (LCA) to a long-running British longitudinal survey, the FBS. Initial work in Chapter 1 involved building a profile of Scottish beef production systems; this took account of the evolving policy context, using official data to inform the analysis performed in this chapter. An advantage of the FBS dataset is that it is representative of the national population of farms in Scotland. Accordingly, the aim of the work in this chapter was twofold. First, an assessment of whether Scottish beef and sheep farmers can be categorised into specific classes or ‘segments’ is performed, and the underlying drivers that define these segments are identified. Both production and environmentally related drivers were considered. Second, the relationship between farmers’ segmentation classes and a collection of farm physical, financial and managerial characteristics was analysed. The main objective, following other authors, is to provide information that will enhance policy design and delivery, as proposed in Chapter 1.

3.2. Materials and Methods

3.2.1. Conceptual framework and data collection

The methodology used in this chapter drew on previous work into segmentation analysis. Using both the Defra Farm Segmentation template (see Defra, 2008a, 2011) and Schwartz’s (1992; 1996) ‘circumplex’ structure of intrinsic and extrinsic values, objective and attitude statements were developed by a team of experts operating within Scotland’s Rural College (SRUC) to capture farmers’ decision-making in relation to both ‘economic’ and ‘environmental’ aspects of farming in Scotland. The resulting farmers’ intentions survey was administered as a module to the Scottish FBS for the 2012/13 accounting year. This study draws on this dataset, focusing on the sample of Scottish beef and sheep farmers surveyed.

Farmers were first asked to rank four objectives for their business using a ‘1 to 4 Likert type scale’ of importance, with ‘1’ being the least important and ‘4’ the most important; farmers’ attitudes were then measured across a standard ‘4-point Likert type scale’ (‘strongly disagree’ to ‘strongly agree’, Table 3.1). ‘Objectives’ related to the results farmers would like to achieve through their decisions, whereas ‘attitudes’ denoted an overall evaluation of some aspect of the farmer’s decision-making – for example, the importance of keeping up-to-date with new farming methods (Zanna and Rempel, 1988;

Hodge, 2006). While there is some debate on the advantages and disadvantages of using this approach (Manstead and Semin, 2001, McIver and Carmines, 2003), it provides an efficient framework for assessing a consistent set of socio-psychological variables, prompting respondents to make a choice as there is no neutral option (Cross, 2005; Barnes et al., 2011c). The next sections describe the methods employed to identify the distinct classes or ‘segments’ of farmers and their associated characteristics.

Table 3.1. Farmers’ objectives and attitudes towards both economic and environmental aspects of farming in Scotland – questionnaire items of the farmers’ intentions survey developed by a team of experts operating within Scotland’s Rural College (SRUC).

	Statements	Measurement scales
Objectives	Maintain your way of life	Standard 4-point Likert type scale of importance (‘not important’ to ‘very important’)
	Enhance the environment	
	Increase the size of the business	
	Maximise annual profits	
Attitudes	To farm successfully it is important for me to keep up-to-date with new farming methods	Standard 4-point Likert type scale of agreement (‘strongly disagree’ to ‘strongly agree’)
	It is important for me to try new varieties or breeds (crops/stock)	
	It is important for me to monitor farm production levels	
	It is important to make best use of my farm’s resources	
	It is important to me to keep debt as low as possible	
	It is important for me to leave the land as good as, or better than, I received it	
	Encouraging wildlife, planting trees and protecting the water supply is important to me	
	It is important to me to pass on the farm to a member of family	

3.2.2. Latent class analysis

Latent Class Analysis (LCA) was applied to estimate membership of different segments or ‘classes’ (Lazarsfeld, 1950; Lazarsfeld and Henry, 1968) based on the farmers’ objectives and attitudes above. The central assumption of the latent class model is that different and distinct classes of farmers exist and that respondents in each class share homogenous characteristics, but characteristics of respondents differ between classes (Zhang et al., 2016; Daxini et al., 2019). LCA employs a ‘mixture model’ that assumes that an underlying unobserved categorical variable distributes a population into mutually exclusive and exhaustive ‘latent’ classes (Goodman, 1974; Collins and Lanza, 2010). Thus, LCA is able to identify the underlying structure of the data to predict the probability that each observation will belong to a specific class (McLachlan and Peel,

2000; Fraley and Raftery, 2002). As a result, the choice of appropriate number of classes among a population for a given criteria of characteristics relies on robust estimation algorithms and therefore, unlike cluster analysis, the choice of cluster criteria is less arbitrary (Morey et al., 2008; Rhead et al., 2018). More specifically, LCA offers a model based clustering approach that derives clusters using a probabilistic model describing the distribution of data, whereas cluster analysis finds clusters using an arbitrarily chosen distance measure based on e.g. nearest neighbours, density or hierarchy to determine the specific class of an observation.

The latent class model calculates the observed joint distribution of the manifest variables as the weighted sum of a finite number, R , of constituent cross-classification tables (Linzer and Lewis, 2011). R is fixed a priori according to theoretical reasons or model fit, but more classes can be iteratively fitted to the model to minimise either the Akaike Information Criterion (AIC; Akaike, 1974) or the Bayesian Information Criterion (BIC; Schwartz, 1978). Following Linzer and Lewis (2011), the mathematical model for LCA can be expressed as follows. Let π_{jrk} represent the class-conditional probability that an observation in class $r = 1, \dots, R$ produces the k th outcome on the J th variable. Within each class, for each manifest variable, the sum of all outcomes for each manifest variable is therefore equal to one. Furthermore, let p_r symbolize the prior probabilities of latent class membership, representing the unconditional probability that an individual will belong to each class before considering the responses provided by Y_{ijk} on the manifest variables.

The probability of an individual i in class r delivering a specific set of J outcomes on the manifest variables, assuming conditional independence of the outcomes Y given class memberships, is the following product:

$$f(Y_i; \pi_r) = \prod_{j=1}^J \prod_{k=1}^{K_j} (\pi_{jrk})^{Y_{ijk}} \quad (3.1)$$

The probability density function across all classes consists of the weighted sum:

$$P(Y_i | \pi, p) = \sum_{r=1}^R p_r \prod_{j=1}^J \prod_{k=1}^{K_j} (\pi_{jrk})^{Y_{ijk}} \quad (3.2)$$

The parameters calculated by the latent class model are p_r and π_{jrk} . The posterior probability that each individual belongs to a particular class, conditional on the

observed values of the manifest variables, can be estimated applying Bayes' formula, with $\hat{p}_r$ and $\hat{\pi}_{jrk}$ being estimates of p_r and π_{jrk} :

$$\hat{P}(r_i|Y_i) = \frac{\hat{p}_r f(Y_i; \hat{\pi}_r)}{\sum_{q=1}^R \hat{p}_q f(Y_i; \hat{\pi}_q)} \quad (3.3)$$

Where $r_i \in \{1, \dots, R\}$.

The latent classes were determined using the poLCA package (Linzer and Lewis, 2011) within the Cran R framework; poLCA estimates the parameters of the latent class model through the expectation-maximum (EM) algorithm. The natural logarithm of the likelihood function is maximised assuming at first one class, then two classes, then three classes, etc., to assess whether each additional class increases the explanatory power of the model. Starting values need to be produced to avoid local maxima. Accordingly, latent class models should be run several times to create stability within the log-likelihood function, with these values being used as the basis for providing probabilities of the latent classes.

A model selection approach was used to estimate the number of latent classes. The fit of four latent class models, expressing a one-, two-, three-, and four-class solution, was compared. Each model was run ten times. The most parsimonious model was then run with a repetition of ten estimates to set starting values (through minimising log-likelihood) and then iterated 3000 times. Model fit was measured with the AIC and BIC scores.

AIC is a method based on in-sample fit to evaluate the likelihood of a model to predict/estimate the future values. A good model is one that presents minimum AIC among all other models. The BIC can also be used for model selection; this assesses the trade-off between model fit and the complexity of the model. A lower AIC and/or BIC value suggests a better fit. The following equations evaluate the AIC and BIC (Akaike, 1974; Stone, 1979) of a model:

$$AIC = -2 \times \ln(L) + 2 \times k \quad (3.4)$$

$$BIC = -2 \times \ln(L) + 2 \times \ln(N) \times k \quad (3.5)$$

Where L is the value of the likelihood, N is the number of recorded measurements, and k is the number of estimated parameters.

3.2.3. Financial and physical data analysis

Physical and financial data from the Scottish FBS returns for the 2012/13 accounting year were used as the main source of data associated with the behavioural segmentation model developed. Within the original databases, only systems producing beef cattle classified according to the FBS farm types were selected. In Scotland, some farms specialise in either cattle or sheep production, but many farms keep both, as detailed in Chapter 1. The sample size was set at 213 FBS co-operators distributed across Scotland. The farm types and sample framework coverage were set as: LFA beef (45.5%), LFA cattle and sheep (26.3%), mixed (21.1%) and lowland farms (7%).

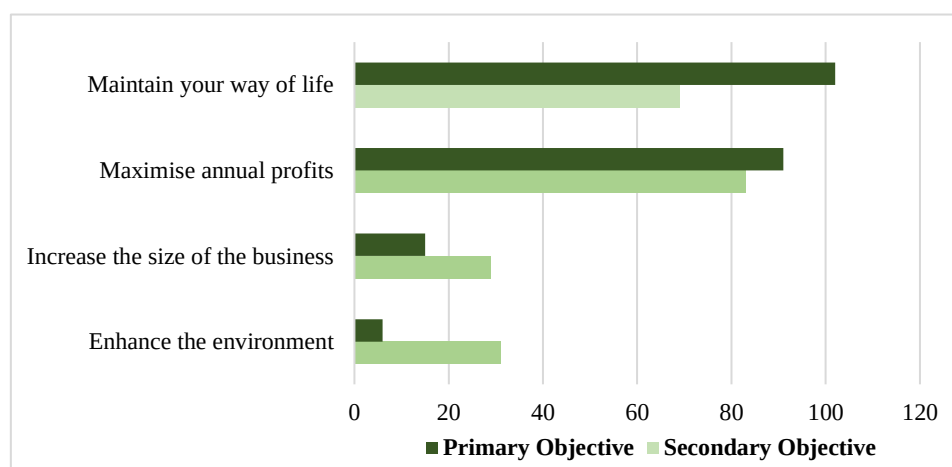
After identifying the segmentation classes, a series of descriptive and statistical tests (ANOVAs; Chi-square) was performed with the level of significance set at 90% to examine differences across class membership. For normally distributed continuous data (e.g. data on farmer age) an ANOVA test was undertaken and post-hoc comparisons were made using the Tukey procedure. For non-continuous or categorical data (e.g. farm type groups) a Chi-Square test was performed. Using the overall sample as reference, average results were produced for the dataset of 213 farms and for each segmentation class to provide comparative data across classes. A similar methodological approach using Defra's behavioural segmentation template (Defra, 2008, 2011) has been previously applied by Wilson et al. (2013) to a sample of FBS co-operators in England.

3.3. Results

3.3.1. Farmers' objectives

The importance of the four objectives in relation to each other, ranked by the farmers, is shown in Figure 3.1. The results suggest that maintaining their way of life is the Scottish beef and sheep farmers' most important objective (47.9%), followed by maximising annual profits (42.3%), increasing the size of the business (7%) and enhancing the environment (2.8%). Secondary objectives followed a similar pattern; however, farmers considered enhancing the environment (14.6%) more important than increasing the size of the business (13.6%).

Figure 3.1. Objectives of the farmer by most important (primary) and secondary important (secondary) objectives, frequency of response – All sample.



3.3.2. Agreement with attitude statements

Table 3.2 shows farmers' attitudes towards statements developed earlier. Overall, on the agreement side (considering the two points of the scale 'agree' and 'strongly agree' added together) most of the farmers agreed with the majority of statements. Lower levels of agreement were found for the importance of trying new varieties or breeds (crops/stock; 54.5%), and of passing on the farm to a member of the family (60.1%).

Table 3.2. Respondents' attitudes towards both economic and environmental aspects of farming in Scotland – All sample.

Statements	Agree		Disagree	
	N	%	N	%
To farm successfully it is important for me to keep up-to-date with new farming methods.	173	81.22	40	18.78
It is important for me to try new varieties or breeds (crops/stock).	116	54.46	97	45.54
It is important for me to monitor farm production levels.	197	92.49	16	7.51
It is important to make best use of my farm's resources.	211	96.06	2	0.94
It is important to me to keep debt as low as possible.	200	93.90	13	6.10
It is important for me to leave the land as good as, or better than, I received it.	209	98.12	4	1.88
Encouraging wildlife, planting trees and protecting the water supply is important to me.	172	80.75	41	19.25
It is important to me to pass on the farm to a member of family.	145	60.08	68	31.92

3.3.3. Latent class analysis

The number of latent classes was estimated using an exploratory approach, where additional classes were added to minimise BIC and AIC criterion values, as models with lower BIC and/or AIC scores are preferable. The BIC and AIC scores for the four models indicate that the three-class model provides the best fit of the data (BIC: 5,095.5; AIC: 4,725.7, see Table 3.3). The three classes identified make up 42.1%, 35.7% and 22.1% of the sample, respectively.

Table 3.3. Fit statistics for the latent classes. Identification of the optimal number of classes based on the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC), with smaller values indicating better fit.

No of classes extracted	Maximum Log-likelihood	AIC	BIC
2	-2356.97	4,859.94	5,105.32
3	-2252.86	4,725.71	5,095.46
4	-2218.55	4,731.11	5,225.22
Final 3 classes model	-2254.60	4,729.19	5,098.93

Key: AIC = Akaike Information Criterion; BIC = Bayesian Information Criterion.

The distribution of the estimated class conditional response probabilities is shown in Table 3.4 (for objectives) and Table 3.5 (for attitudes). Each row shows the probability of a member of that class responding to specific objectives and attitudes statements. For instance, for members of Class 1 (Satisfiers) there is a 0.98 probability of strongly agreeing with the objective ‘Maintain your way of life’, and a 0.7 probability of agreeing with the statement ‘To farm successfully it is important for me to keep up-to-date with new farming methods’. These probabilities are represented as a ‘heat diagram’ in both tables to demonstrate the main areas of response, providing an identifier of each class.

Class 1: Satisfiers

The main characteristic of this class is the high probability of strongly agreeing with the statement ‘maintaining your way of life’ (Figure 3.2). Respondents are likely to think that profitability is important but less likely to see business expansion as important. The emphasis on lifestyle and unwillingness to expand suggests satisfaction with the ‘*status quo*’: this class was therefore termed ‘Satisfiers’. There is an

approximately 50% chance that this class will be moderately interested in the environment.

Class 2: Profit-seekers

Profit-seekers strongly agree with maximising annual profits. As with Satisfiers but to a lesser degree, they are likely to be interested in maintaining a way of life and not interested in expanding the business (Figure 3.2). This class is the most likely of the three to place the statement ‘enhance the environment’ as *not* important (0.6 probability).

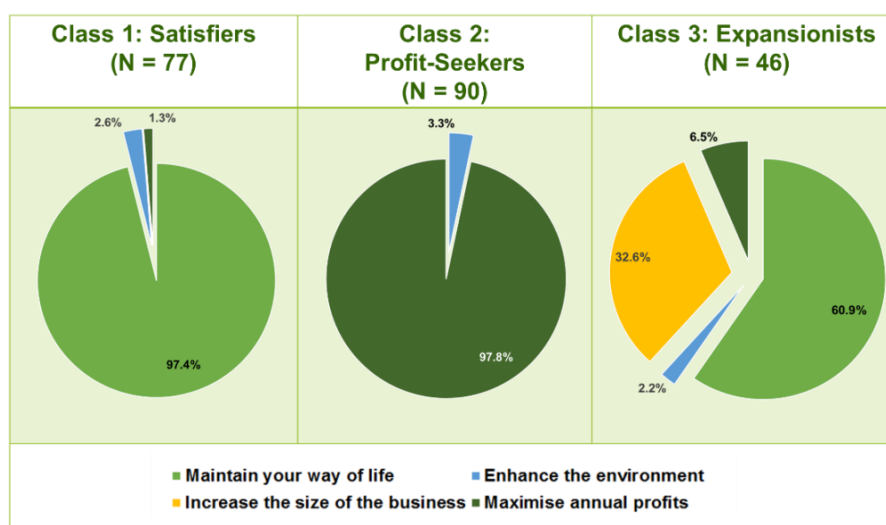
Class 3: Expansionists

The third class has more diverse objectives (Figure 3.2); however, this class is more likely (probability: 0.32 very important; 0.18 important) than Profit-seekers or Satisfiers to want to increase the size of the business, hence being termed ‘Expansionists’. This class is also more interested in enhancing the environment (0.61 probability) and less interested in maximising annual profit, with a 0.66 chance of placing this statement as ‘moderately important’.

Table 3.4. Membership probabilities for the three latent classes, objective statement items and heat diagram. Each row illustrates the probability of a member of a class responding to specific statements.

Objectives	Not Important	Moderately Important	Important	Very Important
Class 1: Satisfiers (N = 77)				
Maintain your way of life	0.0241	0.0000	0.0000	0.9759
Enhance the environment	0.4523	0.5236	0.0000	0.0241
Increase the size of the business	0.5337	0.4663	0.0000	0.0000
Maximise annual profits	0.0000	0.0000	0.9899	0.0101
Class 2: Profit-Seekers (N = 90)				
Maintain your way of life	0.0666	0.1642	0.7692	0.0000
Enhance the environment	0.5990	0.3676	0.0000	0.0334
Increase the size of the business	0.3010	0.4682	0.2308	0.0000
Maximise annual profits	0.0334	0.0000	0.0000	0.9666
Class 3: Expansionists (N = 46)				
Maintain your way of life	0.1948	0.2177	0.0000	0.5875
Enhance the environment	0.2933	0.0247	0.6573	0.0247
Increase the size of the business	0.4108	0.0954	0.1758	0.3180
Maximise annual profits	0.1060	0.6573	0.1620	0.0747

Figure 3.2. Farmers’ classes and their primary business objectives, as measured by the percentage of farmers that chose each of the objectives as primary in each class, percent.



Farmers’ attitudes

A key feature of the ‘Satisfiers’ class is that responses tend to converge at ‘moderate’ agreement. Overall, respondents present a higher probability of moderately agreeing with all the attitude statements when compared to other classes. When we go into detail, statements referring to the importance of keeping-up-to date with new farming methods, monitoring production levels, leaving the land as good as, or better than, received, and of encouraging wildlife, show higher probability values within this class ($p > 0.7$). These are followed by the importance of keeping debt as low as possible, making best use of the farm’s resources, trying new varieties or breeds and of passing on the farm to a member of family.

Profit seekers are characterised by the strong chance of moderate agreement with the importance of keeping up-to-date with new farming methods, monitoring farm production levels and – despite the low probability of environmental concern as an objective - of encouraging wildlife. Farmers also have a tendency to moderately and strongly agree with the importance of making best use of farm’s resources, keeping debt as low as possible, and of leaving the land as good as, or better than, received. Compared to other classes, respondents have a higher probability of disagreeing with the statement related to the importance of trying new varieties or breeds.

The overall impression obtained from the ‘Expansionists’ class is that respondents show a higher probability of moderately agreeing with the relevance of keeping up-to-date, and of encouraging wildlife, in comparison to other classes. Furthermore, members of this class are the most likely to strongly agree that ‘It is important to make best use of my farm’s resources’, as well as ‘It is important to me to keep debt as low as possible’. As with Profit-seekers, opinions are divided on the importance of passing on the farm business to a family member (Table 3.5).

Table 3.5. Membership probabilities for the three latent classes, attitude statement items and heat diagram. Each row shows the probability of a member of a class responding to specific statements.

Statement	Disagreement		Agreement	
	Disagree Strongly	Disagree	Agree	Strongly Agree
Class 1: Satisfiers (N = 77)				
To farm successfully it is important for me to keep up-to-date with new farming methods.	0.0000	0.1833	0.7005	0.1163
It is important for me to try new varieties or breeds (crops/stock).	0.0000	0.4425	0.5575	0.0000
It is important for me to monitor farm production levels.	0.000	0.0394	0.7404	0.2202
It is important to make best use of my farm's resources.	0.000	0.0000	0.6018	0.3982
It is important to me to keep debt as low as possible.	0.000	0.0653	0.6101	0.3246
It is important for me to leave the land as good as, or better than, I received it.	0.000	0.0394	0.7147	0.2459
Encouraging wildlife, planting trees and protecting the water supply is important to me.	0.0130	0.1932	0.7052	0.0885
It is important to me to pass on the farm to a member of family.	0.0525	0.2567	0.4843	0.2066
Class 2: Profit-Seekers (N = 90)				
To farm successfully it is important for me to keep up-to-date with new farming methods.	0.0111	0.2002	0.6104	0.1782
It is important for me to try new varieties or breeds (crops/stock).	0.0111	0.4562	0.4658	0.0668
It is important for me to monitor farm production levels.	0.000	0.1114	0.6337	0.2550
It is important to make best use of my farm's resources.	0.000	0.0111	0.4786	0.5102
It is important to me to keep debt as low as possible.	0.000	0.0665	0.4560	0.4776
It is important for me to leave the land as good as, or better than, I received it.	0.000	0.0111	0.5219	0.4670
Encouraging wildlife, planting trees and protecting the water supply is important to me.	0.0334	0.2004	0.6547	0.1115
It is important to me to pass on the farm to a member of family.	0.0334	0.2772	0.3223	0.3671
Class 3: Expansionists (N = 46)				
To farm successfully it is important for me to keep up-to-date with new farming methods.	0.000	0.1503	0.7191	0.1307
It is important for me to try new varieties or breeds (crops/stock).	0.0212	0.4322	0.4828	0.0638
It is important for me to monitor farm production levels.	0.0424	0.0214	0.5680	0.3682
It is important to make best use of my farm's resources.	0.000	0.0212	0.4294	0.5494
It is important to me to keep debt as low as possible.	0.000	0.0438	0.3955	0.5607
It is important for me to leave the land as good as, or better than, I received it.	0.000	0.000	0.5464	0.4536
Encouraging wildlife, planting trees and protecting the water supply is important to me.	0.0215	0.0702	0.7120	0.1963
It is important to me to pass on the farm to a member of family.	0.0213	0.3305	0.3440	0.3041

3.4. Farm characteristics

We now turn to the different farm characteristics of the distinct classes of farmers, therefore analysing if variations in farmer objectives and attitudes can be potential drivers for differences in farm physical and economic performance. Tables 3.6–3.8 provide the available physical, financial, biographical and managerial characteristics of the overall sample from the FBS, together with the characteristics associated with each segmentation class, with statistical significance at the 90% level (or greater) indicated where appropriate. As shown in Table 3.6, of the 213 co-operator returns, the breakdown by segmentation classes was: Satisfiers (77; 35.7%), Profit-seekers (90; 42.1%) and Expansionists (46; 22.1%). Satisfiers operated the largest average total area (315.5 ha), total area used for agriculture¹⁵ (AUA; 308.1 ha) and tenanted AUA (190.5 ha), which were significantly larger ($p < 0.1$) than Expansionists. However, when considering total adjusted AUA¹⁶ (191.4 ha) and total crops and grass area (159.3 ha), Profit-seekers operated the largest areas: Profit-seekers total adjusted AUA (191.4 ha) was statistically larger when compared to the other classes ($p = 0.055$), whereas total crops and grass area (159.3 ha) presented statistically significantly higher results in comparison to Satisfiers (119.2; $p = 0.026$). Additionally, Profit-seekers average grazing livestock units (193.9 units) were significantly higher than those of Satisfiers (153.1 units, $p = 0.051$).

Farms tended to be LFA beef farms (45.5%; $p = 0.097$), with Satisfiers and Profit-seekers presenting similar values. Almost 72% of the holdings were also classified as SDA farm types, and on average 41.8% of farms were solely owner-occupied.

Significant differences across EU regions by segmentation classes were observed ($p = 0.009$). Geographically, Satisfiers were over-represented in the Highlands and Islands (44.2%), whereas Profit-seekers (40%) and Expansionists (47.8%) were mostly concentrated in South Western Scotland.

¹⁵ Area used for agriculture (AUA) is ‘the area of crops, grass and rough grazing, fallow and any uncropped land that could be returned to agricultural production’ (Defra, 2010).

¹⁶ Total adjusted AUA comprises the ‘AUA reduced by the conversion of rough grazing into the equivalent area of average quality grassland’ (Defra, 2010).

Financially, partly as a reflection of their larger productive area, Profit-seekers returned the highest average revenue from agriculture (£167.5k; Table 3.7), which derived mostly from livestock (£149.8k), recording statistically higher values than Satisfiers ($p < 0.05$). Profit-seekers were on average more reliant on subsidy through the SFP than the overall sample (£47.5k; $p = 0.026$) and returned the greatest average revenue from the SBCS (£4k), significantly higher than Satisfiers (£3.3k; $p = 0.097$). On the other hand, Satisfiers were more dependent on the Less Favoured Area Support Scheme (LFASS; £10.4k; $p = 0.030$), having the greatest proportion of land in SDA.

Profit-seekers' Net Farm Income (NFI) and Management and Investment Income (MII) were significantly larger than those of Expansionists ($p < 0.1$). This indicates that Profit-seekers businesses were more profitable when the opportunity costs of owned land and farm family labour are included, as is the case with MII. However, the relatively low MII suggests that on average, even Profit-seekers were just breaking even in economic terms. Furthermore, Profit-seekers' overall debt increased significantly, both short-term (£12.6k; $p = 0.043$) and long-term (£10.9k; $p = 0.089$); despite this (or perhaps because of it), Profit-seekers presented the healthiest balance sheet, as shown by the greatest Net Worth (£1,245.4k; $p = 0.034$).

Operating the largest farmed area, Profit-seekers recorded the greatest labour usage (1.97 'man' units), which was significantly higher when compared to Satisfiers ($p = 0.012$; Table 3.8). Six businesses had an organic status; interestingly, five out of these six were Profit-seeker businesses (5.6%; $p = 0.090$). Satisfiers were less likely to have a successor (45.5%; $p = 0.068$) and presented the lowest proportion of co-operators with a higher education in an agricultural subject (32.5%; $p = 0.097$). In relation to IT and technical skills, Table 3.8 shows that most of the farms had a personal computer in the household (86.4%) with internet access (84%).

Table 3.6. Physical farm characteristics (mean $\pm$ SD) by farmers' segmentation classes.

Variable		N	All	Farmers' Segmentation Classes						ANOVA/ χ^2 p value ¹
				N	Satisfiers	N	Profit-Seekers	N	Expansionists	
Total Area (ha)		213	279.38 ± 359.27	77	315.48 ± 479.32*	90	300.08 ± 302.51	46	178.43 ± 159.88*	0.095
Total AUA (ha)			273.48 ± 354.71		308.08 ± 476*		293.76 ± 295.07		175.91 ± 158.76*	0.099
Total Adjusted AUA (ha)			165.31 ± 119.42		148.87 ± 108.49*		191.40 ± 135.66*		141.76 ± 92.31*	0.022
Total Crops and Grass Area (ha)			139.35 ± 100.07		119.22 ± 94.52**		159.25± 106.16**		134.10 ± 91.02	0.033
Tenanted AUA (ha)			132.33 ± 339.55		190.46 ± 487.25*		123.39 ± 246.84		52.50 ± 96.16*	0.088
Grazing Livestock Units ²			174.62 ± 112.95		153.07 ± 103.76*		193.92 ± 106.69*		172.96 ± 133.67	0.065
Number and percentage of segment by farm characteristic										
Farm Type (%)	LFA Beef	213	97 (45.54%)	77	33 (42.86%)	90	37 (41.11%)	46	27 (58.70%)	0.097
	LFA Cattle and Sheep		56 (26.29%)		23 (29.87%)		28 (31.11%)		5 (10.87%)	
	Lowland		15 (7.04%)		3 (3.90%)		7 (7.78%)		5 (10.87%)	
	Mixed		45 (21.13%)		18 (23.38%)		18 (20%)		9 (19.57%)	
LFA (%)	All land outside LFA	213	23 (10.80%)	77	8 (10.39%)	90	8 (8.89%)	46	6 (10.53%)	0.306
	Less than half land in LFA		20 (9.39%)		4 (5.19%)		11 (12.22%)		5 (10.87%)	
	DA land		20 (9.39%)		4 (5.19%)		11 (12.22%)		5 (10.87%)	
	SDA land		150 (70.42%)		61 (79.22%)		60 (66.67%)		29 (63.04%)	
	All/some land in LFA (total)		190 (89.20%)		69 (89.61%)		82 (91.11%)		39 (84.78%)	0.526

Table 3.6. Physical farm characteristics (mean $\pm$ SD) by farmers' segmentation classes. (cont.)

Tenure (%)	Owner-occupied		89 (41.78%)		28 (36.36%)		39 (43.33%)		22 (47.83%)	
	Tenanted	213	57 (26.76%)	77	25 (32.47%)	90	24 (26.67%)	46	8 (17.39%)	0.515
	Landlord-Tenant Partnership		2 (0.94%)		1 (1.30%)		0 (0%)		1 (2.17%)	
	Mixed		65 (30.52%)		23 (29.87%)		27 (30%)		15 (32.61%)	
	Not owned (total)		124 (58.22%)		49 (63.64%)		51 (56.67%)		24 (52.17%)	0.425
EU Region (%)	Eastern Scotland	213	37 (17.37%)	77	9 (11.69%)	90	16 (17.78%)	46	12 (26.09%)	0.009
	South Western Scotland		80 (37.56%)		22 (28.57%)		36 (40%)		22 (47.83%)	
	North Eastern Scotland		40 (18.78%)		12 (15.58%)		22 (24.44%)		6 (13.04%)	
	Highlands and Islands		56 (26.29%)		34 (44.16%)		16 (17.78%)		6 (13.04%)	
Farm Size (%)	Small	213	1 (0.47%)	77	0 (0%)	90	0 (0%)	46	1 (2.17%)	0.014
	Medium		105 (49.30%)		46 (59.74%)		34 (37.78%)		25 (54.35%)	
	Large		107 (50.23%)		31 (40.26%)		56 (62.22%)		20 (43.48%)	

Note: Values within a row in bold and with different superscripts are significantly different (* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$), following the Tukey post-hoc test.

Key: AUA = Area Used for Agriculture; LFA = Less Favoured Areas; SDA = Severely Disadvantaged Areas; DA = Disadvantaged Areas.

¹ $p < 0.1$.

²Livestock unit grazing days equivalents: dairy cows, other cattle 2 years and over = 1; cattle less than 2 years = 0.5.

Table 3.7. Financial characteristics (mean $\pm$ SD) by farmers' segmentation classes.

Variable		N	All	Farmers' Segmentation Classes					ANOVA/ χ^2 p value ¹	
				N	Satisfiers	N	Profit-Seekers	N	Expansionists	
Revenue Source (£)	Agriculture (Total farm)	213	143,572.70 ± 117,426.53	77	115,403.36 ± 84,293.63**	90	167,475.93 ± 138,278.03**	46	143,958.52 ± 112,444.73	0.016
	Crop		13,312.70 ± 36,377.51		8,453.05 ± 18,584.40		17,706.98 ± 45,224.86		12,849.83 ± 39,072.25	0.261
	Livestock		130,260 ± 108,731.26		106,950.31 ± 80,576.67**		149,768.96 ± 128,005.41**		131,108.70 ± 103,118.70	0.039
Subsidies (£)	LFASS	213	9,243.97 ± 9,235.58	77	10,390.33 ± 10,731.86**	90	9,872.73 ± 8,872.64*	46	6,094.87 ± 6,200.84*,**	0.030
	SFP		41,169.25 ± 29,422.05		36,078.56 ± 27,113.02**		47,492.36 ± 32,508.98*,**		37,319.33 ± 24,638.11*	0.026
	SFP/ha		214.78 ± 117.09		196.48 ± 116.36		218.06 ± 115.85		238.99 ± 118.27	0.141
	SBCS		3,697.01 ± 2,315.20		3,316.01 ± 2,134.45*		4,054.30 ± 2,215.25*		3,635.70 ± 2,710.13	0.090
Net Farm Income (£)		213	20,726.24 ± 38,844.31	77	17,109.39 ± 30,899.99	90	27,728.91 ± 44,191.93*	46	13,079.67 ± 38,121.54*	0.067
Farm Business Income (£)			28,610.90 ± 41,803.71		23,862.70 ± 31,145.53		35,388.33 ± 50,057.73		23,298.76 ± 38,463.60	0.129
Management and Investment Income (£)			-6,047.78 ± 38,823.97		-9,441.95 ± 31,932.19		447.26 ± 43,159.18*		-13,073.91 ± 39,247.63*	0.099
Closing Net Worth (£)			1065,688.40 ± 916,088.10		879,422.75 ± 609,779.19**		1245,388.30 ± 1149,028.50**		1025,894.30 ± 767,399.86	0.034
Overall debt ² (£)	Δ Short-term		213		6,371.64 ± 41,946.29		77		6,820.81 ± 31,047.34	90
	Δ Long-term	4,492.59 ± 37,245.68		-74.53 ± 34,927.90*	10,860.90 ± 45,812.45*	-322.20 ± 13,551.79		0.089		
Net Investments (£)	Land and buildings	213	14,206.70 ± 48,999.18	77	9,915.71 ± 33,509.49	90	19,374.3 ± 63,040.803	46	11,278.91 ± 38,222	0.418
	Other assets		1,465.99 ± 7,585.09		1,020.86 ± 3,043.46		1,061.77 ± 5,116.76		3,001.96 ± 14,161.41	0.302

Note: Values within a row in bold and with different superscripts are significantly different (*p < 0.1; **p < 0.05; ***p < 0.01), following the Tukey post-hoc test.

Key: LFASS = Less Favoured Area Support Scheme; SFP = Single Farm Payment; SBCS = Scottish Beef Calf Scheme.

¹p < 0.1; ²Overall debt was defined as short-/long-term loans and creditors valuations at the beginning and end of the year; Δ = change.

Table 3.8. Labour, age, organic status, successor, education and IT skills (mean $\pm$ SD) by farmers' segmentation classes.

Variable		N	All	Farmers' Segmentation Classes					ANOVA/ χ^2 p value ¹	
				N	Satisfiers	N	Profit-Seekers	N	Expansionists	
Total Labour (Man unit)		213	1.81 ± 0.84	77	1.60 ± 0.73**	90	1.97 ± 0.91**	46	1.87 ± 0.81	0.015
Organic (%)	Non-organic	213	206 (96.71%)	77	76 (98.70%)	90	85 (94.44%)	46	45 (97.83%)	0.090
	Organic		6 (2.82%)		1 (1.30%)		5 (5.56%)		0 (0%)	
	Converting to organic		1 (0.47%)		0 (0%)		0 (0%)		1 (2.17%)	
Successor (%)	Yes	213	120 (56.34%)	77	35 (45.45%)	90	53 (58.89%)	46	32 (69.57%)	0.068
	No		83 (38.97%)		37 (48.05%)		32 (35.56%)		14 (30.43%)	
	N.A.		10 (4.69%)		5 (6.49%)		5 (5.56%)		0 (0%)	
Farmer's Education Attainment (%)	School only	213	85 (39.91%)	77	35 (45.45%)	90	30 (33.33%)	46	20 (43.48%)	0.097
	Standard grade/Highers		30 (14.08%)		14 (18.18%)		11 (12.22%)		5 (10.87%)	
	College / ND/C in agriculturally related subject		71 (33.33%)		21 (27.27%)		34 (37.78%)		16 (34.78%)	
	College / ND/C in non- agriculturally related subject		8 (3.76%)		0 (0%)		5 (5.56%)		3 (6.52%)	
	Degree in agriculturally related subject		13 (6.10%)		4 (5.19%)		8 (8.89%)		1 (2.17%)	
	Degree in non-agriculturally related subject		4 (1.88%)		3 (3.90%)		0 (0%)		1 (2.17%)	
	Post-graduate qualification in agriculturally subject		2 (0.94%)		0 (0%)		2 (2.22%)		0 (0%)	

Table 3.8. Labour, age, organic status, successor, education and IT skills (mean $\pm$ SD) by farmers' segmentation classes. (cont.)

Age (years)		213	57.18 $\pm$ 10.17	77	56.38 $\pm$ 9.77	90	56.83 $\pm$ 10.07	46	59.22 $\pm$ 10.96	0.298
Personal Computer (%)	Yes	213	184 (86.38%)	77	66 (85.71%)	90	79 (87.78%)	46	39 (84.78%)	0.870
	No		29 (13.62%)		11 (14.29%)		11 (12.22%)		7 (15.22%)	
Internet (%)	Yes	213	179 (84.04%)	77	65 (84.42%)	90	76 (84.44%)	46	38 (82.61%)	0.956
	No		34 (15.96%)		12 (15.58%)		14 (15.56%)		8 (17.39%)	
Years in the Survey		213	19.66 $\pm$ 13.93	77	19.92 $\pm$ 13.56	90	17.37 $\pm$ 12.40**	46	23.72 $\pm$ 16.49**	0.041

Note: Values within a row in bold and with different superscripts are significantly different (*p < 0.1; ** p < 0.05; ***p < 0.01), following the Tukey post-hoc test.

¹p < 0.1.

Key: N.A. = Not Applicable.

3.4. Discussion

The LCA analysis reveals that heterogeneity can be grouped into three classes of farmers with respect to their decision-making towards economic and environmental aspects of farming in Scotland. The emergence of three segments and the existence of statistically significant differences between them are consistent with other studies that have emphasized the intrinsic diversity of farmer behaviour (Defra, 2011; Wilson et al., 2013). Furthermore, this is the first study linking a latent class model to the FBS returns. The results of this combined analysis highlight clear differences in location, cropping and stocking activities, business performance and biographical and managerial characteristics across segmentation classes. The physical, financial and managerial characteristics associated with each segmentation class corresponded to a priori expectations. For example, Profit-seekers represented the largest percentage of the overall sample, were characterised by the primary objective of maximising annual profits and achieved the highest farm business revenue and NFI.

With respect to total adjusted AUA, Profit-seekers operated a larger area in comparison to others. This translated into a higher total farm financial output and NFI, demonstrating the importance of farm size in determining agricultural performance. From this perspective, the greater proportion of medium size farms amongst Satisfiers and Expansionists, when compared to Profit-seekers, reinforces previous studies that report a positive correlation between agricultural performance and farm size (Wilson et al., 2001; Langton, 2012; Wilson et al., 2012). Furthermore, the number of grazing livestock units was greater in Profit-seeker businesses, reflecting a higher stocking density and intensity of activity. Intensity of activity is associated with more focused, production-led objectives (Guillem and Barnes, 2012) and this is verified by the analysis performed.

Total debt levels increased for Profit-seekers, although this group was relatively resilient to increased levels of borrowing, as Net Worth was also higher than in other segments. Previous research in the UK has recognised the association between debt and farm size (with smaller farms carrying lower debt; Langton, 2011) and the correlation between low levels of debt and technical efficiency (Hadley, 2006; Barnes et al., 2011d; Langton, 2012). Even though several authors suggest that more efficient farms have

lower debt profiles (Paul et al., 2000; Gloy et al., 2002; Hadley, 2006), others (Barnes, 2008; Barnes et al., 2011d) find that farmers with a higher debt to total assets ratio are more technically efficient. Zhenghei and Lansink (2006), using data from Dutch crop farms, reported that debt levels had no impact on financial returns, though long-term debt increased productivity growth. The lack of a direct causal relationship between debt and performance underlines the several potential purposes of debt: more profitable businesses can service debt and use this capital to invest, for example, by increasing size, while less profitable businesses may use debt as a business survival strategy (Gloy et al., 2002; Barnes et al., 2011d).

Interestingly, Profit-seekers were more heavily reliant upon subsidies (as a contributor to total Farm Business Income; FBI). Overall, economic performance of this sample of farms was strongly dependent on subsidies. Chapter 1 has previously discussed this reliance on subsidy support, showing that measurements of farm business profitability recorded over many years, at farm-level by the Scottish Government (Scottish Government, 2016; 2018a), indicate that without financial support payments many Scottish farms are not profitable, therefore confirming this finding. Despite producing a premium product, Scottish beef farms have been struggling to break even and such dependence on subsidies probably also decreases production-related performance characteristics, such as farm technical efficiency (Barnes, Bevan and Revoredo-Giha, 2011; Minviel and LaTruffe, 2016). Changes in trade relations and agricultural policy are predicted to have major effects on the resilience and structure of the Scottish agricultural sector ‘post-Brexit’, which have the potential to reinforce existing trends for fewer livestock, reduced agricultural activity, land abandonment and gradual reduction of the agricultural workforce (Moxey and Thomson, 2018). The advent of ‘Brexit’ adds to the existing pressures of farming in Scotland through potential reductions in farm gate prices and - more importantly - support payments, or in delivery mechanisms for these payments.

Within this context, farm-level analysis by the SRUC (Shrestha et al., 2018a) has reported that a significant share of farms would indeed become non-viable if direct Pillar 1 support payments to farmers were withdrawn, as described in Chapter 1. This potential threat to agriculture across Scotland reinforces the need to consider implications for several policy areas and the scope for any mitigation strategies. Several

ways of maintaining agricultural activity are suggested in Moxey and Thomson's report (Moxey and Thomson, 2018), which include: improving agricultural productivity to reduce dependence on support payments, possibly through the adoption of best practice or more innovative and sustainable technologies, and retaining some form of support payments with 'activity' clauses. However, the authors also point out that the scope for such approaches will be highly influenced by the Scottish industry's willingness to change and on the level and type of support that is compatible with budget constraints, domestic common policy frameworks and WTO requirements. In addition, different policy objectives may entail different approaches and trade-offs between objectives are certainly expected.

The analysis performed here suggests that economic and environmental concerns were both important across all three farmer segments: profitability as expressed through 'objectives', and environmental concern as indicated by high probability of agreement with the statement 'Encouraging wildlife, planting trees and protecting the water supply is important to me' (Table 3.5). These findings concur with Wilson et al.'s (2001) analysis of determinants of efficiency: the most efficient wheat growers in a sample of farmers in the East of England gave high priority to the objectives of 'maximising profits' and 'maintaining the environment'. Thus, in terms of these farmers' willingness to pursue environmental objectives, the lack of trade-off between 'business attitudes' and 'environmental attitudes' is very encouraging, particularly from a policy perspective, although it is notable that the majority of farmers do not frame their objectives from an environmental perspective. Other authors draw similar conclusions (Galdeano-Gómez, 2008; Piedra-Muñoz et al., 2016). Encouraging farmers to pursue these aspirations would be very much in line with Defra's 'sustainable intensification' policy objectives. These aim to build a more productive and efficient (including reduction in pollution) farming and food industry while supporting and enhancing biodiversity and wildlife habitats (Defra, 2012). From a UK and within the UK, Scottish perspective, the synergy between environmental and profit-based attitudes of farmers at the time this survey was conducted can partly be explained by the existence of a range of 'stewardship' schemes (e.g. agri-environment schemes), which paid farmers for environmental management, particularly of more marginal areas of land such as field headlands and awkward corners. It is less clear that such synergy would exist if

e.g. penalties for negative externalities – GHG emissions, ammonia pollution, nitrate loss and soil erosion – were policy mechanisms.

Regarding Satisfiers, this class identified mostly with maintaining their way of life and their attitudes tended to converge at what might be termed ‘moderate agreement’. Although farmers’ decisions are influenced by financial incentives, economic drivers are not paramount for all farmers and many farmers might be best viewed as profit satisfiers rather than profit maximisers. Economic performance is often tempered by other considerations, which usually embrace family and lifestyle considerations (Wilson, 2014), including succession (Wheeler et al., 2012) that can determine the direction of the business at critical periods of time (Wilson et al., 2013). These non-economic drivers tend to be long-term objectives, while economic drivers tend to express short-term objectives (Garforth and Rehman, 2006). Several studies have focused on examining the non-economic perceptions of farmers and their impact on decision-making (Paniagua Mazorra, 2001; Burton, 2004; Greiner et al., 2009). Such studies usually suggest that the social aspects of farmer decision-making either prevail over or are equivalent to profit-based drivers (Barnes et al., 2011c).

Notable characteristics among Expansionists were their higher net investments (in other assets), relative age and likelihood of having identified a successor. Succession often is the trigger for new investment (Wilson et al., 2013). The existence of a successor who would take over the farm in the future probably explains the behaviour of this group to an extent: farmers are trying to make decisions that accumulate land and capital. Wheeler et al. (2012) argued that the identification of a successor was linked to current and future farm management practices, with those not having a successor in place being more prone to go into a period of stagnation. The handover of farms to a younger generation of farmers may indicate that farm businesses intend to grow, rather than remaining static or scaling down.

Age or life-stage impact on farm management and performance is important in farmers’ self-segment classification and in terms of behaviour (Plummer, 1974; Dwyer and Blackstock, 2007; Wilson, 2014), as well as having direct policy relevance (Moon and Cocklin, 2011). Fennell (1981) noted that a lack of information and knowledge about succession creates policy issues: it is important that the government and other

stakeholders understand the substantial barriers to successful inter-generational familial succession. One approach would be to encourage farmers to plan for succession. Policy makers could give greater recognition to the relevance of life-stage analysis in policy implementation and acknowledge farmers' long-term views to a greater extent (Burton, 2004; Wilson, 2014).

These different combinations of primary objectives and specific attitudes define each class of farmers and will affect their decision-making. Factors such as farmer self-identity (Burton, 2004; Stock, 2007), intergenerational objectives (Wheeler et al., 2012), education (Wilson et al., 1998), managerial ability and actions (Wilson, 2011), farm size (Edwards-Jones, 2006), subsidy levels (Wilson, 1996) and risk and uncertainty (Backus et al., 1997) are all connected, resulting in complex and well-grounded farmer decision-making. Such biophysical and socio-economic variation appears to have consequences, as different farmers having access to similar information, technology options, and subject to the same agricultural policy may react differently, which is usually the case (van Grieken et al., 2019). As highlighted by Wilson (2014), the challenge for policy makers is to understand and address these multifaceted drivers by communicating with farmers to produce multi-output objectives.

The work reported here suggests that models used to inform policy and decision-making could be improved by better representing the heterogeneity of farmers' objectives and attitudes that underpin behaviour and decision-making, and which lead to distinct farm physical, financial and managerial characteristics. This analysis therefore reinforces the argument that segmentation may prove useful as a policy tool for targeting specific individuals, recognising the need for a tailored approach to advice and support farmers, helping them achieving the range of expected outcomes, and thus encouraging a positive change in farming practices, as supported by Morris et al. (2000), Dwyer and Blackstock (2007) and Defra (2008). Segmentation can also help reveal which segments have greater potential for specific behaviours and how such behaviours can be optimised in policy development. Additionally, there is a strong relevance for communication, as there needs to be different approaches to connect with different groups. Farmers assess opportunities and constraints through dynamic processes (Wilson, 1997; Edwards-Jones, 2006) that are not always focused on the

neoclassical assumptions of maximising profit or optimising production (Darnhofer, 2006; Sattler and Nagel, 2010; Karali et al., 2013). In this sense, for some farmers profitability is not a key business driver, but those farmers are still likely to need a tailored approach to advice, for instance, to improve animal health and welfare.

It is important to be clear about the type of policy mechanism that is relevant here; targeting specific individuals, with different behaviours, will help agricultural *extension* - or in its current guise, *knowledge exchange* activities – such as those that are encouraged through Defra’s Sustainable Intensification Platform (<http://www.siplatform.org.uk/>) to reach desired objectives. With specific respect to the uptake – or lack of uptake - of sustainable agricultural innovations, other factors are also important, not least, the future, probably uncertain, net benefits arising from these innovations. Further on-farm productivity gains are possible, both through the uptake of new technologies and through the widespread adoption of current best practice, which can help mitigate the potential threats posed by ‘Brexit’, as discussed in Chapter 2. The importance of profit maximising objectives to 82.1% of farmers in the survey (Table 3.4, combining ‘important’ and ‘very important’ statements) strongly suggests that economic factors will be the strongest influence on the uptake of innovations by farmers.

This study has proposed three segments representing a diversity of outlooks and perceptions towards both economic and environmental aspects of farming in Scotland with some key implications for policy application. However, the need to assess the consistency of these behavioural segments over time is recognised. As shown, the average years in the FBS are quite high for all farmers, making it possible to have a nearly constant sample over the years. Ongoing assessment of the segments will provide insight into whether these classes remain valid over time, as farmers may not necessarily be defined within a segmentation class for their entire career, as highlighted by Plummer (1974), Jenkins and McDonald (1997) and Burton (2004). The early work of Gasson (1973) argued that farmers’ motivations vary over time and are context-specific, which indicates that decision-making needs to be assessed within an individual’s situational context; the point is also made by Busck (2002). Given the reported effects of Social Media on attitudes to areas of wider societal concern, such as climate change – for example, the tendency for users of Social Media only to interact

with other like-minded users (the so-called ‘echo-chamber’ effect – see Williams et al., 2015 for an example) - it is interesting to speculate whether information exchange through such channels is also affecting farmer attitudes over time.

3.5. Conclusions

This study has classified a sample of Scottish beef and sheep farmers into three segmentation classes following a LCA approach, with this segmentation model being then linked to the FBS returns for Scotland. The results of the combined analysis delivered a range of findings that connected each segmentation class to specific physical, financial and managerial characteristics, capturing different styles of decision-making. The use of nationally representative data enabled the analysis of the heterogeneity verified amongst Scottish beef and sheep farmers, which can contribute to promoting awareness and a greater understanding of the diversity of farmers’ objectives and likely behaviours. Additionally, understanding farmer segments through the constructs used in this study can facilitate the development of more cost-effective strategies for targeting policy design, particularly knowledge exchange and other communication strategies to meet the objectives of specific farmers while promoting desired changes in agricultural practice.

While the discussion here provides insight into the underlying drivers of farmers’ decision-making, it does not address their consistency over time. These initial results support the findings reported in the literature and point towards further research. In particular, the Scottish FBS has presented a relatively constant sample over the years, therefore providing a means of delivering an ongoing assessment of farmers’ behaviour.

4. Chapter 4: Assessing the reliability of Scottish beef and sheep farmers' intentions in predicting actual production decisions

4.1. Introduction

Farmers' intentions surveys are a useful research tool in situations where preference data are scarce or non-existent (Louviere et al., 2000; Bougherara and Latruffe, 2010), or where responses to hypothetical scenarios are being explored, a common practice in ex-ante policy assessments. Such surveys offer a way of collecting direct evidence on farmers' expectations about future developments in farming and their 'business confidence' that is otherwise more challenging to assess (Thomson and Tansey, 1982). Intentions data illustrate farmers' perspectives, which are very likely to have an impact on their actions in the short-term, as expectations usually have an influence on intentions and decisions (Harvey, 2000). Thus, intentions data can provide an overview of the general direction of farmers' future behaviour based on their expectations.

There is some debate on the strengths and weaknesses of using this approach, with a broad range of 'accuracy' rates being reported in the literature. Some follow-up studies suggest that farmers act in accordance with their stated intentions (Harvey, 2000; Tranter et al., 2004; Lefebvre et al., 2014). Conversely, other authors argue that the value of farmers' stated plans for predicting actual behaviour is somewhat limited, due to considerable discrepancies (Glauben et al., 2002; Väre et al., 2010; Viira et al., 2014). The reliability of intention-based surveys is also subject to some practical limitations. First, a constant sample is required and this can be difficult to gather in the context of agriculture. Second, the circumstances and the importance of the questions being asked may have changed over time. Finally, identifying suitable variables to describe discrepancies between intentions and behaviour is not an easy task, as a result of the complexity of the decision-making process.

Some empirical studies have addressed and partially overcome these difficulties, comparing farmers' intentions to their actual behaviour. Thomson and Tansey (1982) report the results of an intention survey carried out on Scottish dairy farmers with

respect to intended herd size, allowing comparison with stated intentions. Väre et al. (2005) examined and compared farmers' succession plans to actual succession. Lefebvre et al. (2014) reassessed a sample of farms where earlier 'investment intentions' had been collected, whereas Hennessy, Kinsella and Thorne (2016) revisited two earlier intentions surveys to assess their reliability in predicting farmers' production decisions for two different years following 'decoupling'. However, of these, only some studies have analysed the determining factors of the stated intentions-behaviour discrepancy, that is, the gap between stated intentions and realised actions.

A key question is whether the intention-behaviour gap can be described in terms of systematic factors (e.g. personal characteristics, social environment; Wong and Sheth, 1985). Following Väre et al.'s (2005) rationale, if the intention-behaviour gap occurs randomly in a sample of farmers then the reliability of the intention measures is reduced as a result of a random measurement error. Conversely, if the intention-behaviour gap and farmer characteristics are significantly associated, the outcomes of econometric models based on intentions would only be accurate if they take into account such characteristics (Hennessy et al., 2016).

While the previous chapter described both the results of an intentions survey performed among Scottish beef and sheep farmers, and their associated characteristics, there is potential to extend this analysis by assessing the reliability of such intentions with respect to farmers' primary objectives for the business. Specifically, this chapter seeks to: (i) compare farmers' intentions to their actual production decisions to investigate the robustness of intentions as a method of accurately predicting farmer behaviour and related policy impact; (ii) identify factors explaining a potential intention-realisation gap at the individual farm-level; and to (iii) provide recommendations on the use of intentions surveys to analyse the agricultural sector, as proposed in Chapter 1.

This chapter is structured as follows. Section 4.2. briefly describes the data and the estimation method. Section 4.3. reports the estimation results, which is then followed by a detailed discussion of the results and conclusions.

4.2. Material and Methods

The role of objectives in explaining farmers' behaviour is well recognised in the literature. For example, in her research on farmers' objectives and goals, Gasson (1973) suggests that objectives direct a persons' behaviour towards a desired end. Intentions and behaviour were the subject of several studies reviewed by Willock et al. (1999), who reported that Scottish farmers' objectives mediated the influence of attitude on farmers' business and environmental behaviours. Similarly, Bergevoet et al. (2004) found that farmers' objectives are a key determinant of strategic and entrepreneurial behaviour.

This study builds on the farmers' intentions questionnaire constructed to collect information on Scottish farmers' primary objectives for their businesses described in Chapter 3. Accordingly, farmers were requested to rank the following four objectives using a '1 to 4 Likert type scale' of importance, with '1' being the least important and '4' the most important: (i) maintain your way of life; (ii) maximise annual profits; (iii) increase the size of the business; and (iv) enhance the environment. As only five respondents reported that enhancing the environment was their main objective, they were removed from analysis. The remaining objectives were further translated into six behavioural responses relating to increasing, maintaining or decreasing farm income (as measured by Net Farm Income; NFI) and livestock numbers.

It is expected a priori that farmers with lifestyle objectives are highly satisfied with farming as a way of life, having a higher intention to maintain family income to preserve such standard of living. It is also hypothesised that farmers who have economic and expansionist objectives are more focused on the factors that determine their success in business, therefore having a higher intention to increase farm income and livestock numbers, respectively. The dataset and the methods of estimation applied in this study are discussed below.

4.2.1. Data

As noted, research on a stated intentions-behaviour gap requires a constant sample, which can be difficult from a practical perspective. However, as discussed in Chapter 1 (where the FBS is reviewed in detail), the FBS for Scotland is a suitable data source

that provides the required farm-level data to sufficiently describe structural and financial characteristics of a consistent sample of professional farms across the distribution of beef farms, which are scalable to the national level.

In 2013, a sample of 500 farmers completed an intentions survey and most of these farms were still in the FBS in 2016. It is therefore possible to compare their actual production decisions with their initial intentions as measured by their primary objectives. The analysis has been confined to cattle and sheep farms building on previous work (Chapter 3), though this survey was conducted for all farm types. Data was available on 197 cattle and sheep farms in both the 2013 intentions survey and the 2016 survey of actual production. In 2013, farmers specified their main objectives for their business, while the 2016 FBS farm data recorded the actual financial position and performance of the businesses, allowing a comparison between farmers' intentions and actual behaviour. Thus, in this chapter, we look at the delivery of farmers' objectives as assessed by the accuracy of their behaviour. Hennessy et al. (2016) used a similar approach to assess the reliability of intentions surveys in Irish cattle and sheep farmers' farms post decoupling.

4.2.2. Data analysis

Descriptive analysis

The FBS dataset does not include specific information on farmer behaviour; however, some structural variables can be thought of as proxies. Thus, to investigate accuracy at the individual farm-level, two proxy indicators were used: Net Farm Income (NFI) and livestock numbers. Net Farm Income is 'the return to the farmer and spouse for their manual and managerial labour and for the tenant-type assets¹⁷ they have invested in the business' (Defra, 2010). It is estimated as net value added (the value of sales less purchases from other firms, adjusted for own-consumption of farm produce, changes in the stocks of products and inputs and after depreciation), less rent (including an imputed rental value for land which is owner occupied), and less labour costs (which include an imputed figure for any unpaid family labour; Phimister, Roberts and Gilbert, 2004; Defra, 2010; Hill, 2012). Net Farm Income is the traditional indicator generated from

¹⁷ Tenant-type capital includes livestock, machinery, crops in store, stocks of consumables, work in progress, orchards, other permanent crops, glasshouses, cash and other assets needed to run the business. It does not include land and buildings (Scottish Government, 2016).

the FBS to demonstrate the economic performance of the sector, being considered a reasonable performance indicator of the income derived from farming, and thus the profitability of farming (Phimister et al., 2004; Hill, 2012). Livestock numbers covered all beef and sheep animals on the farm to represent the best estimate possible of the average animal numbers over the considered years, being measured in livestock units.

Farmers were categorised based on how accurately their behaviour represented their earlier stated plans, i.e. their primary objectives. Farmers were therefore classified as 'Accurate', 'Optimistic' or 'Pessimistic' (in 2016) according to their main primary objectives (in 2013). Farmers who intended to maintain the way of life were classified as:

- Accurate, if their actual NFI was within 10% of their 2013 values;
- Pessimistic, if their actual NFI was at least 10% higher than in 2013;
- Optimistic, if their actual NFI was at least 10% lower than in 2013.

Those who intended to maximise annual profits were considered:

- Accurate, if their actual NFI was at least 10% higher than in 2013;
- Optimistic, if their actual NFI either decreased at least 10%, or was within 10% of their 2013 values.

Farmers with the main objective of increasing the size of the business were classified as:

- Accurate if their actual livestock numbers were at least 10% higher than in 2013;
- Optimistic, if their actual livestock numbers either decreased at least 10%, or were within 10% of their 2013 values.

A series of descriptive and statistical tests (ANOVAs, Chi-squares) were then undertaken with the level of significance set at 90% to characterise the sample of farmers in 2016. The results were sourced from the 2015/2016 FBS returns combined with the aforementioned farmers' classification, farmers were therefore classified in relation to the accuracy of their intentions.

Multinomial logistic regression

The following step focused on investigating the determinants of farmers' responses to assess the main factors behind farmers' intentions and behaviour. Hence, two multinomial logistic models were estimated. The first model was used to investigate the characteristics of the farmers who stated they would maintain way of life, maximise annual profits or increase the size of the business. The second model was run to evaluate whether the intention-behaviour gap was a random error, or whether it could be explained by a number of factors for which data were collected. This was achieved by using a second multinomial logistic model to explore the characteristics of the Accurate, Pessimistic and Optimistic farmer groups.

The multinomial logistic regression is the most frequently used approach when categorical responses exceed a binary outcome and responses are not ordered. In the case of multinomial regression, the effects of independent variables are allowed to differ for each outcome. Hence, in equation 4.1 let y be the dependent variable with J nominal outcomes, and let m be the classes of y numbered 0 through J (for instance, (0) maintain way of life; (1) maximise annual profits; and (2) increase the size of the business).

Hence, given the range of nominal outcomes y with the classes 0, 1 and 2, with n_0 , n_1 and n_2 observations accordingly, the predicted probability of the i^{th} farmer selecting a nominal outcome ($y = 0, 1, 2$) given x' is (Wooldridge, 2010):

$$\Pr(y_i = m | x'_i) = \frac{e^{x'_i \beta_m}}{\sum_{j=1}^J e^{x'_i \beta_j}} \quad (4.1)$$

Where $\beta_0 = 0$.

This provides indications of the probability of a change in the independent variable x affecting membership of one of the three classes (Barnes et al., 2016). In the first model, three runs were performed, using each of the objectives as a baseline outcome to examine the key variables that determine membership of a specific objective. In the second model, the base outcome class 'Accurate' was estimated for referencing change. Sample size guidelines for multinomial logistic regression specify a minimum of 10 cases per independent variable (Schwab, 2002).

For ease of interpretation, the results of the multinomial logistic models are presented as relative risk ratios (RRR) of the explanatory variables, which are calculated by taking the exponent of the log-odds. This is a measure of relative effect, as it can be explained as the ratio of the probability of selecting one outcome category over the probability of selecting a base outcome category (Barnes et al., 2013). Relative risk ratios indicate the change in the relative risk when an independent variable increases. An RRR greater than one indicates that the risk increases as the independent variable increases. Estimation was conducted within Stata 15 (StataCorp, 2017). The explanatory variables used in these models are described in the following section, being discussed in light of their contribution to explaining the intention-behaviour gap in previous studies.

4.2.3. Explanatory variables

Even though the literature on the accuracy of farmers' intentions is relatively scarce, a few studies suggest that a number of variables available from the panel data might be able to explain the intention-behaviour gap. Accordingly, focus was set specifically on farm structural and financial characteristics including farm income, farm size, reliance on subsidies, debt, livestock numbers, total labour, and major sources of revenue that are hypothesized to affect the intent-behaviour discrepancy (Table 4.1).

A preliminary analysis of the data showed that the majority of the sample of farmers intends to either maintain way of life or maximise annual profits. This suggests that these farmers' purpose for being in farming is to either maintain or increase farm income to preserve or improve the standard of living, respectively. Economic variables, including intensity of production, gross margin, debt, farm income and reliance on subsidies are usually used to explain behaviour (Lefebvre et al., 2014; Hennessy et al., 2016). Based on the assumption that most of the sample wants to either maintain way of life or maximise annual profits, economic variables are expected to potentially affect farmers' intentions and behaviour.

As previously mentioned, the farm income measure used in the study is NFI, which places all farms on a tenanted basis, with imputed rent costs applied to owner occupiers (Scottish Government, 2016). Gross returns include income from livestock and crop sales, and government payments. To assess the farm financial situation, the level of change in debt was examined (measured by change in short- and long-term debt). The

impact of livestock numbers was also explored, as they are one of the main drivers of farming activity. The probability of an intention-behaviour gap occurring has been reported in the literature as significantly increasing with farm size (Lefebvre et al., 2014), hence farm area was taken into account. The impact of total labour was also considered.

Although farmer's age was reported in the literature as having an impact on the intention-behaviour discrepancy (Väre et al., 2005; Hennessy et al., 2016), farmers in the UK tend to be within an older age band, of between 50 and 65 (Scottish Government, 2011). This homogeneity was also found within the sample, and thus age was removed from further analysis due to the lack of differentiation in response (similar findings were reported by Barnes et al., 2013). Each of the variables used in the models are specified in Table 4.1.

Table 4.1. Description of the independent variables used for the estimation.

Variable	Type	Description
Farm size	Continuous	Total area of the farm
Farm income	Continuous	Net Farm Income (NFI)
Revenue source	Continuous	Livestock revenue
Reliance on subsidies	Continuous	Single Farm Payment (SFP)/ Basic Payment Scheme (BPS) Less Favoured Area Support Scheme (LFASS)
Change in debt	Continuous	Short-term and long-term debts which are defined as short-/long-term loans and creditors valuations at the beginning and end of the year
Livestock numbers	Continuous	Livestock numbers measured in livestock units
Total labour	Continuous	Labour measured in man units

Several other aspects other than those collected by the FBS could possibly affect the intentions-behaviour discrepancy. However, the purpose of this study is not to empirically examine all these different explanations. This would go beyond the data available in the FBS dataset and could not be done without additional variables and experimental evidence (similar arguments are made by Väre et al., 2005 and Hennessy et al., 2016). Using the FBS dataset, the final selection of variables to be considered in the two multinomial logistic models was made based on log-likelihood comparisons between different models.

4.3. Results

The results are presented in three steps. First, a descriptive account of stated intentions and actual behaviours in the sample of farmers is provided. Second, this descriptive information is analysed to measure the intention-realisation discrepancy. In the third step, the results of the multinomial logistic models are described.

4.3.1. Descriptive statistics

Table 4.2 presents data on the number of farmers that indicated they would maintain their way of life, maximise their annual profits or increase the size of the business as a primary objective in the 2013 survey. Data on the number of farms that increased, decreased or maintained NFI, or livestock numbers over the year are also illustrated, leading to the classification of farmers as Accurate, Optimistic or Pessimistic according to their main objectives.

Table 4.2. Stated intentions and actual behaviour as measured by farmers' primary objectives and two proxy indicators (Net Farm Income and livestock numbers), respectively. Farmers were labelled based on how accurately their behaviour in 2016 represented their objectives in 2013.

Objectives (2013)	No. farms (2013)	Behaviour (2016)		Label	No. farms (2016)
Maintain way of life	94 (47.72%)	NFI	Maintained	Accurate	8 (8.51%)
			Increased	Pessimistic	36 (38.30%)
			Decreased	Optimistic	50 (53.19%)
Maximise annual profits	88 (44.67%)	NFI	Maintained	Optimistic	6 (6.82%)
			Increased	Accurate	35 (39.77%)
			Decreased	Optimistic	47 (53.41%)
Increase the size of the business	15 (7.61%)	Livestock Numbers	Maintained	Optimistic	8 (53.33%)
			Increased	Accurate	3 (20%)
			Decreased	Optimistic	4 (26.67%)

Key: NFI = Net Farm Income.

The largest group of respondents interviewed in 2013, almost 50% of farmers (n = 94), stated intentions to maintain way of life by 2016. Forty five percent of farmers, 88 co-operators, indicated they would maximise annual profits, whereas 7.6% (n = 15) said they would increase the size of the business.

When the actual performance data for 2016 are investigated, the results show that of those indicating they would maintain production, only 8.5%, i.e. eight farmers, were accurate in the 2013 survey by maintaining NFI. Similarly, for the farmers who stated they would increase the size of the business, the results show that only three farmers (20%) were accurate and increased livestock numbers. Alternatively, of those planning to maximise annual profits, almost 40% were accurate in the 2013 survey and have increased NFI, so the direction of change was correct, being in line with a priori expectations.

Of those wanting to maintain their way of life as a primary objective, the remaining ‘inaccurate’ farmers were more likely to be optimistic and decrease NFI (53.2%), rather than increasing NFI (38.3%). A similar effect is shown for the farmers planning to maximise annual profits, with the majority of ‘inaccurate’ farmers decreasing NFI (53.4%) in 2016. However, when it comes to increase the size of the business, farmers in this ‘inaccurate’ category were more likely to maintain livestock numbers (53.3%) than reduce them (26.7%).

Table 4.3 shows the total number of farmers that were Accurate, Optimistic or Pessimistic. About 23.4% of farmers are classified as Accurate in 2016, whereas the remaining ‘inaccurate’ farmers tend to be Optimistic (53.4%) rather than Pessimistic (18.3%).

Table 4.3. Farm types based on intention-behaviour gap. Total number of farmers that were Accurate, Optimistic or Pessimistic according to their primary objectives for the business.

	Accurate	Optimistic	Pessimistic
Number of farms	46 (23.35%)	115 (58.38%)	36 (18.27%)

The intentions survey was only a reliable indicator of future production in about 23% of the sample, which indicates a substantial intention-behaviour gap. As mentioned, an interesting question to address is whether this intention-behaviour gap is influenced by systematic factors, as suggested by Wong and Sheth (1985). With the FBS dataset, it is possible to test such hypothesis, for instance, by comparing the characteristics of the

farmer groups identified in Table 4.2, and by examining the multinomial logistic models outlines.

4.3.2. Farmers' actual behaviour

In a second step, the factors describing the intention-realisation gap were explored. Descriptive statistics for the main variables according to farmers' actual behaviour (Table 4.4) are presented, with statistical significance at the 90% level noted where appropriate.

In Table 4.4, the characteristics of the overall sample are reported, together with the characteristics associated with each behavioural group of farmers. The results suggest that Optimistic farmers operated with larger areas (302.1 ha), while returning lower NFIs (£2.4k) and recording a lower change in debt (short- and long-term; £-8.5k) than Accurate and Pessimistic farmers. Financially, Pessimistic farmers tended to be less reliant on subsidies (£56.2k), return lower agricultural revenues (livestock and crops; £101.6k) and present lower net investments (£2.1k) when compared to others. On average, Pessimistic farmers recorded the lowest labour usage (1.5 man units), livestock numbers (124.5 units), and grazing livestock units (141.9 units).

Table 4.4. Summary statistics for the main variables according to farmers' actual behaviour (2016), with statistical significance at the 90% level noted where appropriate.

Variables		Accurate	Optimistic	Pessimistic	All	P value
Total area (ha)		309.54 ± 284.36	302.12 ± 456.42	246.31 ± 272.44	293.66 ± 391.79	0.7228
AUA (ha)		303.39 ± 277.10	296.86 ± 453.70	242.42 ± 269.86	288.43 ± 388.38	0.7327
NFI (£)		36,846.52 ± 47,834.85	2,376.48 ± 36,361.58	21,113.78 ± 29,189.95	13,849.40 ± 40,713.11	0.00001
Revenue source (£)	Agriculture (total farm)	164,598.15 ± 133,198.98	147,590.95 ± 130,190.73	101,628.28 ± 96,614.376	143,162.90 ± 126,629.03	0.0689
	Livestock	159,254.30 ± 131,293.93	135,835.73 ± 125,010.44	98,890.14 ± 97,297.14	134,552.55 ± 122,945.15	0.0859
	Crops	5,343.85 ± 10,310.51	11,755.22 ± 29,838.72	2,738.14 ± 5,557.10	8,610.36 ± 23,715.37	0.0774
Subsidies (£)	BPS	51,409.13 ± 31,269.31	47,677.02 ± 35,751.30	48,198.33 ± 35,250.31	48,643.74 ± 34,527.88	0.8238
	LFASS	9,356.76 ± 8,914.12	8,889.28 ± 9,222.92	8,034.08 ± 8,230.95	8,842.16 ± 8,944.28	0.8004
Change in debt ² (£)	Short-term	3,150.65 ± 4,0967.60	-9,154.78 ± 126,758.13	315.28 ± 28,868.76	-4,550.86 ± 99,550.58	0.7401
	Long-term	790.43 ± 29,835.68	650.45 ± 25,164.85	-2,195.47 ± 6,262.75	163.07 ± 24,103.17	0.811
Net investments (£)	Land and buildings	12,304.94 ± 55,780.42	16,345.12 ± 83,662.54	820.33 ± 3,449.53	12,564.71 ± 69,435.70	0.5061
	Other assets	660.33 ± 1,952	756.76 ± 2,378.10	1,304.67 ± 4,657.53	834.37 ± 2,844.13	0.5397
Total labour (man unit)		1.93 ± 0.90	1.79 ± 0.77	1.50 ± 0.75	1.77 ± 0.81	0.0488
Livestock numbers (livestock units)		200.94 ± 108.10	148.45 ± 91.18	124.52 ± 98.69	156.33 ± 99.74	0.0009
Grazing livestock units ¹ (units)		216.24 ± 117.26	159.35 ± 95.71	141.85 ± 123.40	169.44 ± 109.17	0.0025
Farm type (%)	LFA Beef	22 (47.83%)	51 (44.35%)	19 (52.78%)	92 (46.70%)	0.756
	LFA Cattle and Sheep	14 (30.43%)	27 (23.48%)	9 (25%)	50 (25.38%)	
	Lowland	3 (6.52%)	9 (7.833%)	3 (8.33%)	15 (7.61%)	
	Mixed	7 (15.22%)	28 (24.35%)	5 (13.89%)	40 (20.30%)	

Note: Values within a row in bold are significantly different ($p < 0.1$).

¹Livestock unit grazing days equivalents: dairy cows, other cattle 2 years and over = 1; cattle less than 2 years = 0.5.

²Change in debt was defined as short-/long-term loans and creditors valuations at the beginning and end of the year.

Key: AUA = Area Used for Agriculture; NFI = Net Farm Income; LFASS = Less Favoured Area Support Scheme; BPS = Basic Payment Scheme; LFA = Less Favoured Areas; SDA = Severely Disadvantaged Areas.

4.3.3. Multinomial logistic models: farmers' intentions versus behaviour

In the third step, two multinomial logistic models were used to identify potential drivers of each specific intention, and of the intention-behaviour discrepancy. In the initial models specifications all variables specified in Table 4.4 were considered, however not all variables appear in the final multinomial logistic models outlined in Tables 4.5 and 4.6, as a result of the stepwise regression process.

Under the final specifications of the model (Table 4.5) some variables proved to be highly significant; however, the estimates generated a pseudo R^2 of 0.1566 ($p < 0.0000$), indicating high levels of unexplained variation within the sample. This was also a common finding in previous studies of intentions, for instance, Giannoccaro and Berbel (2013; $R^2s \leq 0.20$), Latruffe et al. (2013; $R^2s < 0.15$) and Hennessy et al. (2016; $R^2s < 0.05$).

In Table 4.5 the RRR are presented against the base outcome objective in each column. Those variables with an RRR below one imply they are more likely to determine membership of the base outcome objective compared to the comparison objective as the variable increases. Conversely, an RRR above one implies that they are more likely to lead to membership of the comparator objective, compared to the base outcome objective.

Table 4.5. Multinomial logistic model of farmers' intentions (2013) to investigate the characteristics of the farmers who stated they would maintain way of life, maximise annual profits or increase the size of the business.

	Variable	Base Outcome Objective: Maintain way of life		Base Outcome Objective: Maximise annual profits		Base Outcome Objective: Increase the size of business	
		Coef.	p value	Coef.	p value	Coef.	p value
Maintain way of life (N = 94)	Total area			1	0.633	0.99	0.112
	NFI			1.01	0.179	1.06	0.092
	Livestock revenue			0.99	0.832	0.99	0.264
	SFP			1	0.809	0.99	0.704
	LFASS			0.92	0.022	0.88	0.053
	Livestock numbers			1.05	0.013	1.07	0.001
	Δ Short-term debt			1	0.429	0.97	0.035
	Δ Long-term debt			1.01	0.228	0.99	0.284
	Total labour			1.39	0.297	2.28	0.167
	Constant			0.26	0.001	0.02	0.000
Maximise annual profits (N = 88)	Total area	1	0.633			0.93	0.089
	NFI	0.99	0.179			1.01	0.400
	Livestock revenue	1	0.832			0.99	0.278
	SFP	1	0.809			0.98	0.557
	LFASS	1.09	0.022			0.97	0.570
	Livestock numbers	0.96	0.013			1.07	0.029
	Δ Short-term debt	1	0.429			0.97	0.016
	Δ Long-term debt	0.99	0.228			0.98	0.093
	Total labour	0.72	0.297			1.64	0.390
	Constant	3.90	0.001			0.08	0.003
Increase the size of the business (N = 15)	Total area	1.01	0.112	1.06		0.086	
	NFI	0.96	0.098	0.99		0.400	
	Livestock revenue	1.01	0.264	1		0.278	
	SFP	1.01	0.704	1.01		0.557	
	LFASS	1.14	0.053	1.05		0.570	
	Livestock numbers	0.94	0.001	0.95		0.023	
	Δ Short-term debt	1.05	0.035	1.11		0.016	
	Δ Long-term debt	1.02	0.284	1.07		0.094	
	Total labour	0.44	0.167	0.61		0.390	
	Constant	49.80	0.000	12.75		0.003	

LR χ^2 (16) = 56.11
Log likelihood = -151.0415
Prob > χ^2 = 0.0000
Pseudo R² = 0.1566

Note: Values within a row in bold are significantly different ($p < 0.1$). Key: NFI = Net Farm Income; SFP = Single Farm Payment; LFASS = Less Favoured Area Support Scheme; Δ = change.

The results indicate that farmers more reliant on LFASS and with lower livestock numbers were more likely to have the primary objective of maintaining way of life. Farmers recording a higher change in short-term debt were also more likely to have the intention of either maintaining way of life or maximising annual profits, rather than increasing the size of the business.

Conversely, if farmers returned a higher NFI they had a lower probability to intend maintaining way of life compared to increasing the size of the business. Furthermore, higher livestock numbers seemed to be a key determinant in dictating the likelihood of increasing the size of the business when compared to others. Farm related factors also determining higher likelihoods of maximising annual profits, relative to increasing the size of the business, were total area and change in long-term debt. A second model is shown below to inform the discussion of the intention-behaviour gap.

4.3.4. Multinomial logistic model of the accuracy of farmers' intentions

Table 4.6 illustrates the results of the multinomial logistic model of the accuracy of farmers' intentions. Farmers that were previously categorised as Optimistic or Pessimistic are compared to those that were Accurate in their intentions. The final model is statistically significant (pseudo $R^2 = 0.1350$; $p < 0.0000$) and most variables were significant at 0.1 level. Fewer significant variables could be found for characterising Pessimistic farmers, reflecting the lower number of observations for this class.

Table 4.6. Multinomial logistic model of the accuracy of farmers' intentions (2016) to explore the characteristics of the Accurate, Optimistic and Pessimistic farmer groups.

Variable	Base Outcome Behaviour Optimistic		Base Outcome Behaviour Pessimistic		
	Coef.	p value	Coef.	p value	
Accurate (N = 46)	Total area	1.05	0.053	1	0.209
	NFI	0.94	0.000	1.01	0.604
	Livestock revenue	1.06	0.028	1	0.835
	BPS	0.99	0.479	1	0.705
	LFASS	1.02	0.539	1	0.958
	Livestock numbers	0.96	0.040	0.98	0.017
	Constant	4.04	0.001	2.56	0.076

LR χ^2 (12) = 51.30
Log likelihood = -164.3516
Prob > χ^2 = 0.0000
Pseudo R² = 0.1350

Note: Values within a row in bold are significantly different ($p < 0.1$). Key: NFI = Net Farm Income; BPS= Basic Payment Scheme; LFASS = Less Favoured Area Support Scheme.

As can be seen a higher total area and livestock revenue increased the probability of being Optimistic relative to being Accurate, i.e. those operating higher areas and returning higher livestock revenues were more likely to overestimate their future production plans in the intentions survey. Furthermore, the profitability measure, NFI, generated an RRR of below one, suggesting that lower profit increased the probability of being Optimistic rather than Accurate. Alternatively, farmers presenting higher livestock numbers were more likely of being Accurate.

The fact that general farm and farmer characteristics, including reliance on subsidies, net investments and farm type are not statistically significant indicates that the intention-behaviour gap cannot be fully explained by several variables recorded in the FBS dataset.

4.4. Discussion

Compared to the existing literature on farmers' intentions, this study is innovative in the sense that it is the first study exploring the reliability of an intentions survey on the primary objectives of Scottish beef and sheep farmers. One of the key findings of the study is that farmers' intention to change, i.e. maximise annual profits or increase the size of the business rather than maintain way of life, appears to be driven, in part, by common farm structural and socio-economic variables. Farmers intending to increase the size of the business or maximise annual profits were more likely to have certain characteristics. As such, profitability, livestock numbers, and reliance on support payments seemed to be the most significant indicators, which indicates that beef producers with higher net farm incomes and livestock numbers are more likely to seek a change in the farm business. These farmers are focused on profit and farm expansion, perhaps reflecting a more production-orientated approach to farming, as discussed in Chapter 3. This is in line with the work of Walford (2003), Burton and Wilson (2006) and Gorton et al. (2008) where it is suggested that 'productivist' tendencies prevail among English farmers, despite a number of concurrent studies tentatively suggesting a transition towards what could be described as 'post-productivism' and/or 'multifunctionality' (Wilson, 2001). More recently, research has shown that some farmers still retain a 'productivist' mind-set, although agricultural policy has moved from production-oriented towards more decoupled forms of payment (O Donoghue and

Howley, 2012; Howley et al., 2015), as highlighted in the review of the agricultural policy context in Chapter 1.

Conversely, farmers more reliant on LFASS were more likely to want to maintain their way of life. As expected, higher levels of LFASS reflect a greater proportion of land classified as LFA. As argued by Barnes et al. (2015b), a possible explanation is that farmers who have a major part of their farms in disadvantaged areas have a more constrained set of agricultural possibilities, which may limit the desire for change within the business.

Examining individual farmers' responses, the intentions survey was only accurate in about 20% of the cases. Overall, the results show that the majority of farmers overestimated their future production plans - were 'optimistic' - which suggests that stated intentions were not a good predictor of realised objectives. This result corroborates the findings of previous research on farmers' intentions (e.g. Lefebvre et al., 2014; Viira et al., 2014) where farmers' stated plans showed significant discrepancies when compared to their actual behaviour. Whether such discrepancies can be described by physical and financial characteristics of the sample is an important topic in the intention-behaviour gap literature. As argued by Hennessy et al. (2016), if that is the case, this evidence can help enhance the accuracy of intentions surveys either through better sample selection and/or informed adjustment of the results. For instance, 2016 was a particularly challenging year in terms of grass growth in Scotland, which led to higher feed costs, helping to justify the low accuracy of farmers' responses in this specific year, as farmers had experienced higher costs of production. Furthermore, it is also important to note that although farmer decisions seem to be driven not solely by economic returns, of those farmers intending to maximise annual profits, almost 40% were accurate. This finding is consistent with the study performed by Barnes et al. (2014a) among Scottish beef farmers, where LP model estimations of the impacts of two potential CAP reform scenarios (full decoupling and partial decoupling) on beef farmers in Scotland post 2015 were in line with farmers' intentions, thus reinforcing the adoption of economic rationality within farming.

A thorough analysis of the characteristics of the farmers participating in the study showed that only a few variables were significantly associated with the probability of

being accurate in the intentions survey. This indicates that the set of variables currently available in the FBS dataset can only explain the intention-behaviour gap to some extent. Similar results were reported by Hennessy et al. (2016) in relation to Irish cattle and sheep farms.

Such discrepancy between intentions and actual behaviour may exist for a number of reasons. First, farmers' decisions may not mirror their original intentions as a result of external conditions and information availability. More, or new, information may become available following the survey, either due to a change in the environment (e.g. economic conditions pertinent for the decision, family situation), or because the farmer did not have access to such information previously (Manski, 1990; Väre et al., 2005). The intention-realisation gap is likely to increase with the interval between the intentions survey and the data collection on actual behaviour, since circumstances are more likely to change over longer periods of time (Ajzen, 1985; Barnes et al., 2014b). However, shorter periods between both surveys do not automatically imply that the gap between intentions and realisations will be reduced, as this will be determined by the timing of the potential changes involved. For instance, the discrepancies reported in this study can also be partially explained by the NFI not being fully under the control of the farmer, as markets for agricultural commodities have an inherent tendency to be volatile.

Several reasons may contribute for the time lag between the initial decision and its actual implementation, for instance, due to legal requirements, which increase the likelihood of changes in the available information and context. Furthermore, actual decisions on family firms include actions of different family members, whereas surveys are usually addressed to one person only (Kimhi, 1997). Surveys often take into account the farm operator's frame of mind, however the farm operator's plans do not always take place. As stated by Horowitz (1992), farmers can be time-inconsistent, meaning that their preferences when planning future activities may contrast to their preferences at the time of execution.

In addition, as with all surveys of future intent, farmers' responses may present some built-in bias that would be a reflection of existing agricultural conditions and outlook (Barnes et al., 2016). In Scotland, at the time of the intentions survey (2013), farmers

were recovering from severe wet weather conditions that caused loss of stock in more remote areas. Accordingly, less optimistic responses would have been expected, i.e. less farmers declaring that they intended to maximise annual profits or increase the size of the business. The high level of persistence to improve farm business performance and remain within farming found in this study may also support the robustness of the survey in gathering farmers' views on the future of the industry. This rather positive view of the future in the face of recent challenges is in line with Lobley and Potter's (2004) and Barnes et al.'s (2014b, 2015b) findings, where the majority of farmers expressed strong willingness to continue farming despite recent hardships. Similarly, Harvey (2000) found that farmers were reluctant to change, maintaining an agricultural focus, although recognising that this way of life and business was not ultimately sustainable. In the same way, Gorton et al. (2008) highlighted that most farmers in their study wished to maintain an agricultural focus in spite of potential changes in agricultural policy.

Apart from the factors related to context, the literature also emphasizes the existence of biases likely to influence farmers' responses in intentions surveys. First, farmers may dedicate little time to answering survey questions in comparison to the amount of time and effort they put into making decisions. Thus, their answers might not reflect their true preferences. Bagozzi and Yi (1989) and Vare et al. (2005) argued that farmers might also feel obligated to answer the survey even though they might not have made particular plans. Such intentions are likely to vary quickly with time, only having a weak effect on behaviour.

Another type of bias has been noted by Fujii and Gärling (2003), which stems from the need to be seen as socially responsible, or to exert influence toward a desired end. As mentioned by Thomson and Tansey (1982), these are relevant concerns in agricultural policy research, as farmers' responses might be biased if they believe their views can affect the results of the survey and subsequent policy decisions.

Taking a broader view of the results, a limitation of this study is the sample size. Further research is needed to provide validation of results, if possible with a larger sample and including additional farm types. Furthermore, a regular collection of data on farmers' intentions could improve understanding not only of the development of intentions, but

also of possible sources of discrepancy between intentions and behaviour. This would help building a more systematic classification of the characteristics that guarantee reliability of stated intentions among a sample of farmers.

4.5. Conclusions

In this chapter, farmers' intentions and actual behaviour in relation to their main objectives for the business were summarised using a combination of an intentions survey and the full FBS survey. Three groups of farmers with different intentions were compared to advance knowledge about farmers' decision-making by considering associations between farmers' intentions and actual farm financial, and performance data. The majority of farmers overestimated their future production plans, suggesting that, in general, stated intentions were not a good predictor of realised objectives, which is in line with previous studies. An analysis of farmers' characteristics showed that some variables were significantly associated with the probability of being accurate in the intentions survey; however, overall explanatory power was poor indicating that the set of variables presently available in the FBS dataset can only explain the intention-behaviour gap to some extent. A larger sample coupled with a regular collection of data on farmers' intentions could help improve understanding of both farmers' intentions and potential sources of discrepancies between intentions and behaviour. Developing such understanding is crucial in light of the broader context of recent falls in agricultural income in Scotland, and the need to change and adapt to remain viable in view of current market and policy challenges. Within this context, this study opens related areas for further investigation, including both the analysis of farm vulnerability and resilience under an evolving policy context, and the potential impacts of on-farm improvements on farm output and profitability that can be achievable through the adoption of specific sustainable technologies and/or practices.

5. Chapter 5: Estimating the impacts of technological innovations and agricultural support policy scenarios on Scottish beef and sheep farm systems

5.1. Introduction

Technological innovation has always been the main driver of productivity growth in agriculture, as well as an important part of achieving resilience to market and policy uncertainties (e.g. Spielman and Birner, 2008; OECD, 2013). Technology adoption per se is a broader concept that is affected by the development, dissemination and implementation at the farm level of existing practices or new techniques that depend on farm capital and other inputs (OECD, 2001). Technology adoption is also influenced by the active exchange of technological knowledge between research and farmers, e.g. demonstration or monitor farms, training, education and advice, among others, which encourage the diffusion of innovative practices and technologies, thus building the basis of farmers' knowledge (Toma et al., 2018).

Knowledge gaps about the existence of an innovative practice and the estimated costs and benefits of adoption can act as major barriers to adoption (Lubell et al., 2011). Information about the direct impacts of technological innovations, for instance, in terms of profit through labour saving, are not always available. By estimating the effect of innovations, in terms of losses and benefits, farmers can improve their managerial decisions, researchers can recognise the influence on particular agricultural sectors such as livestock, and policy makers can make decisions and plan policies to support more efficient adoption. Assessments of the impacts of innovations are therefore important sources of information and advice, particularly in the light of current market and policy contexts detailed in Chapter 1 (Section 1.4.2.).

Across all sectors, net incomes in Scotland are heavily subsidised with support payments. In particular, Scotland continues to pay coupled support payments in the beef and sheep sectors, and directly supports farmers within the LFAs, with payments ranging from £34-£71/ha (Silcock et al., 2017). The review of the economic performance of Scottish beef production systems presented in Chapter 1 clearly shows that economic vulnerability is of primary concern considering recent policy challenges,

which require farmers to respond quickly to potential new market situations. With ‘Brexit’ uncertainty on the horizon and the future of farm subsidy payments uncertain, the importance of becoming more focused on efficiency has been emphasized (e.g. Scottish Government, 2018e), in which Scottish beef and sheep farmers’ can play a significant role: by exploring opportunities for productivity growth that have been shown to have a major impact on profitability. This can be achieved, for instance, by adopting the more efficient combinations of technological innovations that will lead to the greater returns to the farm business.

The technologies with potential to help sustainably improve profitability and productivity in Scottish beef and sheep farms described in Chapter 2 (Section 2.4.) include: grassland reseeding (Creighton et al. 2011a; Shalloo et al., 2011), bovine EID (EC, 2011b; AHDB, 2015), further genetic gains in growth efficiency (Islam et al., 2013a; Amer et al., 2015) and animal health planning (AHP; Islam et al., 2013b; Boden et al., 2017). The potential benefits of implementing these technologies have been assessed individually and rarely within a systems context. Considering the farm system as a whole enables more comprehensive comparisons, and allows to rigorously test combinations of innovations. A better understanding of the potential interactions of new technologies as part of a farm system is fundamental, because in practice farmers will usually be adopting a combination of technologies to address several agricultural production constraints (Toma et al., 2018).

As discussed in Chapter 2, a few studies have examined the financial impacts of implementing new practices at farm-level using mathematical programming models of production. The use of mathematical programming models offers a cost-effective opportunity to investigate the response of farms to change resulting from technological advances (Crosson et al., 2006). Some of these studies only consider a single activity on a farm and assume no interconnecting effects between farm activities (e.g. Häsler et al., 2012), others assume interconnected activities to assess average impacts on the farm and establish a national estimate based on that assessment (e.g. Ash et al., 2015). Even though these studies consider the production and management variability within a farm, they do not take into account the variabilities that exist between farms, therefore limiting the understanding that can be achieved from a national-level perspective

(Shrestha et al., 2018b). A national-level analysis can inform not only farmers, but also policy makers planning future agricultural support policies.

In addition, these methods usually only consider averages for all farm types to generalize economic impacts. The use of average representative farms reveals the broad pattern of results, however it necessarily masks variation in individual farm circumstances. To date, there is little evidence about the direct impacts of innovations on economic vulnerability at the individual farm-level. As a result of the farm variability that exists between different farm types, impacts of technologies and farm responses are likely to vary from farm to farm, which depend on farm resources, management practices and production efficiencies. Due to this variability, some farms are more capable of responding to policy reforms than others (Breen et al., 2005; Vosough Ahmadi et al., 2015; Shrestha et al., 2018b). By incorporating farm variability, all the physical and financial characteristics, and interactions between different activities of the farm system can be used to estimate the effects of such measures. Studies that tested farm vulnerability and resilience under agricultural policy reforms (Shrestha, Hennessy and Hynes, 2007; Hennessy, Shrestha and Farrell, 2008; Shrestha et al., 2018b) report that changes in support payments can expose farms to economic vulnerability. As a step towards addressing this information gap in the current literature, this chapter builds on the segmentation model developed in Chapter 3, and combines information from the review of beef production systems and policy context introduced in Chapter 1, and the discussion of the adoptability of agricultural innovations from Chapter 2 to test this hypothesis. The extent of a farm's reliance on direct support payments was thus considered an indicator of financial vulnerability.

Accordingly, a farm-level economic model, ScotFarm, is used under five innovation scenarios and two policy scenarios: (i) direct payments retained as currently under the CAP, and (ii) elimination of direct payments. As proposed in Chapter 1, the financial impacts of such innovations on Scottish beef and sheep farms are examined in both policy scenarios due to the possibility of change in farm support payments in the UK following 'Brexit', which are likely to influence the impacts and significance of agricultural innovations and their adoption. The chapter is structured as follows: the next section describes the modelling approach employed and dataset, followed by sections outlining the results and their subsequent discussion.

5.2. Materials and Methods

ScotFarm model

ScotFarm is a farm-level Linear Programming (LP) model that maximises farm net income, which is defined as the sum of gross margins from all farm activities and farm support payments (BPS [S] and LFASS), less fixed costs (FC). Following Shrestha et al. (2018b), the general mathematical formulation of maximising farm net income is as follows:

$$\text{Max}_{x_{f,i} \geq 0} Z_f = \sum [gm_{f,i}] x_{f,i} + S_f + LFASS_f - FC_f \quad (5.1)$$

Subject to,

$$\sum_i A_{f,i} x_{f,i} \leq b_f \quad (5.2)$$

Where Z represents optimised net income of all activities from all the enterprises of a farm; gm denotes gross margin of activities; index i symbolises agricultural activities such as livestock and crops while f represents individual farms; $x_{f,i}$ is the non-negative activity level in hectares or heads of farm f activity i ; S is the farm direct support payment; $LFASS$ represents LFASS payment; FC is total fixed costs; A is an input–output coefficient for activity x ; and b represents limited farm resources.

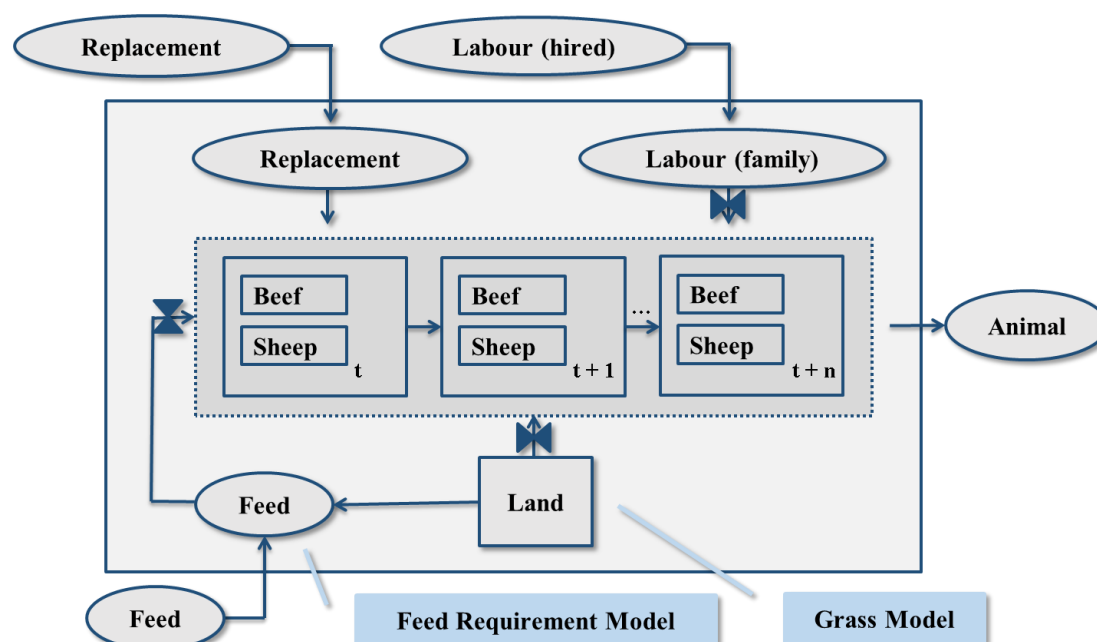
ScotFarm, which is solved using GAMS 24.9.2¹⁸ (Brooke et al., 1998; GAMS, 2019), assumes that farmers are profit-oriented and maximises farm net income within a set of limiting farm resources. Beef and sheep production systems are the centre of the model (Figure 5.1). These systems are constrained by land, labour, feed and animal replacements available on a farm. However, farms can buy-in feed, animal replacements and hire casual labour if required. The beef system contains four categories of animals: calf, suckler, beef under 1 year old and beef under 2 years old. Calves and beef under 1 year old can be sold and replaced at the end of year (Vosough Ahmadi et al., 2015). The model assumes a seven-year replacement structure where 14.3% of suckler cows are culled each year and replaced by either on-farm or off-farm replacement stocks. The sheep system includes two categories of animals: lambs and ewes. A proportion of female lambs are sold and the remainder are kept for use as

¹⁸ The LP model was written in the mathematical programming software package Generic Algebraic Modeling System, GAMS (2019), and was solved using the ‘CONOPT’ solver (see <https://www.gams.com/>).

replacements. Cast ewes can be sold and replaced at the end of the year. Similarly, these ewes are replaced by on-farm and off-farm replacement stocks. Calving, lambing and survival rates were adjusted according to each farm type. The resources including labour and feed required are then calculated based on the number of animals on farm each year¹⁹.

ScotFarm is a ‘pseudo-dynamic’ model that runs within an established timeframe. When interpreting results, the outcomes from initial and final years are removed and the model outputs from the middle years are averaged. This minimises the starting and terminal effects of LP (Ahmad, 1997; Shrestha, 2004). While this chapter represents the first application of the ScotFarm model to the task of assessing the impacts of different innovation scenarios in Scottish beef production systems, the model and methodology have been applied in several studies, e.g. Vosough Ahmadi et al. (2015), Glenk et al., (2017) and Shrestha et al. (2018a,b). See Chapter 1 for an extended discussion.

Figure 5.1. A schematic diagram of ScotFarm, a farm-level Linear Programming (LP) model that maximises farm net income.



¹⁹ Details of the model are available in https://www.sruc.ac.uk/download/downloads/id/3513/scotfarm_%E2%80%93_a_farm_level_optimising_model.pdf

Data

Farm-level data of 195 Scottish beef and sheep farms were obtained from the Scottish Government's 2016 Farm Business Survey (FBS; Scottish Government, 2016), which summarises the 2015/2016 reporting year. As reviewed in Chapter 1 (Section 1.3.), the survey collects physical and financial information from sampled farms. The data used in the model consisted of physical data, including agricultural utilised area under temporary and permanent grass, grass silage, crops and rough grazing, number of animals and labour availability; and financial data such as variable costs (i.e. costs incurred for inputs into specific farm activities; e.g. artificial insemination [AI], veterinary costs, seed costs), fixed costs (i.e. machinery, labour, rent), prices (livestock and feed prices) and farm support payments (BPS and LFASS). Actual livestock prices from the FBS and efficiency scores for each farm were used. To include price effects in the results, price indices derived from a partial equilibrium model, FAPRI (AFBI, 2017), were used for the timeframe in the model. All other financial parameters such as off-farm and diversification incomes stay constant.

Farms are categorised into three classes of farmers and respective farm types. The methodology is based on previous work into segmentation analysis (Chapter 3) through an application of a latent class model based on farmers' objectives and attitudes towards both economic and environmental aspects of farming in Scotland. As detailed in Chapter 3, latent class analysis revealed three distinct classes of farmers: Satisfiers, Profit-seekers and Expansionists. Maintaining their way of life and profitability were important to Satisfiers, Profit-seekers strongly identified with maximising annual profits and Expansionists had diverse objectives but were more likely than the other two classes to be interested in increasing the size of the business. Four farm types were included: LFA cattle and sheep, LFA beef, lowland and mixed farms. Thus, an important feature of this chapter is that it combines data on both farm-level performance and farmers' behaviour. In this sense, segmentation analysis can be applied to investigate how heterogeneity in structural and financial characteristics across Scottish beef systems may influence the costs and benefits of adopting specific technologies and practices, as well as the reliance on agricultural support policy.

In the first step, the averages of farm data in each class and respective farm type were considered as representative farm data, and were used in ScotFarm. Then, due to the

farm variability that exists between different farm types, an analysis of individual farms was also carried out.

Modelling scenarios

The five innovation scenarios that were examined are outlined in Table 5.1. These scenarios were informed by both the literature and input from a meeting with experts in animal health, genetics, nutrition and pasture management. The purpose of the meeting was to identify opportunities for encouraging further profitability and productivity gains in Scottish beef production systems. As discussed in Chapter 2, following Dicks et al. (2018), technologies that were feasible, commercially viable, with environmental or social benefits, associated with the potential to improve productivity or profitability were identified. Attention was also given to the current policy context and future legislation. The assumptions behind the benefits and costs of each innovation were generalised across farm types. In the model, costs estimates under each innovation scenario were considered as additional costs of production. The benefits were either directly incorporated in the model, for instance, as an increase in revenues collected e.g. due to an increase in the live weight of animals, or indirectly, for example, as an increase in grass yields and hence a reduction in feed costs.

Table 5.1. An overview of the innovation scenarios that were modelled using ScotFarm.

Technology	Scenarios
Grassland reseeding	Increasing grassland productivity
Animal Electronic Identification (EID)	Improved efficiency of data recording, traceability and information flow
Animal Health Planning (AHP)	Improved farm health management
Genetic Improvement (GI)	Improved growth efficiency through genetic gain
Combined technologies (CT)	Simultaneous application of the four technologies

Simulation of each of the five scenarios required specific settings in the ScotFarm model, as follows:

a) Grassland reseeding

Data from several studies have shown that newly reseeded swards can produce an extra three to five tonnes of DM per hectare (e.g. Creighton et al., 2011a; Shalloo et al., 2011; Teagasc, 2011). To simulate grass growth, an external grass model, *Simulateur*

mulTidisciplinaire pour les Cultures Standard (STICS; Brisson et al., 2003) developed at INRA, is used to generate fresh grass and grass silage yields under pre-set farm management practices, with these parameters being then included in ScotFarm. The soft link between STICS and ScotFarm is therefore achieved by directly incorporating outputs from STICS in ScotFarm. The assumptions behind both models in relation to the use of fertiliser, stocking density, crops in rotation, grazing pattern, silage cuts, soil type and location of the modelled farms need to be consistent (Shrestha, 2004). The effect of increased pasture yield from reseeding was thus simulated by increasing initial grass yields estimated by STICS by five tonnes of DM per hectare in ScotFarm.

In the model, grassland (*gland*) is initialised using farm level data. In the subsequent years, grassland (*gland*) consists of grassland used for grazing (*gfland*), grass silage (*gsland*) and hay (*ghland*):

$$gland(f, y) = gfland(f, y) + gsland(f, y) + ghland(f, y) \quad (5.3)$$

Where *f* represents individual farms and *y* symbolises each year the model is run. It is assumed that farmers can reallocate land to grazing or silage/hay production based on the feed requirements for animals on farm. The costs of grassland reseeding using the ‘overseeding’ method were also considered (£24/ha/year; SAC, 2015) when calculating farm gross margin.

b) Electronic Identification (EID)

Proposals for introducing bovine EID within the EU have been progressing over the last few years. According to the European Commission (EC, 2011b), all bovine animals would need to have an electronic identifier within the first year the new regulation comes into effect. In ScotFarm, this was achieved by considering all the costs involved in the EID tagging of beef animals when determining farm gross margin, and the time saved per reading using a handheld reader in comparison to manual reading (1.75 minutes per animal; Table 5.2). The costs included labour costs, costs of tagging and retagging beef animals (following estimates of the loss rate of ear tags reported by the EC), applicators and identifiers. It was assumed that each farm would require two handset readers (490€ per unit), with the costs of maintenance and training for usage being also included (15% of the total cost). Assumptions followed an impact assessment of the introduction of EID in the EU produced by the EC (EC, 2011b).

Table 5.2. Breakdown of the cost of identifying one bovine animal (EC, 2011b).

	1 EID-ear tag and 1 conventional ear tag (€)
<i>Labour cost</i>	1.47
Cost of tagging	1.31
5% retagging of conventional ear tags	0.09
4% retagging of EID ear tags	0.07
<i>Applicator</i>	0.45
<i>Identifier</i>	2.37
<i>Cost of tagging</i>	2.20
5% retagging of conventional ear tags	0.06
4% retagging of EID ear tags	0.11
Total (excl. Re-ID)	3.96
Total (incl. Re-ID)	4.29

Regarding the labour saving benefits of EID, the total labour required on a farm per year was calculated using published labour requirements for beef cattle enterprises (Standard Labour Requirement [SLR²⁰] coefficients, 12 hours/animal/year; SAC, 2015, 2017). This calculation took into account the time saved per reading using EID ear tags. Assuming that an average of 1.6 readings per animal are required for regulatory purposes each year (EC, 2011b), 2.8 minutes (0.047 hours) can be saved per animal annually:

- Labour requirements per livestock category (*livlab*)

$$livlab(f, a, y) = totani(f, a, y) \times [LAB(a) - 0.047] \quad (5.4)$$

- Total labour requirement on a farm per year (*tlab*)

$$tlab(f, y) = \sum_a livlab(f, a, y) \quad (5.5)$$

Where *f* represents individual farms; *a* is the livestock category; *y* symbolises each year the model is run; *totani* is the number of animals on farm; and *LAB* is the SLR coefficient. It is assumed that all labour used in the model is skilled labour, and the use of unpaid family labour is maximised where available. Thus, total labour requirement on a farm (*tlab*) is determined by first using family labour, with labour only being hired if additional labour is required.

²⁰ The SLR coefficient represents the input of labour required per animal under typical conditions for enterprises of average size and performance.

c) *Genetic improvement (GI)*

An improved growth efficiency through genetic gain was assumed in this scenario, by considering a live weight growth improvement of 10% in order to obtain more productive/prolific livestock. ScotFarm uses an external feed requirement model to determine the daily weight gain of an animal based on the Brody growth function (Kaps, Herring and Lamberson, 2000):

$$W_t(t) = A - (A - W_{t0})e^{-kt} \quad (5.6)$$

Where W_t is weight at given time t in days; W_{t0} is the weight at birth; A is the mature weight; and k is the maturing rate index.

Energy and protein requirements for an individual animal each day for maintenance, growth, pregnancy and lactation are then determined based on Alderman and Cottrill (1993). For instance, total energy requirement (T_e) is calculated using:

$$T_e = M_e + G_e + P_e + L_e \quad \forall t \quad (5.7)$$

Where M_e is the energy requirement for maintenance; G_e symbolises energy requirement for growth; P_e represents the energy requirement for pregnancy; and L_e is the energy requirement for lactation. Each of the components in the above equation is determined separately, for instance, energy requirement for maintenance is determined as follows:

$$M_e = (F + A)/k_m \quad (5.8)$$

Where F represents fasting allowance; A represents activity allowance; and k_m is the efficiency coefficient for maintenance. In addition to energy and protein requirements, dry matter intake (DMI) by individual animals is also calculated in the feed requirement model taking into account weight gain and metabolisability of a feed (Shrestha, 2004).

To achieve a live weight growth improvement of 10%, the relevant coefficients were adjusted in the external feed requirement model. Weight gains were calculated using the Brody function to model growth, and these estimates were then used to determine energy, protein and dry matter requirements using specific formulae, as described. Livestock prices and AI costs were also adjusted in ScotFarm, with heavier animals

being sold at higher prices assuming a 10% increase in weight, and AI costs being included in the variable costs. It has been reported that efficiencies of this magnitude can be achieved through genetic improvement (Amer et al., 2015; McHugh and McGee, 2016).

d) Animal Health Planning (AHP)

In this scenario, Bovine Viral Diarrhoea (BVD) vaccination and prevention were assumed. The Scottish Government has been supporting an industry-led scheme to eradicate BVD from Scotland, therefore having estimates of the financial benefits and costs of BVD prevention in Scottish beef farms can provide important considerations to help effectively reduce the incidence of disease. It was assumed that by adopting this AHP strategy, farms would increase calf numbers because of a reduced barren rate (seven additional suckled calves) and calf mortality (five additional suckled calves; ADAS, 2013), leading to an additional income calculated according to actual calf prices reported in the FBS. The costs of persistent-infection (PI) testing, vaccination and labour were also considered, following a case study estimating the financial costs of a typical occurrence of BVD in a 100 cow suckler herd, with calves sold at an average of 270 kg live weight (ADAS, 2013; Table 5.3).

Table 5.3. Typical estimated cost benefit of eliminating PI animals and vaccinating against BVD in a 100 cow suckler herd (ADAS, 2013).

Cost benefit of prevention	Calculation	£/herd (100 cows)	Cost (£/cow)
Cost of vaccination (2 doses at £3 per dose)	2 x £3	600	6
Labour costs to administer (1 day per vaccination for 100 cows)	2 x £100 per day	200	2
Cost of PI testing the herd (2 hours vet time at £100/hour plus lab fees plus materials (£600))	£200 + £600	800	8
Total cost of BVD vaccination and prevention	£600 + £200 + £800	1,600	16
Additional income - reduced barren rate from 12% to 5% = 7 additional suckled calves at forecast sale value of £540/head less production costs*	7 calves at £486/head	3,402	34
Reduced calf mortality from 8% to 3%	5 calves at £486/head	2,430	24
Additional calf value less additional cost	£5,832 - £1,600	4,232	42

*270 kg live weight at £2.0/kg less £54 production costs – marketing £12, transport £17, vet/meds £5 and feed £20

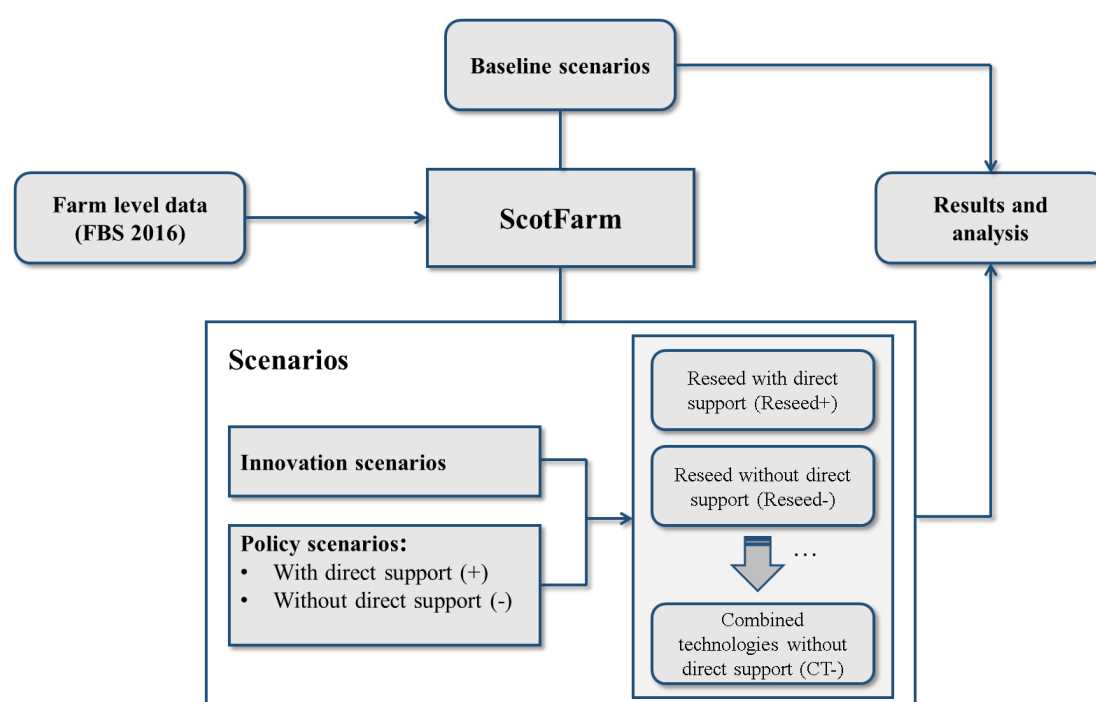
e) Combined technologies (CT)

The individual scenarios were combined to analyse the effects of multiple technological improvements. These four technologies were selected taking into account that when combined they would likely benefit different areas of animal production, providing potentially more additive than substitutional impacts. The model was tested using step-wise addition of each of the individual scenarios to test there were no unusual interactions, following Ash et al. (2015). Although the full impact of some innovation scenarios would need several years to take effect (e.g. genetic improvement), the analysis was performed without a ramp-up period and it was assumed that these innovations would have been fully adopted from the start of the scenario runs. It was also ensured that the new practices or technologies could be introduced sustainably, hence not leading to overgrazing and land degradation. Animal numbers were not allowed to increase significantly to avoid overstocking and utilisation of pasture increasing beyond sustainable levels. The number of animals was constrained over a threshold of maximum number to limit the number of animals to a farm's holding capacity.

Model runs and innovation scenarios

ScotFarm uses farm-level data for each of the sampled farms and runs a baseline scenario where support payment stay at existing levels (2015/16). The model was then optimised for the five innovations scenarios (i.e. Reseed+, EID+, GI+, AHP+ and CT+). Each scenario was also considered when direct support is withdrawn and LFASS is reduced to 50% of current rates (2015/16) in recognition of likely budget constraints 'post-Brexit' (i.e. Reseed-, EID-, GI-, AHP- and CT-). Hence, 10 scenarios for each group of farms were examined. Results for each scenario were then compared with both baselines accordingly (classified as 'with' and 'without direct support'). In the model, direct support is withdrawn in 2019 and the results shown are for 2026. The results of individual farms were further analysed after grouping the farms into four performance categories ('quartiles') based on each farm's baseline net profitability as measured by net income, to identify if these scenarios had a different impact depending on 2016 profitability levels. An outline of the ScotFarm methodology is presented in Figure 5.2.

Figure 5.2. Flow chart of the modelling approach used in this study.



5.3. Results

The combination of three classes of farmers with four different farm types modelled across a baseline and five innovation scenarios generated a large volume of results. These results are summarised below by farm type; first, the focus was set on the range of representative farm-level circumstances derived from the FBS, and then on individual farms. To illustrate farms' susceptibility to the removal of direct support, net incomes resulting from the modelling scenarios are also analysed without the existing levels of support. For ease of comparison, the same colour keys are used throughout.

5.3.1. Estimated average changes by farm type

Farm type characteristics

As mentioned, previous analysis identified three classes of farmers and four beef farm types across Scotland (Chapter 3). These farms differ from each other on production level, land capability, labour use, financial support and farm net income. Average farm characteristics are provided in Table 5.4. LFA cattle and sheep farms have on average lower stocking densities and higher rough grazing areas, being more extensive. With more sheep, these farms receive comparatively higher direct support and LFA payments and have higher net incomes. An average LFA beef farm carries comparatively fewer

finishing cattle, has lower variable costs and uses slightly less family labour. Recording the highest stocking densities and largest grazing land areas, lowland farms return the second highest average farm net income and direct support payment. Mixed farms present on average higher beef numbers, arable land, and have more family labour to draw on while incurring higher variable and overhead costs in their farm system. These farms also receive less financial support and generate less net income than other farm types.

Modelling results: Overall trend

In general, the direction of impacts on farm net income due to innovation scenarios is similar in each group of farms (Table 5.5). For example, net income rises under scenarios where output prices and gains are expected to increase (GI and AHP scenarios), and falls where costs are estimated to increase (Reseed and EID scenarios). Overall, these changes in net income due to innovations are similar with and without support payments. Differences between these policy scenarios are also represented in Table 5.5. Net income reductions are generally most severe under the EID scenarios, and gains higher under GI, AHP and CT scenarios. Reseeding has the least impact. However, there are a few differences between and within farm types when direct support is removed. This variation reflects a combination of factors such as different exposures to livestock prices and levels of subsidy dependence, as shown in the next section.

Table 5.4. A selection of farm characteristics for an average farm in each class of farmers in study.

Farm characteristics	Satisfiers				Profit-Seekers				Expansionists			
	LFA Cattle and Sheep	LFA Beef	Lowland	Mixed	LFA Cattle and Sheep	LFA Beef	Lowland	Mixed	LFA Cattle and Sheep	LFA Beef	Lowland	Mixed
INPUTS												
Beef (1-2 yr old cattle)	25.3	29.8	80.8	52.6	43.4	32.1	55.7	97.3	38	41	54.9	87.7
Suckler cows	70.9	88.8	157	60.5	101.5	101.1	80.6	92	39.7	97.5	115.4	43.2
Ewes	720.8	191.1	518.7	186.8	1129.3	266.9	202.4	102.2	604.8	188.9	248.1	55.3
Stocking rate (LU/ha)	0.4	0.9	1.5	1.2	0.6	1	1.8	1.8	0.9	1.1	1.1	1.2
Grassland (ha)	107.3	106.5	274.5	84.4	206.3	120.8	84.9	116.9	101.6	119.1	138.3	107.4
Arable land (ha)	7.4	7	14.3	42.5	17.8	5.7	15	64.8	2.4	5	5.5	56.8
Rough grazing (ha)	683.2	70.5	54.8	29.2	321.1	65.6	3.5	54.8	144.3	19.7	23	6
Family Labour (man unit)	1.6	1.4	1.5	1.5	1.8	1.5	1.4	1.7	1.5	1.4	1.5	1.9
COSTS												
Variable costs (£/LU)	255.5	274.1	286.1	459.9	291.4	246.2	260.1	402	286	269.8	299.4	623.1
Overhead costs (£/LU)	235.9	314.5	243.1	445.8	285.9	239.9	242.6	456	232.9	257.9	231.6	376.9
FINANCIAL SUPPORT												
Direct Support Payments (£)	64,010.8	40,494.2	76,256.7	31,903.4	78,768.9	46,808.9	33,218.1	5,0985	35,178.3	41,605.6	38,060	37,426.2
LFA payments (£)	17,358.7	9,288.7	13,549.7	3,156.8	16,466.5	8,978.9	1,744.3	3,824	6,702.7	6,699.1	5,102.6	1,459.2
NET INCOME												
Farm net income (£/year)	83,624.1	50,348.9	100,792.2	17,846.7	97,824.8	90,361.3	31,140.1	16,465	44,198.2	66,620.5	91,138.6	-3,448.2

Table 5.5. Average estimated difference in farm net income in 2026 (with and without direct support; mean $\pm$ SD) due to innovations for different representative farm types under five innovation scenarios compared to the baseline scenarios.

Baseline Net Income Quartile	N	Average Baseline Net income		Scenario Results – Average Change in Net income from Baseline									
		+	-	Reseeding		EID		Genetic Improvement		AHP		Combined technologies	
				+	-	+	-	+	-	+	-	+	-
Satisfiers													
LFA Cattle and sheep		£83,624.1	£2,394.8	£0		-£2,007.6 ± £0		£6,184.3 ± £0		£6,910.5 ± £0		£11,955.2 ± £0	
LFA Beef		£50,348.9	-£6,175.6	-£1,200 ± £363.9		-£-2,187.4 ± £363.2		£5,774.1 ±£363.9		£9,055.2 ± £363.9		£11,689.5 ± £363.9	
Lowland		£100,792.2	£8,630.5	-£1,318.5 ± £0		-£-1,959.4 ± £42.9		£13,284.9 ±£2,562.2		£10,963.4 ± £3,923.9		£22,106.9 ± £2,971.7	
Mixed		£17,846.7	-£22,781.2	-£1,463 ± £41.6		-£-1,806.4 ± £69.6		£8,953.3 ± £212.8		£6,464 ± £97.4		£13,040.4 ± £97.4	
Profit-Seekers													
LFA Cattle and sheep		£97,824.8	-£2,700.7	-£1,454.1± £0		-£2,871.6 ± £0		£12,320.2 ± £0		£10,944.2 ± £0		£20,322.6 ± £0	
LFA Beef		£90,361.3	£25,166	-£2,239.4 ± £0		-£2,900.4 ± £0		£8,091.8 ± £0		£11,246.4 ± £0		£15,604 ± £0	
Lowland		£31,140.1	-£11,857.7	-£1,784.7 ± £0		-£2,030.8 ± £0		£6,318.2 ± £0		£7,989.1 ± £0		£11,517.1 ± £115.8	
Mixed		£16,465	-£47,612.6	-£1,998.8 ± £15.3		-£-2,410.4 ± £6		£13,295.4 ± £7.4		£10,032 ± £7.4		£20,169.2 ± £7.4	
Expansionists													
LFA Cattle and sheep		£44,198.2	£145.4	-£2,012.5 ± £0		-£1,548.4 ± £0		£3,663.2 ± £0		£4,469.8 ± £0		£5,114.7 ± £0	
LFA Beef		£66,620.5	£8,963.3	-£3,153 ± £0		-£2,729.4 ± £0		£4,277.1 ± £0		£10,279.4 ± £0		£11,291.1 ± £0	
Lowland		£91,138.6	£37,548.6	-£1,719.9 ± £0		-£2,676.1 ± £0		£11,628.8 ± £0		£11,640.5 ± £0		£20,335.4 ± £0	
Mixed		-£3,448.2	-£43,027.1	-£210.4 ± £372.2		-£-1,208.1 ± £206.3		£6,241.5 ± £3,532.5		£3,483.4 ± £3,291.2		£9,652.1 ± £2,656.4	

Key: ‘+’ - with direct support; ‘-’ – without direct support; EID – Electronic Identification; AHP – Animal Health Planning.

Production and financial performance

a) With direct support

Even though reseedling tends to have the least impact on all four farm systems studied, both reseedling and EID scenarios have a slight negative impact on Scottish beef farm profitability. Under these scenarios, the model results suggest all farm types lose out financially except Satisfiers LFA cattle and sheep farms. With continued direct support, this negative impact is higher for mixed farms. In particular, Expansionists mixed farms lose almost 13.7% (-£473.5) of their farm net income under Reseed+ scenario when compared to the baseline scenario, which is further decreased by 17% (-£1.1k) when EID+ is introduced. With a reduction of 30.8% (-£1.1k) on net income, Expansionists mixed farms are the farm group which lose the most under EID+ scenario.

All farms show an improvement in their net incomes under GI and AHP scenarios. This increase widely varies between farm groups. Overall, when direct support payments remain, mixed farms show the largest changes in farm net income, with farms showing increases of 51% (Satisfiers mixed farms: £9.1k) up to 253.4% (Expansionists mixed farms: £8.7k), and 36.6% (Satisfiers mixed farms: £6.5k) up to 168.5% (Expansionists mixed farms: £5.8k) under GI+ and AHP+, respectively. Expansionists and Profit-seekers LFA beef farms, and Satisfiers and Expansionists LFA cattle and sheep farms show lower increases under GI+ (less than 10%) when compared to others. Similarly, Satisfiers LFA cattle and sheep farms show increases of less than 10% under AHP+. The CT+ scenario follows a similar trend representing, however, the largest impact within the sample of farms, with farms showing an increase of 11.6% (£5.1k; Expansionists LFA cattle and sheep farms) up to 334.4% (£11.5k; Expansionists mixed farms) in net income.

Overall, with existing levels of farm support, the largest variation in farm net income under different scenarios is verified as being among mixed farms, where farm profitability is often marginal. Conversely, LFA cattle and sheep farms are the least affected by these innovations.

b) Without direct support

The removal of direct support payments is estimated to lead to a significant decrease in the viability of the Scottish beef and sheep sector. The changes in net income due to innovation scenarios remain largely consistent when direct support is removed, with losses being amplified under Reseed- and EID- scenarios, and gains achieved under GI- and AHP-, which help some farms staying profitable. However, as mentioned, even with existing levels of direct support, Reseed+ and EID+ scenarios are expected to have a slight negative impact on Scottish beef and sheep farms profitability and, in some cases, lead to Scotland's beef and sheep production to decrease. Without direct support, all farm types are estimated to make losses in 2026 (Table 5.6) when compared to actual levels of support; these losses are particularly high for LFA cattle and sheep, lowland and mixed farms.

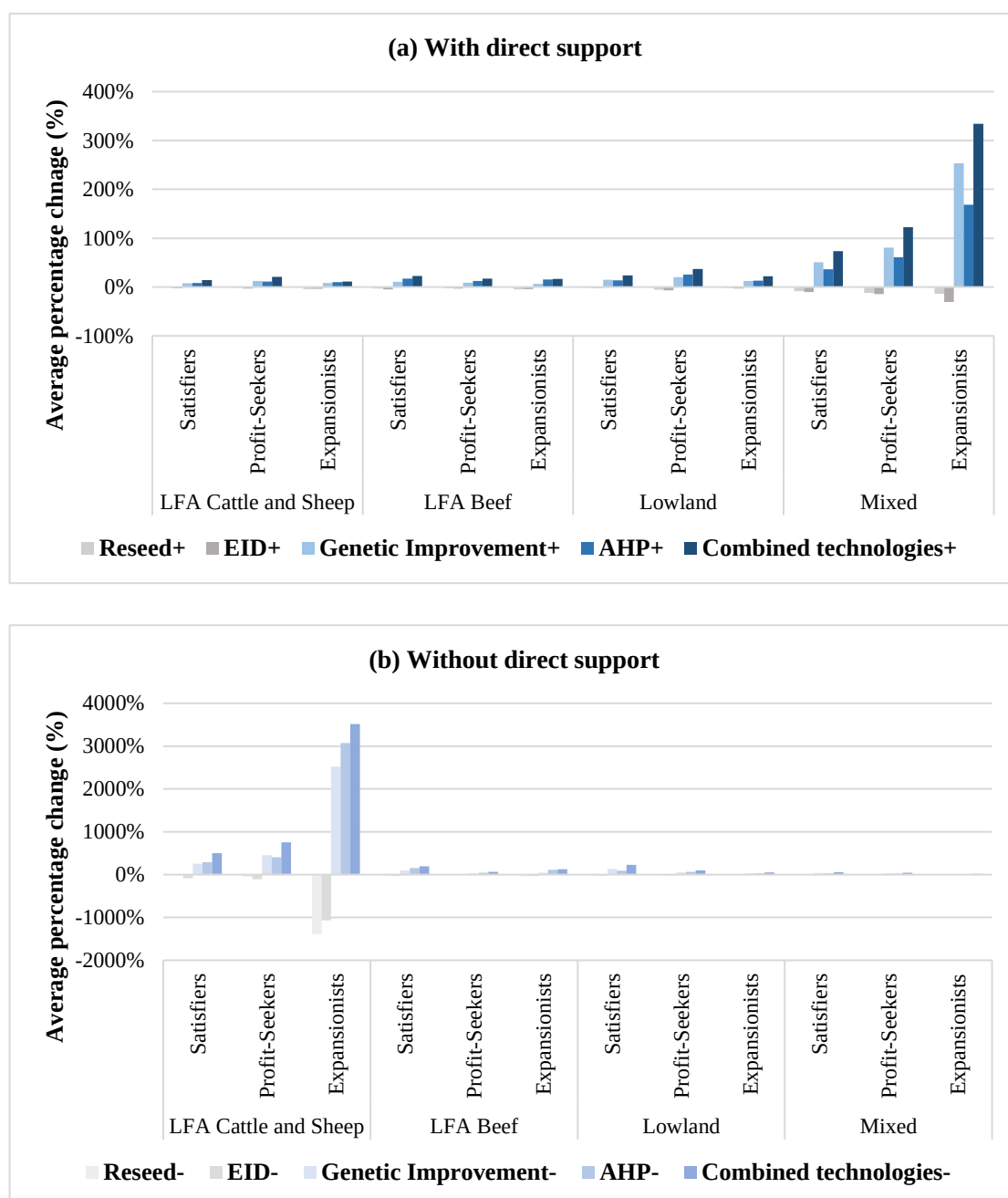
Less Favoured Areas cattle and sheep farms are expected to experience substantial financial pressure under 'Brexit'. Looking at the variation in farm net income, loss of support payments is usually a more important determinant of farm profitability than livestock price and cost changes. When direct support is removed, the largest average percentage change in net income is observed among these farms under all scenarios, particularly in Expansionists LFA cattle and sheep farms (Figure 5.3). For instance, if support payments are removed an average of 32% to 57% of LFA cattle and sheep farms move from profit making to loss making under Reseed- and EID- scenarios, compared to only 8% of these farms moving to loss making when direct support is included. As mentioned, on average LFA cattle and sheep farms receive higher payments and generate higher net incomes than the other farms. As a result of their higher production level, the absolute loss under different scenarios is also higher in these farm systems. Conversely, mixed farms show the lowest average percentage change, as their baseline net profitability is lower when compared to others.

Table 5.6. Proportion of individual farms estimated to be loss making in 2026 under the modelling scenarios (reseeding, EID – Electronic Identification, GI – Genetic Improvement, AHP – Animal Health Planning, and a combined scenario; losses $\geq 50\%$ are in bold).

Farm type	Farmer class	Innovation Scenarios											
		Baseline		Reseed		EID		Genetic Improvement		AHP		Combined technologies	
		+	-	+	-	+	-	+	-	+	-	+	-
LFA Cattle and Sheep	Satisfiers	0%	26.3%	0%	31.6%	0%	42.1%	0%	15.8%	0%	15.8%	0%	15.8%
	Profit-Seekers	7.7%	53.8%	7.7%	53.8%	7.7%	53.8%	3.8%	46.2%	3.8%	42.3%	3.8%	30.8%
	Expansionists	0%	57.1%	0%	57.1%	0%	57.1%	0%	28.6%	0%	28.6%	0%	14.3%
LFA Beef	Satisfiers	3%	33.3%	3%	33.3%	3%	39.4%	0%	24.2%	0%	21.2%	0%	21.2%
	Profit-Seekers	0%	21.2%	0%	21.2%	0%	24.2%	0%	15.2%	0%	12.1%	0%	9.1%
	Expansionists	8%	44%	8%	44%	8%	48%	8%	40%	8%	40%	8%	36%
Lowland	Satisfiers	0%	66.7%	0%	66.7%	0%	66.7%	0%	66.7%	0%	66.7%	0%	66.7%
	Profit-Seekers	20%	80%	20%	80%	20%	80%	20%	60%	20%	60%	20%	60%
	Expansionists	20%	40%	20%	40%	20%	40%	20%	20%	20%	20%	0%	20%
Mixed	Satisfiers	37.5%	87.5%	37.5%	87.5%	37.5%	87.5%	37.5%	81.3%	31.3%	81.3%	31.3%	75%
	Profit-Seekers	23.5%	64.7%	29.4%	64.7%	29.4%	64.7%	17.6%	52.9%	11.8%	58.8%	11.8%	52.9%
	Expansionists	50%	83.3%	50%	83.3%	50%	83.3%	16.7%	83.3%	33.3%	83.3%	16.7%	83.3%

Key: ‘+’ - with direct support; ‘-’ – without direct support; EID – Electronic Identification; AHP – Animal Health Planning.

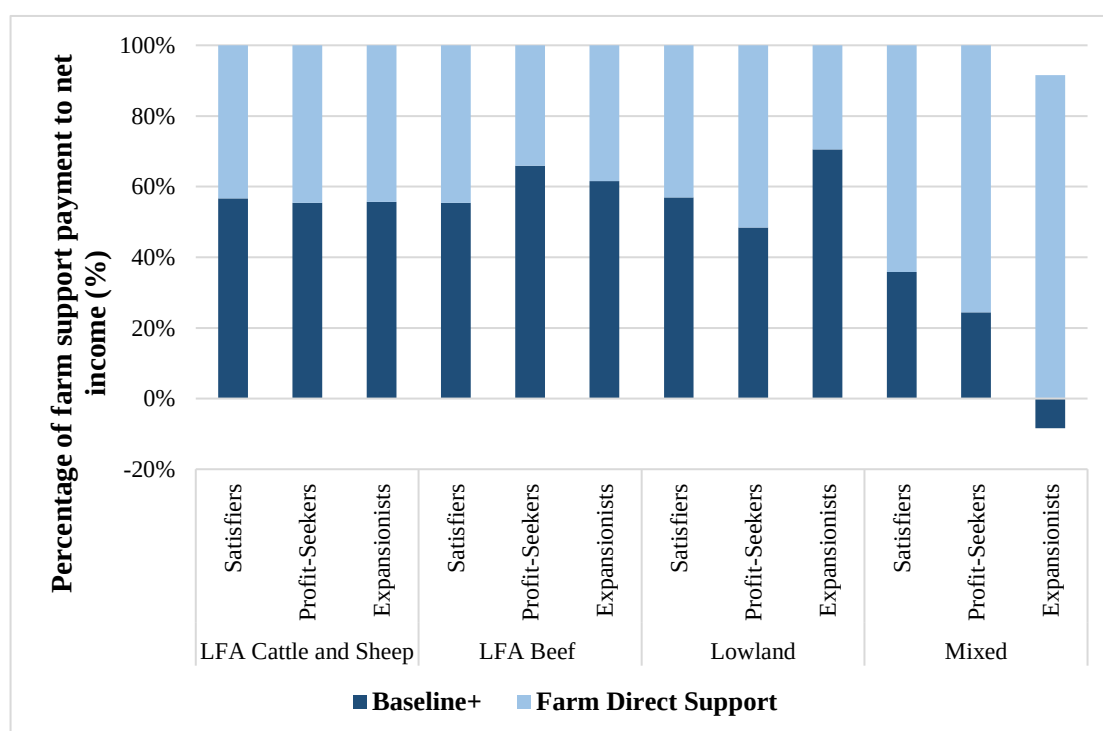
Figure 5.3. Estimated average percentage change from the baseline net income in 2026 resulting from innovation scenarios – a) with direct support; b) without direct support.



Between farm type and farmers' class differences essentially reflect differential exposure to livestock prices and/or reliance on direct support. Basic Payment Scheme rates differ between farm types, which reflects variations in land quality and remoteness; input prices and farm areas vary among farms. For example, lowland farms in this study generally present higher beef prices across scenarios, whereas LFA cattle and sheep farms are generally more reliant upon support payments as part of their net

income. Figure 5.4 shows the average percentage of farm direct payment to farm net income received by farms.

Figure 5.4. Grouping of farms based on the average percentage of farm direct payment to farm net income under the baseline scenario.



Herd and flock dynamics

a) With direct support

With continued direct support, under Reseed+ scenario the optimum beef numbers substantially decrease in Satisfiers (-20%) and Expansionists (-45.4%) LFA beef farms and Expansionists mixed farms (-10.1%) farms. This is less significant when EID+ is implemented in Profit-seekers lowland and Expansionists LFA beef farms, which present smaller increases in beef numbers (1% and 8%, respectively); or in Profit-seekers LFA cattle and sheep farms, which increase sheep numbers by 1%, most likely in a bid to insulate the negative impacts of higher EID costs. Conversely, EID+ leads to a 20% decrease in beef numbers in Expansionists mixed farms.

Under GI+ scenario beef numbers increase in Satisfiers LFA beef (39.1%) and Expansionists mixed farms (100%). Similarly, Profit-seekers lowland farms increase beef numbers by almost 13%, while reducing sheep numbers by 13.9%, whereas the

beef herd remains stable in the remaining farm groups. Equally, Expansionists mixed farms doubled beef numbers under AHP+ scenario (53.2%). A similar trend is verified under the combined technologies scenarios regarding herd and flock dynamics. The highest variation in beef numbers under all scenarios is again on mixed farms, in this case on Expansionists mixed farms. Furthermore, the remaining farm groups do not show any change in animal numbers under all scenarios.

b) Without direct support

As expected, the difference between ‘with direct support’ and ‘without direct support’ payments estimated changes in beef and sheep numbers are more significant among Expansionists mixed farms. Scottish beef production in these farms is estimated to substantially decrease under Reseed- (-67.6%) and EID- (-167.6%) scenarios. However, the GI- scenario is considered beneficial for these mixed farm systems, leading to increases of 700% in herd size, although these farms had a small number of beef animals on farm to start with. Furthermore, without direct support, the number of beef animals in Satisfiers LFA beef farms falls by almost 17% under the Reseed-scenario, and increases in the remaining scenarios up to almost 45% under the GI-scenario (Table 5.7).

Table 5.7. Average percentage change in beef and sheep numbers under innovation scenarios compared to the baseline scenarios.

	Reseed				EID				Genetic Improvement				AHP				Combined technologies			
	Beef		Sheep		Beef		Sheep		Beef		Sheep		Beef		Sheep		Beef		Sheep	
	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-
Satisfiers																				
LFA Cattle and Sheep	0%		0%		0%		0%		0%		0%		0%		0%		0%		0%	
LFA Beef	-20%	-16.6%	0%		4.6%		0%		39.1%	44.7%	0%		0%	4.1%	0%		19.5%	24.4%	0%	
Lowland	0%		0%		0%		0%		0%		0%		0%		0%		0%		0%	
Mixed	0%		0%		0%		0%		0%		0%		0%		0%		0%		0%	
Profit-Seekers																				
LFA Cattle and Sheep	0%		0%		0%		1%		0%		0%		0%		0%		0%		1.1%	
LFA Beef	0%		0%		0%		0%		0%		0%		0%		0%		0%		0%	
Lowland	0%		0%		1%		0%		12.8%	-13.9%	0%		0%		0%		21.1%		-22.8%	
Mixed	0%		0%		0.4%		0%		0%	1.1%	0%		0%	1.1%	0%		0%	1.1%	0%	
Expansionists																				
LFA Cattle and Sheep	0%		0%		0%		0%		0%		0%		0%		0%		0%		0%	
LFA Beef	-45.4%		0%		8%		0%		0%		0%		0%		0%		6.6%		0%	
Lowland	0%		0%		0%		0%		0%		0%		0%		0%		0%		0%	
Mixed	-10.1%	-67.6%	0%		-20%	-167.6%	0%		100%	713.7%	0%		53.2%	451.5%	0%		100%	1003%	0%	

Key: ‘+’ - with direct support; ‘-’ – without direct support; EID – Electronic Identification; AHP – Animal Health Planning.

5.3.2. Analysis of individual farms

LFA Cattle and Sheep

There were 52 LFA cattle and sheep farms included in our sample. Figure 5.5 illustrates the results when existing levels of direct support are continued. The net profitability of each individual farm under the baseline scenario is represented with bars and the coloured markers represent the five innovation scenarios.

The results show that all of these farms, except one, were expected to be in profit in 2026 under the baseline scenario. As for the representative farms, the estimated net incomes of the majority of farms decrease slightly under Reseed+ (orange markers) and EID+ (green triangle markers) scenarios, whereas under GI+ (black markers), AHP+ (blue markers) and CT+ (light green markers) scenarios farm net incomes increase. When compared to the baseline, farms in all quartiles are estimated to have higher 2026 net incomes under GI+, AHP+ and CT+ scenarios, but lower net incomes under Reseed+ and EID+ scenarios.

The impact of the innovation scenarios on farms (with and without farm payments) in different performance quartiles is summarised in Table 5.8, where it is clear how farm profitability is particularly susceptible to the removal of direct support. The estimated differences in net incomes due to innovations under all scenarios remain largely consistent in both policy scenarios. Overall, Satisfiers and Profit-seekers farms already making higher profits benefit significantly more from GI and CT scenarios ($p < 0.1$), i.e. the higher the net income the more farms gain from such innovations. Conversely, farms in the bottom quartiles lose significantly less under EID scenarios ($p < 0.1$), as their net income is lower (Figure 5.6).

Figure 5.5. Estimated 2026 farm net income (with direct support) of LFA cattle and sheep farms under the baseline scenario and five innovation scenarios (reseeding, EID – Electronic Identification, GI – Genetic Improvement, AHP – Animal Health Planning, and a combined scenario).

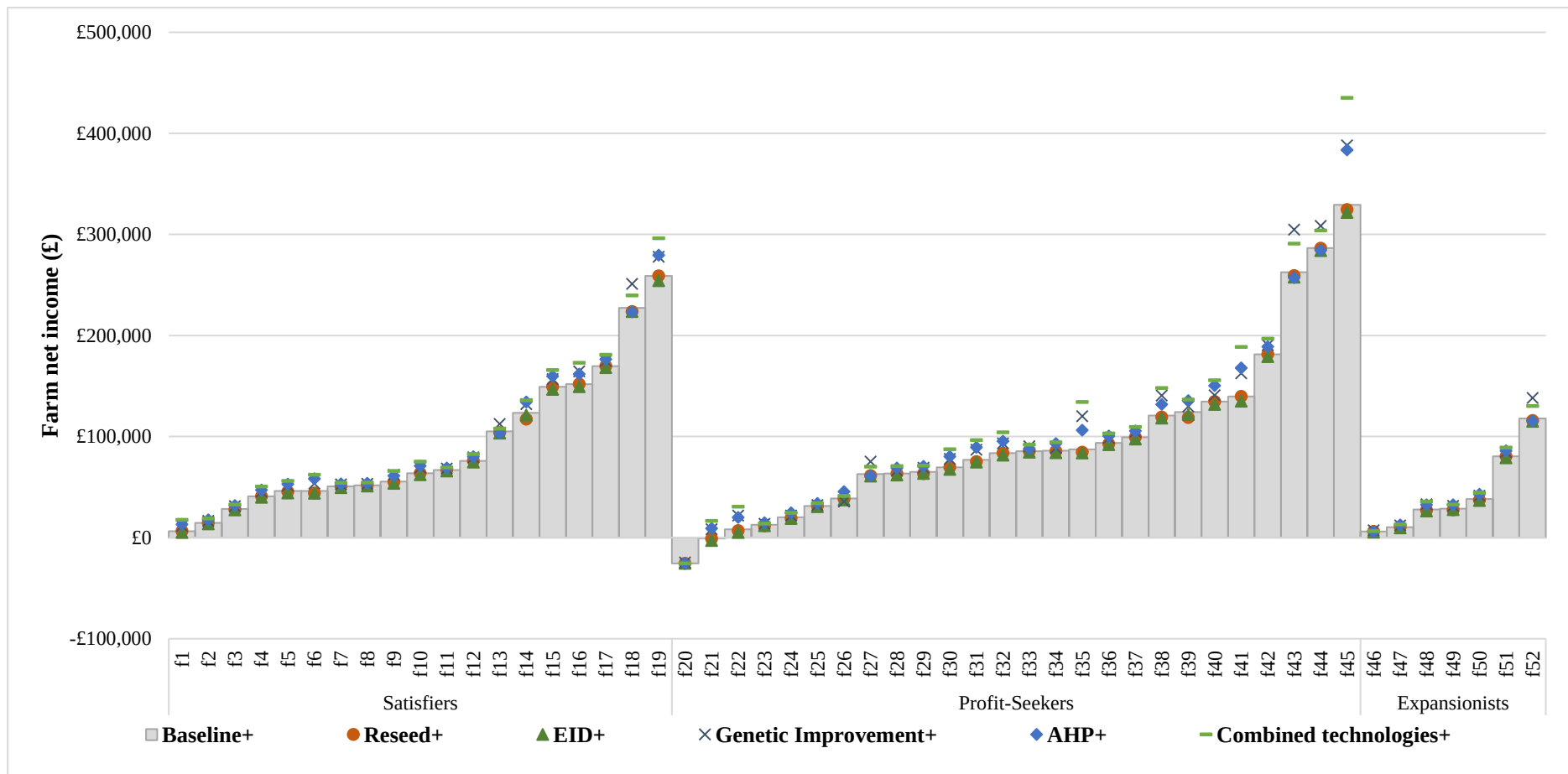


Table 5.8. Estimated difference in farm net income in 2026 due to innovations (with and without direct support; mean $\pm$ SD) for different performance quartiles under five innovation scenarios compared to the baseline scenarios – LFA cattle and sheep farms.

Baseline Net Income Quartile	N	Average Baseline Net Income		Scenario Results – Average Change in Net Income from Baseline									
		+	-	Reseed		EID		Genetic Improvement		AHP		Combined technologies	
				+	-	+	-	+	-	+	-	+	-
Satisfiers													
Top (Q1)		£191,421.7 ^{a,b,c}	£31,210.8 ^{a,b}	-£757.7 ± £0		-£3,063.3 ± £0 ^{a,b,c}		£13,478.3 ± £0 ^{a,b,c}		£8,669.8 ± £0		£19,511 ± £0 ^{a,b}	
2 nd (Q2)		£92,835.1 ^{a,d}	£19,548.3	-£1,860.9 ± £0		-£1,648 ± £0 ^a		£5,166.8 ± £0 ^a		£3,821.6 ± £0		£5,988 ± £0 ^a	
3 rd (Q3)		£53,611.1 ^b	-£2,043 ^a	-£545.6 ± £0		-£1,630.7 ± £0 ^b		£4,490.8 ± £0 ^b		£5,774.3 ± £0		£8,794.3 ± £0	
Bottom (Q4)		£27,337.7 ^d	-£5,225 ^b	-£331.9 ± £0		-£1,358.6 ± £0 ^c		£3,806.7 ± £0 ^c		£5,046.1 ± £0		£7,756.6 ± £0 ^b	
All farms	19	£91,220.6	£10,416.2	-£822.1 ± £0		-£1,939.7 ± £0		£6,818.2 ± £0		£5,933.5 ± £0		£10,750.6 ± £0	
Profit-Seekers													
Top (Q1)		£208,361.5 ^{a,b,c}	£43,938.9 ^a	-£2,015.2 ± £0		-£4,015.3 ± £0 ^{a,b,c}		£23,686.6 ± £0 ^a		£15,527.3 ± £0		£35,502.6 ± £0 ^a	
2 nd (Q2)		£95,536.1 ^{a,d}	-£9,368.8	-£1,695.8 ± £857.3		-£2,968.7 ± £507.6 ^a		£11,440.6 ± £152		£8,571.65 ± £2.8		£17,830.5 ± £147.1	
3 rd (Q3)		£70,293.5 ^b	-£1,808.8	-£890.3 ± £0		-£2,057.8 ± £0 ^b		£7,834.2 ± £0		£7,192.1 ± £0		£12,974.6 ± £0	
Bottom (Q4)		£12,139.4 ^{c,d}	-£36,485.5 ^a	-£540.4 ±£2		-£1,417.1 ± £0 ^c		£3,356.7 ± £1.5 ^a		£5,251.4 ± £0		£7,153.4 ± £1.5 ^a	
All farms	26	97,634	-£572.8	-£1,284.9 ± £198.3		-£2,539.8 ± £117.2		£11,728.6 ± £34.6		£9,232.1 ± £0.6		£18,593.1 ± £33.6	
Expansionists													
Top (Q1)		£99,237.8 ^{a,b}	£20,934.4	-£1,039.4 ± £0		-£2,288.2 ± £0		£12,109.8 ± £0		£1,251.4 ± £0		£10,369.7 ± £0	
2 nd (Q2)		£38,175.5	£1,834.4	-£1,040.9 ± £0		-£1,400.6 ± £0		£3,345.7 ± £0		£4,718.1 ± £0		£6,188.5 ± £0	
3 rd (Q3)		£28,337.8 ^a	£1,355.6	-£1,027.2 ± £0		-£1,386.2 ± £0		£3,816.3 ± £0		£3,990.2 ± £0		£5,884.3 ± £0	
Bottom (Q4)		£8,249.1 ^b	-£21,357.8	-£84.8 ± £0		-£882.5 ± £0		£1,362.5 ± £0		£906.3 ± £0		£1,419.4 ± £0	
All farms	7	£44,260.7	£528.4	-£763.4 ± £0		-£1,502 ± £0		£5,417.6 ± £0		£2,430.6 ± £0		£5,933.6 ± £0	

Note: Values within a row in bold and with different superscript letters are significantly different ($p < 0.1$), following the Tukey post-hoc test.

Key: ‘+’ - with direct support; ‘-’ – without direct support; EID – Electronic Identification; AHP – Animal Health Planning.

Figure 5.6. Difference in LFA cattle and sheep farms net income in different quartiles under innovation scenarios compared to the baseline scenarios (mean $\pm$ SD).

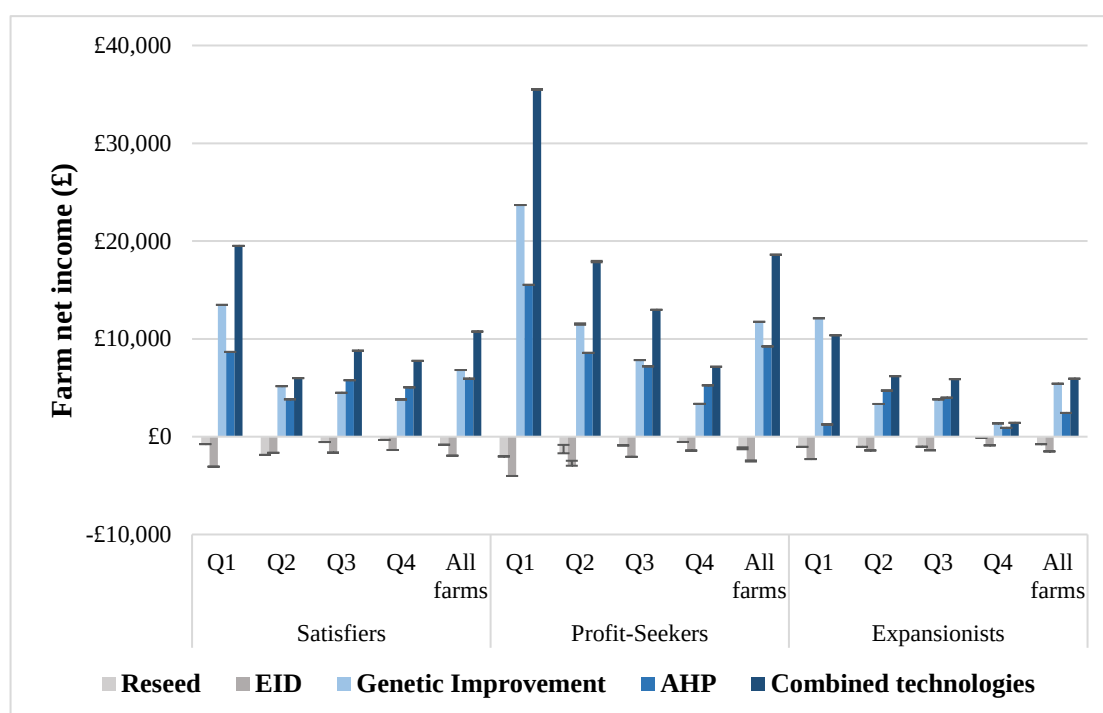


Table 5.9 shows that an average Satisfier and Profit-seeker farm in the top quartile (Q1) receives significantly larger support payments than an average farm in the bottom quartile (Q4). Overall, the top performing farms are significantly larger, with greater grassland area and higher numbers of suckler cows and ewes, though with a slightly lower stocking density.

Table 5.9. Characteristics of LFA cattle and sheep farms in quartiles based on the baseline farm net income (mean $\pm$ SD). Average of farms in top and bottom 25% groups (*p < 0.01, **p < 0.05, ***p < 0.1).

Farm Input Variable	Average value of Top quartile (Q1)	Average value of Bottom quartile (Q4)
Satisfiers		
Grassland (ha)**	161.6 $\pm$ 67.1	56.8 $\pm$ 51.4
Rough grazing land (ha)**	899.2 $\pm$ 567.2	1388.2 $\pm$ 115.5
Family labour unit**	2.2 $\pm$ 0.9	1.1 $\pm$ 0.2
Stocking density (LU/ha)	0.3 $\pm$ 0.2	0.5 $\pm$ 0.2
Variable costs (£/LU)	240.1 $\pm$ 41.4	360 $\pm$ 108.8
Direct Support Payments*	119,010.4 $\pm$ 43,163.8	24,976.6 $\pm$ 6648.7
LFA payments*	34,039.8 $\pm$ 12419.6	6,202.2 $\pm$ 1569.9
Beef (1-2 yr old cattle)	51.3 $\pm$ 63.2	10.3 $\pm$ 14.7
Suckler Cows*	134 $\pm$ 60.1	35.1 $\pm$ 9.7
Ewes*	1,096.4 $\pm$ 242.2	384 $\pm$ 204
Profit-Seekers		
Grassland (ha)*	310.1 $\pm$ 110.6	107.9 $\pm$ 73.1
Rough grazing land (ha)*	667.1 $\pm$ 476.7	80.7 $\pm$ 81.3
Family labour unit**	2.3 $\pm$ 0.8	1.3 $\pm$ 0.5
Stocking density (LU/ha)	0.5 $\pm$ 0.4	0.7 $\pm$ 0.3
Variable costs (£/LU)***	228.9 $\pm$ 49.5	407.4 $\pm$ 230.4
Direct Support Payments*	128,046.9 $\pm$ 27,401.6	40,653.7 $\pm$ 31,992.6
LFA payments*	31,068.1 $\pm$ 7,726.2	5,744.6 $\pm$ 2,329.2
Beef (1-2 yr old cattle)***	72.4 $\pm$ 61.4	24.7 $\pm$ 28.6
Suckler Cows**	177 $\pm$ 107.8	46.6 $\pm$ 44.1
Ewes*	1,790.8 $\pm$ 814.4	574.5 $\pm$ 512.9
Expansionists		
Grassland (ha)	153.7 $\pm$ 60.4	59.2 $\pm$ 20.6
Rough grazing land (ha)	460.7 $\pm$ 579.3	14.2 $\pm$ 20
Family labour unit	1.3 $\pm$ 0.4	1.5 $\pm$ 0.7
Stocking density (LU/ha)	0.8 $\pm$ 0.9	1.4 $\pm$ 0.5
Variable costs (£/LU)***	205.3 $\pm$ 21.7	300.3 $\pm$ 33.5
Direct Support Payments	62,503.5 $\pm$ 8,940	26,527.5 $\pm$ 23,045.3
LFA payments	11,255.5 $\pm$ 6,103	3,529.5 $\pm$ 2,700.4
Beef (1-2 yr old cattle)	57.4 $\pm$ 63	63.8 $\pm$ 86.6
Suckler Cows***	78.6 $\pm$ 32	11.8 $\pm$ 9.6
Ewes***	1,308.5 $\pm$ 453.3	352.3 $\pm$ 150.3

LFA Cattle and Sheep – without direct support

Figure 5.7 presents the ScotFarm estimated net incomes in 2026 under all five innovation scenarios with the removal of direct support payments from 2019. All farms are expected to have substantial reductions in net profitability if existing levels of support are removed. Overall, ScotFarm estimates that when direct payments are removed only an average of 50% of LFA cattle and sheep farms remain profitable under Reseed- and EID- scenarios, with the number of profitable farms increasing to an average of 70% to 80% farms under GI-, AHP- and CT- scenarios. Profit-seekers are however the most affected by the removal of direct support.

Similar to the ‘with direct support’ scenarios, farms already making higher net incomes benefit more from GI-, AHP- and CT- scenarios. However, others farms also benefit from these technologies, which is particularly relevant when considering the removal of subsidies. For instance, by adopting the range of selected technologies, some farms (e.g. ‘f35’, ‘f41’) are able to return a positive net income, in contrast to their baseline (i.e. Baseline-). In other cases the implementation of GI- leads to higher net incomes when compared to the CT- scenario (e.g. ‘f18’, ‘f43’, ‘f52’), which appears to be linked to the underlying productivity and profitability of each farm.

The variability in the amount of direct support received by each farm helps to explain the extent of changed profitability, with the top quartile farms receiving significantly higher direct support payments and having more sheep and cattle, meaning they have greater sensitivity to support changes (Figure 5.8). The difference in net income between the ‘with’ and ‘without direct support’ payment scenarios shows that these LFA cattle and sheep farms are more susceptible to changes in support payments than other farm types, showing the largest variation in net income. LFA cattle and sheep farms have a high reliance on support in relation to overall business turnover and as a proportion of their profitability when compared to others.

Figure 5.7. Estimated 2026 farm net income (without direct support) of LFA cattle and sheep farms under the baseline scenarios and five innovation scenarios (reseeding, EID – Electronic Identification, GI – Genetic Improvement, AHP – Animal Health Planning, and a combined scenario).

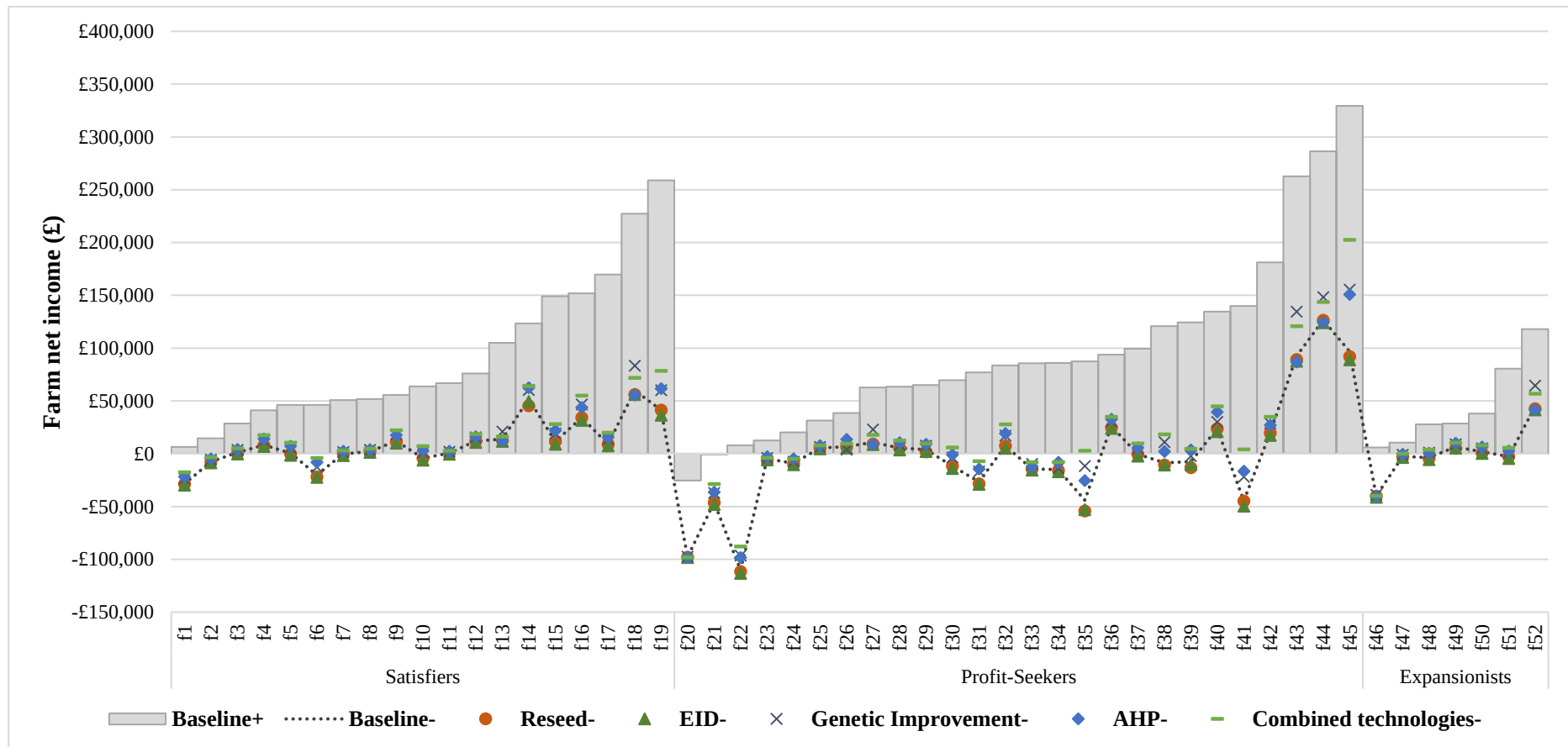
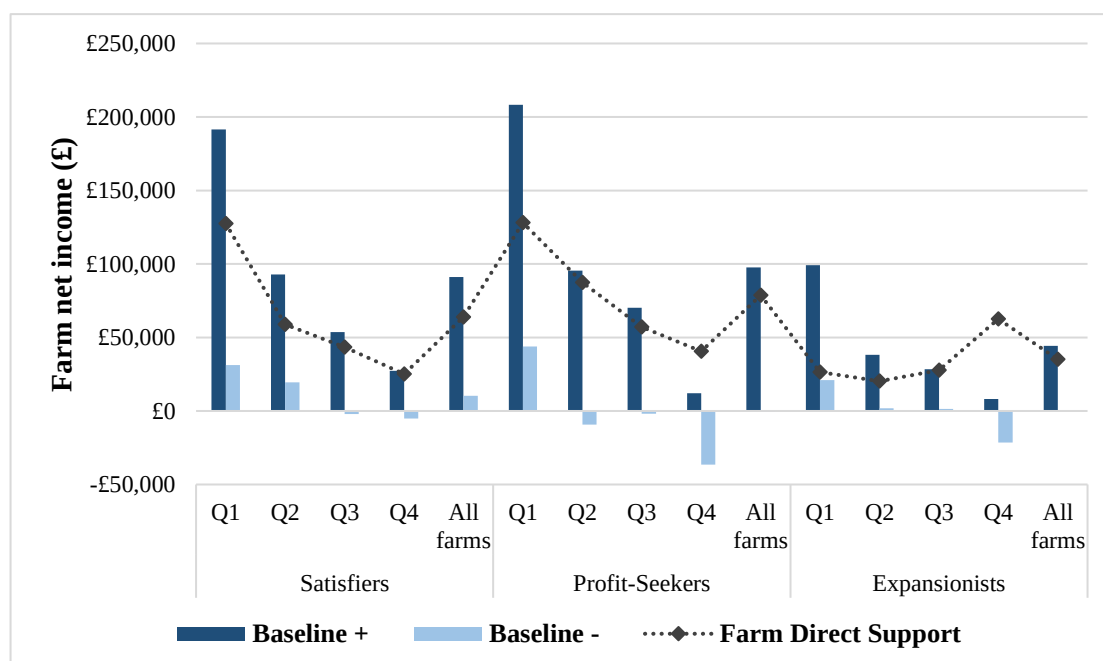


Figure 5.8. Farm net incomes in 2026 for different performance quartiles under the baseline scenarios – LFA cattle and sheep farms.



LFA Cattle and Sheep farms - herd and flock dynamics

Satisfiers and Expansionists tend to maintain beef numbers under all scenarios while reducing sheep numbers under Reseed and CT scenarios. The largest variations are verified among Profit-seekers, which reduce animal numbers when reseeding is implemented, increase beef numbers under EID, GI and CT scenarios, and decrease sheep numbers under AHP- and CT- scenarios (Table 5.10).

Table 5.10. Percentage change in beef and sheep numbers under innovation scenarios compared to the baseline scenarios - LFA cattle and sheep farms.

	Reseed				EID				Genetic Improvement				AHP				Combined technologies				
	Beef		Sheep		Beef		Sheep		Beef		Sheep		Beef		Sheep		Beef		Sheep		
	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	
Satisfiers																					
All farms	0%		-3%		-3.2%		0%		0.1%		0%		0%		0%		0%		-2.9%		-3.1%
Profit-Seekers																					
All farms	-1.2%	-1.3%	-4.5%	-4.4%	3.9%	3.5%	0.2%	0.1%	6%	9%	1.2%	2.4%	-0.1%	0%	-2.4%	9.6%	9.3%	-3.5%	-6.1%		
Expansionists																					
All farms	0%		-3.2%		0%		0%		0%		0%		0%		0%		0%		-3.2%		

Key: ‘+’ - with direct support; ‘-’ – without direct support; EID – Electronic Identification; AHP – Animal Health Planning.

LFA Beef

ScotFarm used 2016 FBS data from 91 LFA beef farms. Figure 5.9 shows the net income for each farm in 2026 for the baseline scenario and each of the five innovation scenarios, with direct support payments maintained. The results show that the majority of beef farms present positive farm net incomes in 2026 under the baseline scenario when direct support is maintained.

A summary of the expected impacts of these innovation scenarios in different performance quartiles is shown in Table 5.11. Whilst the results show that the estimated profitability of all farms is slightly reduced under Reseed+ and EID+ scenarios, the majority of farms remain profitable (although with lower net incomes) due to the continuation of direct support (Figure 5.10). Similarly, the net income of Scottish LFA beef farms is estimated to increase significantly by 2026 under GI+, AHP+, and CT+ scenarios assuming direct payments remain, with top quartile farms achieving significantly higher gains.

Figure 5.9. Estimated 2026 farm net income (with direct support) of LFA beef farms under the baseline scenario and five innovation scenarios (reseeding, EID – Electronic Identification, GI – Genetic Improvement, AHP – Animal Health Planning, and a combined scenario).

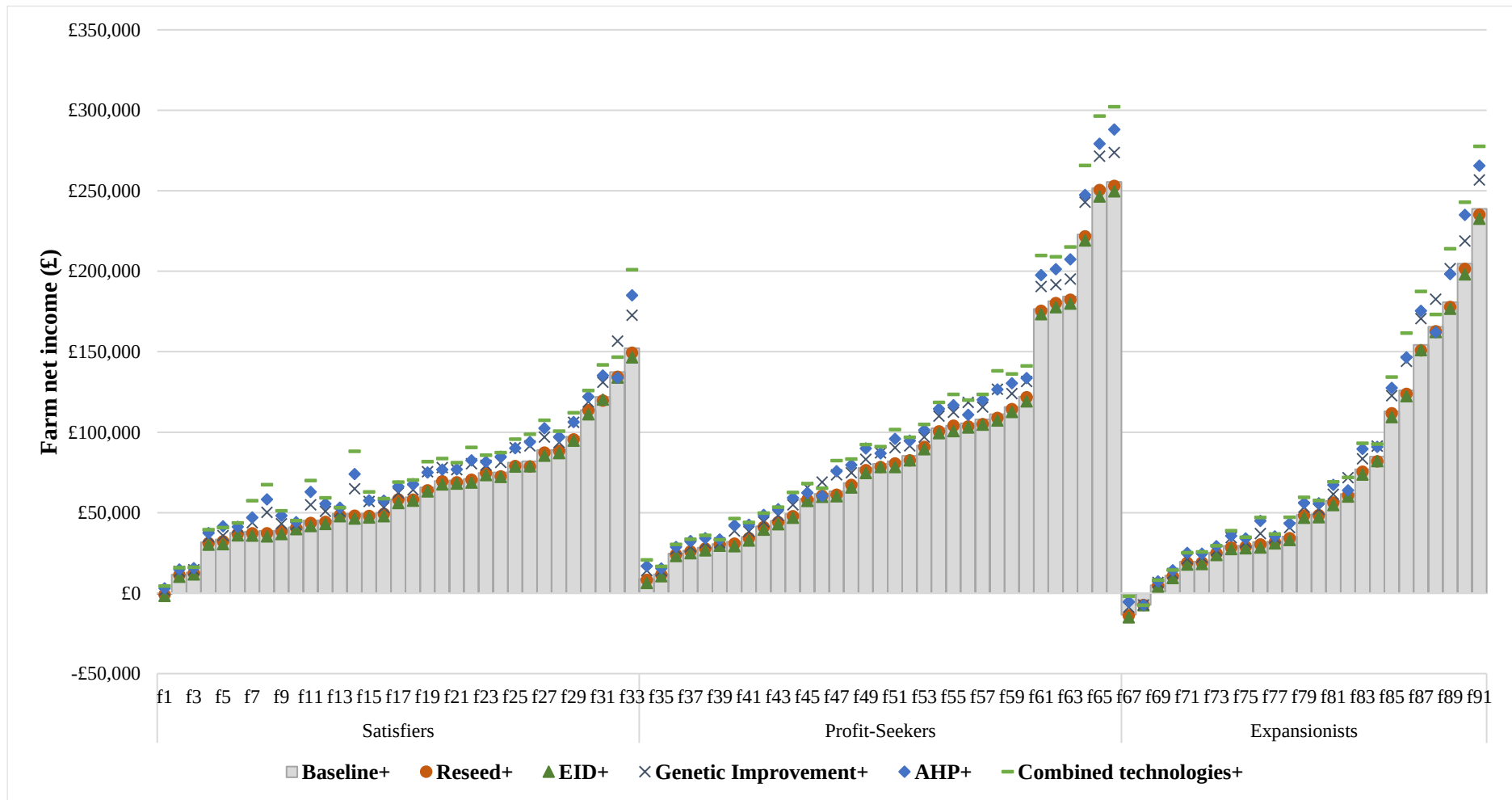


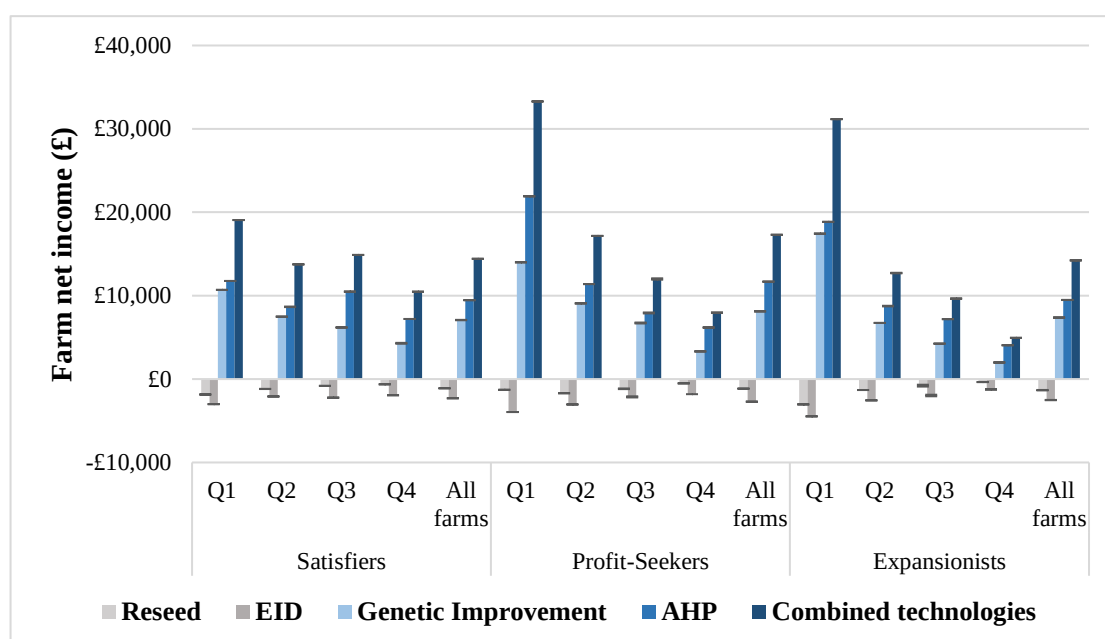
Table 5.11. Estimated difference in farm net income in 2026 due to innovations (with and without direct support; mean $\pm$ SD) for different performance quartiles under five innovation scenarios compared to the baseline scenarios - LFA beef farms.

Baseline Net Income Quartile	N	Average Baseline Net Income		Scenario Results – Average Change in Net Income from Baseline									
		+	-	Reseed		EID		Genetic Improvement		AHP		Combined technologies	
				+	-	+	-	+	-	+	-	+	-
Satisfiers													
Top (Q1)		£110,287.2 ^{a,b,c}	£20,473.2 ^a	-£1,847.7 ± £0 ^a		-£3,006.1 ± £0 ^a		£10,696.7 ± £0 ^a		£11,765.8 ± £0		£19,068.4 ± £0	
2 nd (Q2)		£70,876.5 ^{a,d,e}	£19,508.7	-£1,191.6 ± £20.2		-£2,114.6 ± £61.7		£7,454.2 ± £66.3		£8,630.6 ± £66.3		£13,721.5 ± £66.3	
3 rd (Q3)		£48,437.8 ^{b,d,f}	£1,461.6 ^b	-£813.4 ± £0		-£2,225.1 ± £0		£6,188.2 ± £0		£10,485.7± £0		£14,886.6 ± £0	
Bottom (Q4)		£26,898.3 ^{c,e,f}	-£9,250.1 ^{a,b}	-£626.9 ± £0 ^a		-£1,935.6 ± £0 ^a		£4,235.6 ± £107.5 ^a		£7,207.7± £0		£10,475.9 ± £0	
All farms	33	£62,996.9	£7,524.2	-£1,105 ± £4.9		-£2,308.7 ± £15		£7,055.6 ± £45.3		£9,452.3 ± £16.1		£14,415 ± £16.1	
Profit-Seekers													
Top (Q1)		£188,738.7 ^{a,b,c}	£81,184.2	-£1,285.1 ± £0 ^a		-£3,951.2 ± £0 ^{a,b,c}		£14,000.8 ± £0 ^{a,b,c}		£21,913.8 ± £0 ^{a,b,c}		£33,288.5 ± £0 ^{a,b}	
2 nd (Q2)		£98,758.9 ^{a,d,e}	£28,580.9	-£1,696.2 ± £0 ^b		-£3,041.4 ± £0 ^{a,d}		£9,075.7 ± £0 ^{a,d}		£11,391 ± £0 ^a		£17,168 ± £0 ^{a,c}	
3 rd (Q3)		£63,024.5 ^{b,d,f}	£14,429.5	-£1,200.1 ± £77.8		-£2,204 ± £138.3 ^b		£6,666 ± £116.5 ^b		£7,873.1 ± £113.1 ^b		£11,920.6 ± £159.2 ^b	
Bottom (Q4)		£26,521.6 ^{c,e,f}	-£3,963.2	-£512.9 ± £0.1 ^{a,b}		-£1,810.2 ± £0 ^{c,d}		£3,295.3 ± £41.7 ^{c,d}		£6,183.6 ± £0 ^c		£7,945.1 ± £40.5 ^c	
All farms	33	£92,208.2	£29,026.9	-£1,153.6 ± £18.9		-£2,723.2 ± £33.5		£8,109 ± £16.8		£11,669 ± £27.4		£17,288.6 ± £27.5	
Expansionists													
Top (Q1)		£178,355.1	£77,008.1 ^a	-£3,035 ± £0		-£4,466.8 ± £0		£17,438.6 ± £0		£18,853.8± £0		£31,164.7± £0	
2 nd (Q2)		£73,792.4	£5,776.3	-£1,313.8 ± £5.8		-£2,573.5 ± £47.7 ^a		£6,729.5 ± £10.7		£8,715.7± £75 ^a		£12,677 ± £68.4 ^a	
3 rd (Q3)		£34,382.3	-£7,772.7	-£898.6 ± £224.2		-£2,063.2 ± £189.4		£4,250 ± £0		£7,188.7± £0		£9,651.5± £0	
Bottom (Q4)		£8,482.3	-£12,225.6 ^a	-£356.5 ± £0		-£1,239.4 ± £0 ^a		£1,988.6 ± £0		£4,056.1± £0 ^a		£4,946.6± £0 ^a	
All farms	25	£71,142.2	£14,579.6	-£1,359.2 ± £55.2		-£2,531.9 ± £34		£7,377.2 ± £2.6		£9,477.7 ± £18		£14,223.4 ± £16.4	

Note: Values within a row in bold and with different superscript letters are significantly different ($p < 0.1$), following the Tukey post-hoc test.

Key: ‘+’ - with direct support; ‘-’ – without direct support; EID – Electronic Identification; AHP – Animal Health Planning.

Figure 5.10. Difference in LFA beef farms net income in different quartiles under innovation scenarios compared to the baseline scenarios (mean $\pm$ SD).



Characteristics of the average beef farm in the top (Q1) and bottom (Q4) quartiles are presented in Table 5.12. Statistically, farms in Q1 have significantly more grazing land. On average, these farms also have significantly higher support payments and carry significantly more suckler cows, finishing cattle and ewes. Lower quartile farms have slightly lower stocking density and hence are comparatively more extensive in nature. In addition, these farms have less family labour to draw on and incur higher variable costs in their farm system. Even though the trend in response to the selected innovations is largely consistent among classes and respective farm types, the magnitude of the response of these farms was also analysed when direct support was removed.

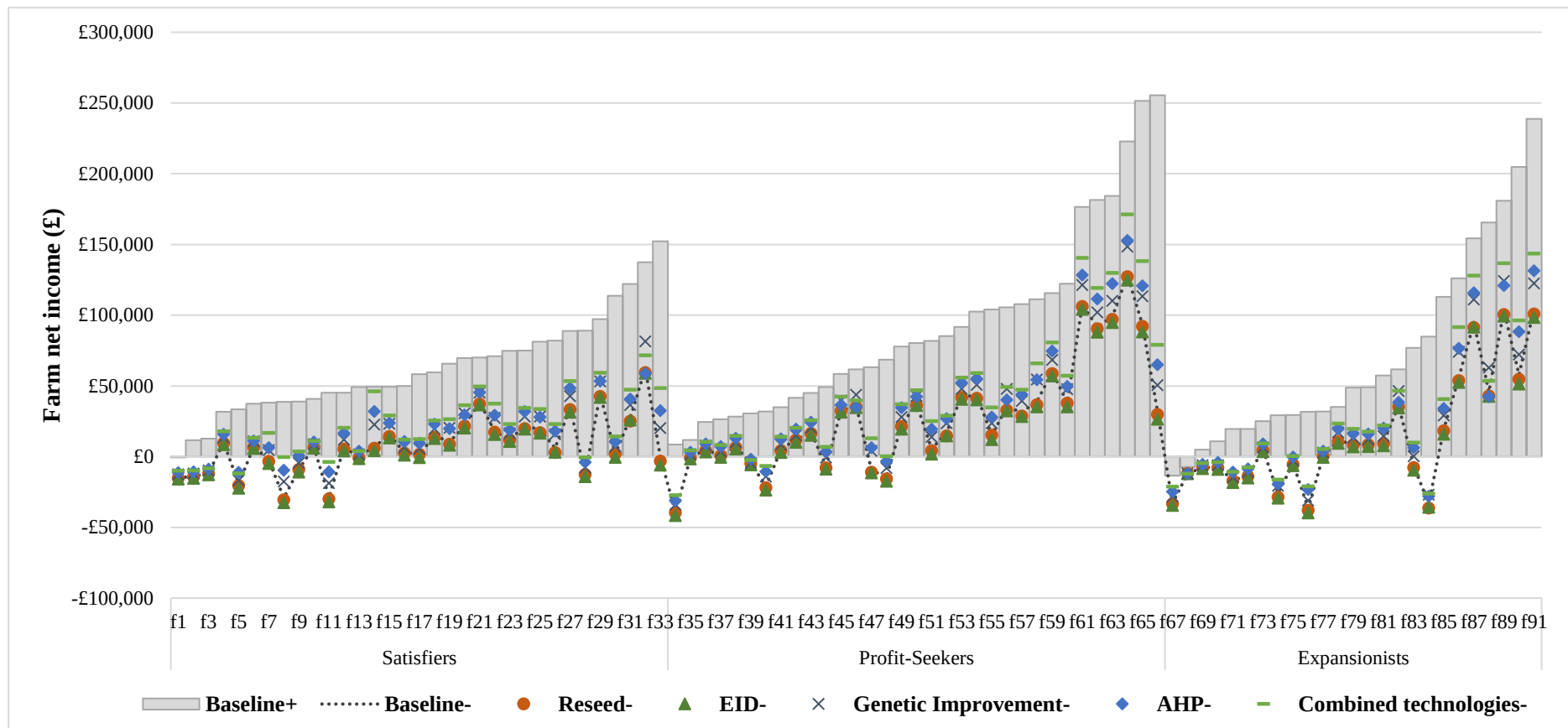
Table 5.12. Characteristics of LFA beef farms in quartiles based on the baseline farm net income (mean $\pm$ SD). Average of farms in top and bottom 25% groups (*p <0.01, **p < 0.05, ***p < 0.1).

Farm Input Variable	Average value of Top quartile (Q1)	Average value of Bottom quartile (Q4)
Satisfiers		
Grassland (ha)*	163.7 $\pm$ 83	77.2 $\pm$ 25.1
Rough grazing land (ha)	92.5 $\pm$ 151.2	18.3 $\pm$ 34.9
Family labour unit	1.5 $\pm$ 0.5	1.3 $\pm$ 0.4
Stocking density (LU/ha)	0.9 $\pm$ 0.4	0.8 $\pm$ 0.5
Variable costs (£/LU)	238.8 $\pm$ 49	324.1 $\pm$ 164.7
Direct Support Payments*	67,016.1 $\pm$ 26,509.8	23,180.7 $\pm$ 8,367.1
LFA payments*	16,397.9 $\pm$ 9,692.1	5,251 $\pm$ 3,666.3
Beef (1-2 yr old cattle)**	45.6 $\pm$ 45.8	12.9 $\pm$ 9.8
Suckler Cows*	136 $\pm$ 55.9	55.2 $\pm$ 33.3
Ewes*	383.1 $\pm$ 210.6	63.7 $\pm$ 80.8
Profit-Seekers		
Grassland (ha)*	175.5 $\pm$ 115.7	79.8 $\pm$ 81.1
Rough grazing land (ha)**	126.5 $\pm$ 105.6	32.2 $\pm$ 45.2
Family labour unit	1.4 $\pm$ 0.5	1.3 $\pm$ 0.5
Stocking density (LU/ha)	0.9 $\pm$ 0.5	0.8 $\pm$ 0.3
Variable costs (£/LU)*	185.4 $\pm$ 46.6	306.7 $\pm$ 79.7
Direct Support Payments*	79,303.6 $\pm$ 45,236.4	24,252.3 $\pm$ 12,084.8
LFA payments*	14,900 $\pm$ 4,965.1	4,497.6 $\pm$ 2,202.7
Beef (1-2 yr old cattle)**	41.2 $\pm$ 22.9	17.7 $\pm$ 18.2
Suckler Cows*	154.4 $\pm$ 42.4	57.2 $\pm$ 26.9
Ewes	377.2 $\pm$ 531.2	221.2 $\pm$ 274.5
Expansionists		
Grassland (ha)*	179.9 $\pm$ 94.5	65.6 $\pm$ 25.6
Rough grazing land (ha)	14.8 $\pm$ 24.3	7.8 $\pm$ 6.7
Family labour unit	1.7 $\pm$ 1	1.1 $\pm$ 0.3
Stocking density (LU/ha)**	1.6 $\pm$ 0.3	1 $\pm$ 0.6
Variable costs (£/LU)**	190.4 $\pm$ 38.6	321.2 $\pm$ 118.5
Direct Support Payments*	72,300.2 $\pm$ 28,382.1	15,296.6 $\pm$ 8,029.9
LFA payments*	10,963 $\pm$ 4,920.3	2,525.9 $\pm$ 1,472.7
Beef (1-2 yr old cattle)*	89 $\pm$ 24.7	26.2 $\pm$ 36.9
Suckler Cows*	182.7 $\pm$ 68.9	38.5 $\pm$ 23.9
Ewes*	385.1 $\pm$ 298.7	14.2 $\pm$ 37.6

LFA Beef – without direct support

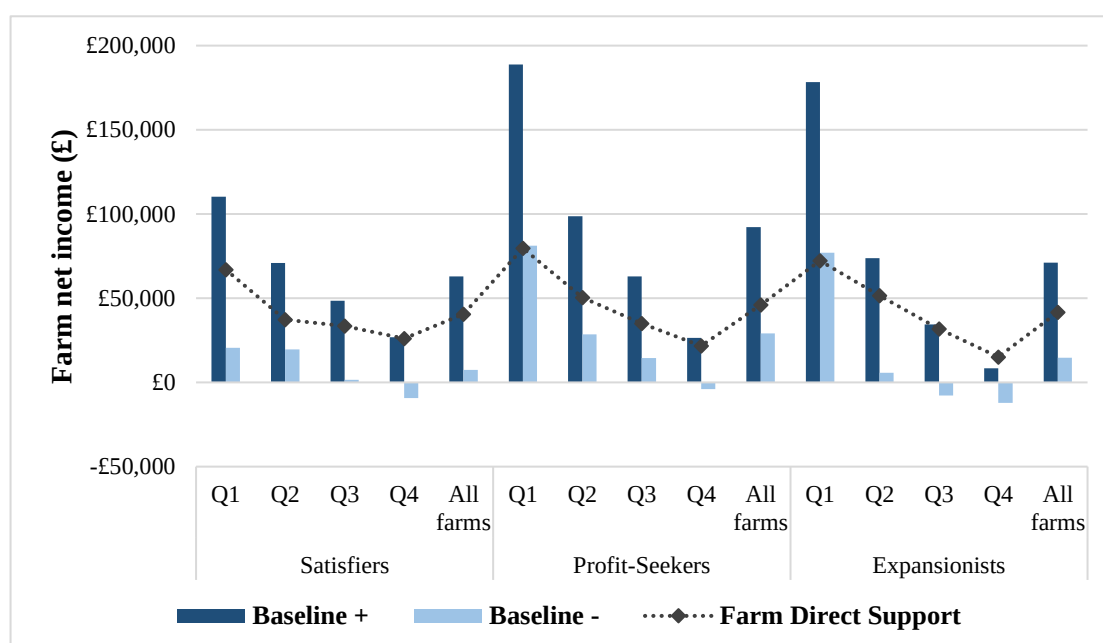
When direct support payments are removed, as expected, LFA beef farms net profitability for each scenario is reduced by 2026 (Figure 5.11). Similar to LFA cattle and sheep farms, GI-, AHP- and CT- scenarios allow some farms to remain profitable when compared to their baseline (e.g. ‘f7’, ‘f47’, ‘f83’). In particular, by implementing AHP the majority of farms return higher net incomes than the GI- scenario. These farms are specialist beef farms that have on average more suckler cows than LFA cattle and sheep farms, therefore obtaining higher net incomes due to AHP.

Figure 5.11. Estimated 2026 farm net income (without direct support) of LFA beef farms under the baseline scenarios and five innovation scenarios (reseeding, EID – Electronic Identification, GI – Genetic Improvement, AHP – Animal Health Planning, and a combined scenario).



ScotFarm estimates that when direct payments are removed only 56%-60% of Expansionists LFA beef farms remain profitable under Reseed-, GI- and AHP-scenarios, falling to 52% of farms under EID-scenario. However, average net incomes of Profit-seekers and Expansionists farms are expected to stay higher than those of Satisfiers when support is removed. As shown in Figure 5.12, farms in the top quartile (Q1) are most susceptible to the removal of support as they receive higher direct support payments and are larger, meaning they also are more exposed than smaller farms in other quartiles.

Figure 5.12. Farm net incomes in 2026 for different performance quartiles under the baseline scenarios – LFA beef farms.



LFA Beef - herd and flock dynamics

The largest variation in beef numbers is verified among Profit-seekers under the AHP-scenario followed by Satisfiers under GI and CT scenarios. However, these farms had a small number of beef animals on farm (<15) under the baseline scenarios. Expansionists tend to increase the suckler herd under EID and CT scenarios, most likely to insulate against the effects of EID costs (Table 5.13).

Table 5.13. Percentage change in beef and sheep numbers under innovation scenarios compared to the baseline scenario - LFA beef farms.

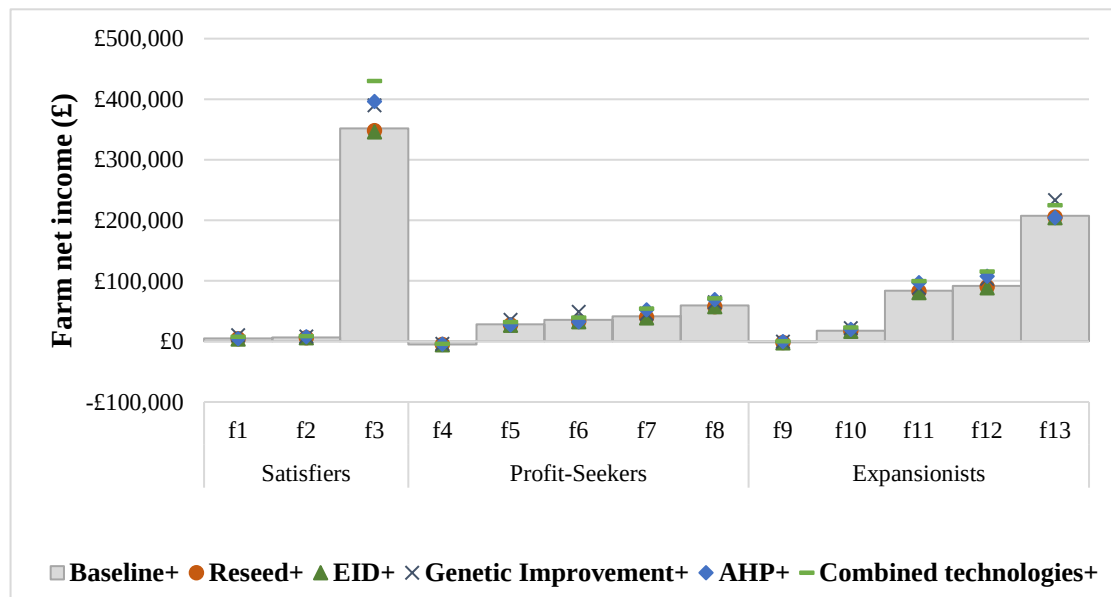
	Reseed				EID				Genetic Improvement				AHP				Combined technologies			
	Beef		Sheep		Beef		Sheep		Beef		Sheep		Beef		Sheep		Beef		Sheep	
	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-
Satisfiers																				
All farms	-1.2%		-2%	-1.4%	0.1%		0.2%		220.4%		0%		0%		0%		217.9%	217.8%	-1.8%	
Profit-Seekers																				
All farms	0%		-1.8%	-2.9%	0%		0.2%		3%	4.2%	0%		0%	2371.8%	0%		3%		-1.6%	
Expansionists																				
All farms	0%		-6.5%	-5.5%	25.7%	25.4%	0.7%	2.8%	4%	4.1%	0.7%	-0.1%	0%	0.1%	0%	-0.1%	29.7%	29.8%	-6.1%	-5.6%

Key: ‘+’ - with direct support; ‘-’ – without direct support; EID – Electronic Identification; AHP – Animal Health Planning.

Lowland

Data from 13 FBS lowland farms was used by ScotFarm. The net profitability of these individual farms under the baseline scenario, and the five innovation scenarios with direct support payments is presented in Figure 5.13. The majority of farms are expected to be profitable in 2026 with 20% of Expansionists and Profit-seekers farms, respectively, estimated to return losses under the baseline scenario.

Figure 5.13. Estimated 2026 farm net income (with direct support) of lowland farms under the baseline scenario and five innovation scenarios (reseeding, EID – Electronic Identification, GI – Genetic Improvement, AHP – Animal Health Planning, and a combined scenario).



As for the other farm types, the model estimates improvements in net incomes for the majority of farms under GI+, AHP+ and the CT+ scenarios when direct payments are in place (Table 5.14). The difference in farm net income in 2026 for different performance quartiles under five innovation scenarios is also presented in Figure 5.14.

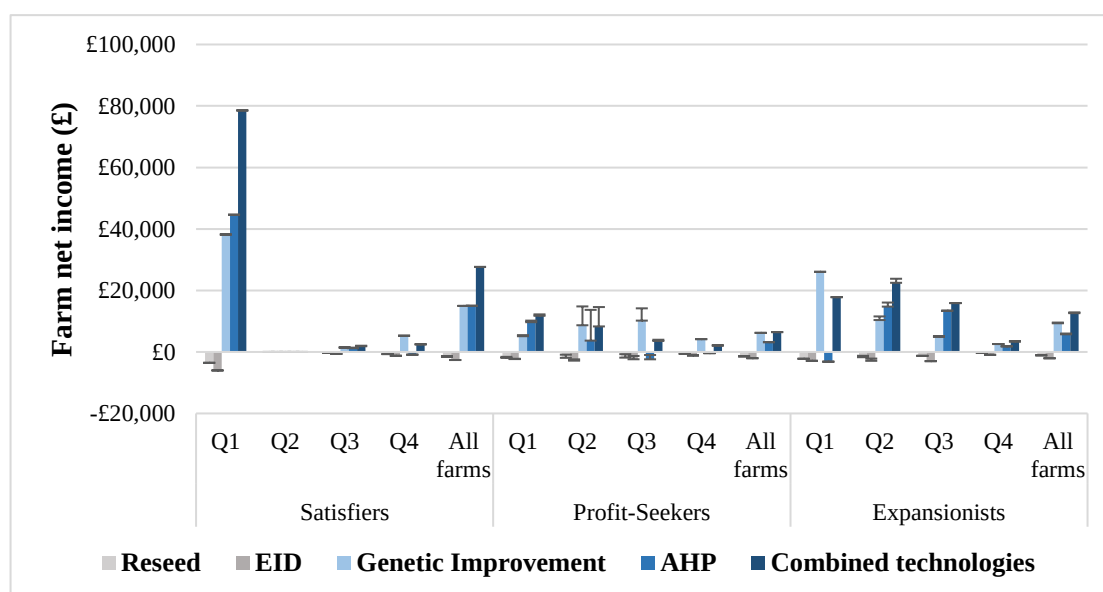
Table 5.14. Estimated difference in farm net income in 2026 due to innovations (with and without direct support; mean $\pm$ SD) for different performance quartiles under five innovation scenarios compared to the baseline scenarios – Lowland farms.

Baseline Net Income Quartile	N	Average Baseline Net Income		Scenario Results – Average Change in Net Income from Baseline				
		+	-	Reseed	EID	Genetic Improvement	AHP	Combined technologies
Satisfiers								
Top (Q1)	3	£351,673.5	£105,169.9	-£3,527 ± £0	-£6,000 ± £0	£38,201.5 ± £0	£44,633.2 ± £0	£78,547.3 ± £0
2 nd (Q2)		£0	£0	£0	£0	£0	£0	£0
3 rd (Q3)		£6,517.3	-£10,101.2	-£251.2 ± £95.6	-£651.8 ± £58.3	£1,432.2 ± £36.8	£1,217.5 ± £188.7	£1,859.7 ± £172.1
Bottom (Q4)		£5,141.8	-£20,447.7	-£688.4 ± £0	-£1,240.2 ± £0	£5,289 ± £0	-£881.3 ± £0	£2,479.1 ± £0
All farms		£121,110.9	24,873.6	-£1,488.9 ± £31.9	-£2,630.7 ± £19.4	£14,974.2 ± £12.3	£14,989.8 ± £62.9	£27,628.7 ± £57.4
Profit-Seekers								
Top (Q1)	5	£59,539.3	£6,014.6	-£1,940.2 ± £355.5	-£2,315.2 ± £100	£5,117.4 ± £358.4	£9,681.4 ± £509.3	£11,754.7 ± £472.6
2 nd (Q2)		£41,263.6	-£8,087.5	-£1,916.6 ± £1,032.9	-£2,827.5 ± £424.5	£8,687.6 ± £6,124.4	£3,686.5 ± £10,006.1	£8,306 ± £6,295
3 rd (Q3)		£35,616.1	-£18,738.2	-£1,848.4 ± £1,129.4	-£2,373.8 ± £1,066	£10,191.9 ± £3,997.1	-£2,395.4 ± £1,405	£3,574.3 ± £396.6
Bottom (Q4)		£11,697.6	-£13,352.6	-£574 ± £0	-£1,127.2 ± £0	£4,168.7 ± £0	-£389.1 ± £0	£2,117.6 ± £0
All farms		£31,962.9	-£9,503.3	-£1,434.5 ± £0	-£2,030.8 ± 0£	£6,216.7 ± £0	£3,183.2 ± £0	£6,453.5 ± £0
Expansionists								
Top (Q1)	5	£207,273.3	£111,664.7	-£2,208.9 ± £0	-£2,878 ± £0	£26,064.8 ± £0	-£3,156.8 ± £0	£17,821 ± £0
2 nd (Q2)		£91,906.3	£34,828.7	-£1,706.9 ± £466.2	-£2,889.7 ± £736.3	£10,382.2 ± £1,175.3	£14,752.9 ± £1,317.2	£22,489.4 ± £1,317.2
3 rd (Q3)		£83,666.9	£12,607.7	-£1,252.5 ± £0	-£2,988.1 ± £0	£5,029.8 ± £0	£13,417.7 ± £0	£15,892.3 ± £0
Bottom (Q4)		£8,045.7	-£5,550.2	-£272.8 ± £0	-£934 ± £0	£2,581.5 ± £0	£1,834.6 ± £0	£3,433.4 ± £0
All farms		£79,787.6	£29,600.2	-£1,142.8 ± £93.3	-£2,124.8 ± £147.2	£9,328 ± £235.1	£5,736.6 ± £263.5	£12,613.9 ± £263.5

Note: Values within a row in bold and with different superscript letters are significantly different ($p < 0.1$), following the Tukey post-hoc test.

Key: ‘+’ - with direct support; ‘-’ – without direct support; EID – Electronic Identification; AHP – Animal Health Planning.

Figure 5.14. Difference in lowland farms net income in different quartiles under innovation scenarios compared to the baseline scenarios (mean $\pm$ SD).



Assessment of the physical characteristics of the farms in the top and bottom baseline performance quartiles only found statistically significant differences in the means of lowland Profit-seekers and Expansionists farms (Table 5.15). An average Profit-seeker and Expansionist farm in the top quartile (Q1) receives significantly higher levels of direct support payment than an average farm in the bottom quartile (Q4). These farms also have significantly higher numbers of suckler cows. Overall, top performing farms in each class present larger grassland areas, more family labour, more sheep and are more reliant on support payments.

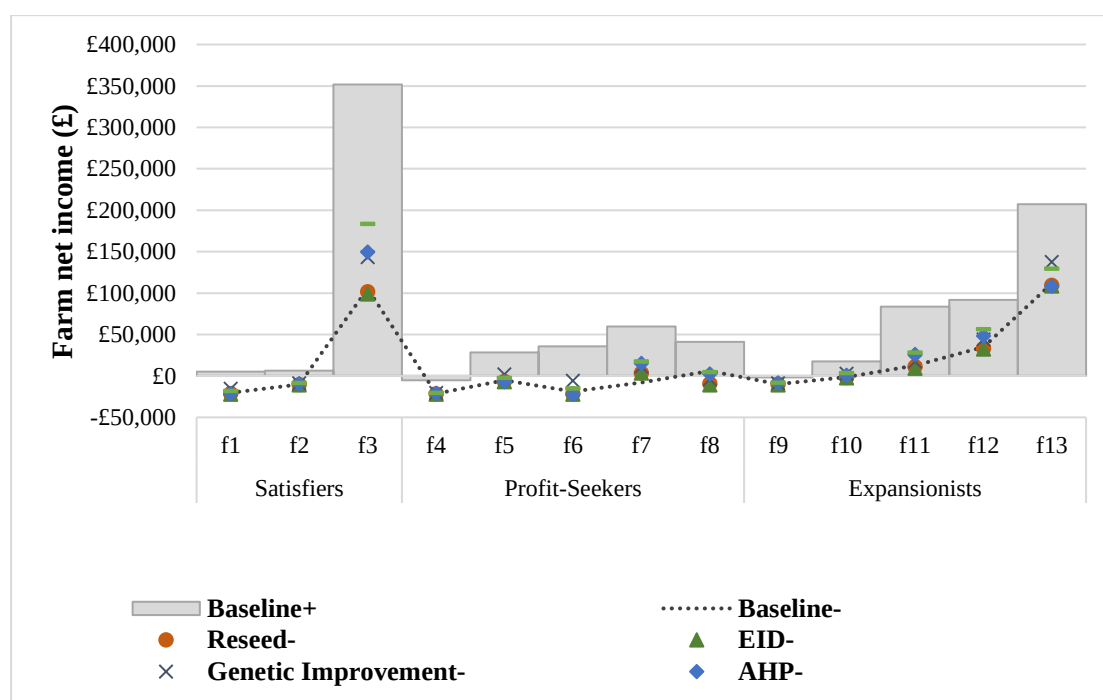
Table 5.15. Characteristics of lowland farms in quartiles based on the farm net income (mean $\pm$ SD). Average of farms in top and bottom 25% groups (*p < 0.01, **p < 0.05, ***p < 0.1).

Farm Input Variable	Average value of Top quartile (Q1)	Average value of Bottom quartile (Q4)
Satisfiers		
Grassland (ha)	724.6 $\pm$ 0	59.30 $\pm$ 0
Rough grazing land (ha)	161.2 $\pm$ 0	-
Family labour unit	2 $\pm$ 0	1.5 $\pm$ 0
Stocking density (LU/ha)	0.6 $\pm$ 0	2.5 $\pm$ 0
Variable costs (£/LU)	304.3 $\pm$ 0	233.1 $\pm$ 0
Direct Support Payments	193,748 $\pm$ 0	21,374 $\pm$ 0
LFA payments	37,921 $\pm$ 0	757 $\pm$ 0
Beef (1-2 yr old cattle)	83.4 $\pm$ 0	134.5 $\pm$ 0
Suckler Cows	383.8 $\pm$ 0	33.8 $\pm$ 0
Ewes	1,507.5 $\pm$ 0	48.5 $\pm$ 0
Profit-Seekers		
Grassland (ha)	95 $\pm$ 49	62.1 $\pm$ 13
Rough grazing land (ha)***	1 $\pm$ 1.4	5.7 $\pm$ 1.8
Family labour unit	1.4 $\pm$ 0.2	1 $\pm$ 0.1
Stocking density (LU/ha)	2.8 $\pm$ 1.9	1.1 $\pm$ 0.7
Variable costs (£/LU)***	201.3 $\pm$ 59.2	376.6 $\pm$ 22.8
Direct Support Payments***	50,789 $\pm$ 14,828	14,711.5 $\pm$ 1,317.3
LFA payments	3,020.5 $\pm$ 3,727.2	-
Beef (1-2 yr old cattle)	40.3 $\pm$ 26.1	45.6 $\pm$ 20.9
Suckler Cows***	117.5 $\pm$ 33.2	18.8 $\pm$ 16.7
Ewes	389.8 $\pm$ 317.1	114.5 $\pm$ 161.9
Expansionists		
Grassland (ha)***	325.5 $\pm$ 0	56 $\pm$ 25
Rough grazing land (ha)	62.7 $\pm$ 0	-
Family labour unit	2.8 $\pm$ 0	1.3 $\pm$ 0.4
Stocking density (LU/ha)	1.1 $\pm$ 0	0.9 $\pm$ 0.2
Variable costs (£/LU)	190.3 $\pm$ 0	403.3 $\pm$ 168.6
Direct Support Payments***	75,137 $\pm$ 0	11,322.5 $\pm$ 6101.6
LFA payments***	13,455 $\pm$ 0	995 $\pm$ 1,407.1
Beef (1-2 yr old cattle)	145.2 $\pm$ 0	47.6 $\pm$ 43.3
Suckler Cows***	229 $\pm$ 0	14.8 $\pm$ 8.1
Ewes***	812.5 $\pm$ 0	37.0 $\pm$ 25.5

Lowland – without direct support

When direct support payments are removed, lowland farm net profitability for each scenario is inevitably reduced by 2026 (Figure 5.15).

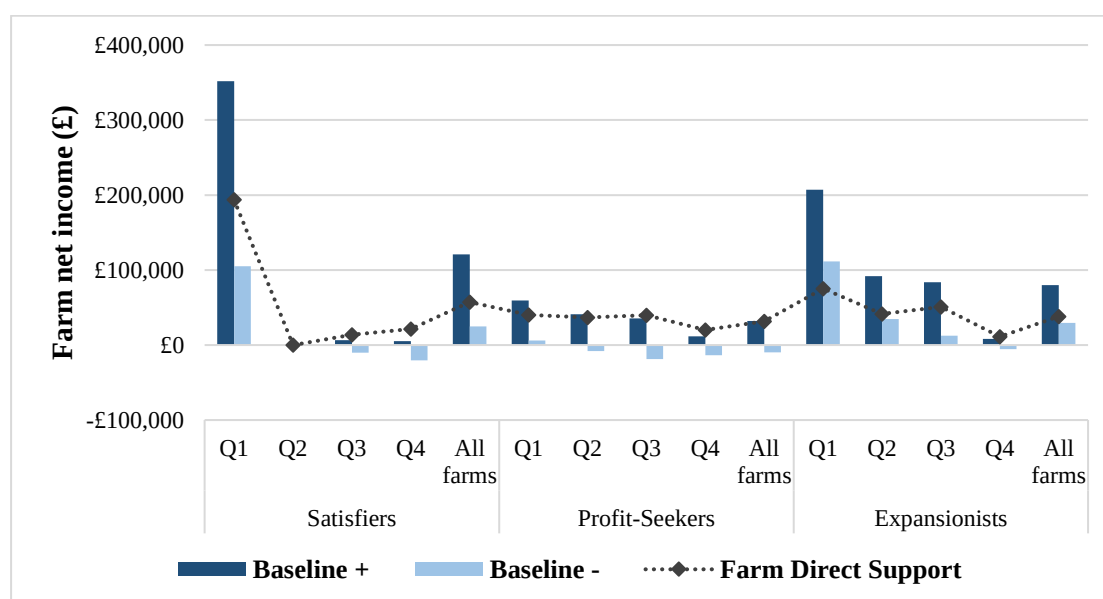
Figure 5.15. Estimated 2026 farm net income (without direct support) of lowland farms under the baseline scenarios and five innovation scenarios (reseeding, EID – Electronic Identification, GI – Genetic Improvement, AHP – Animal Health Planning, and a combined scenario).



Compared to the baseline, ScotFarm estimates that most Satisfiers and Profit-seekers lowland farms in this study become uneconomical in 2026. However, some Profit-seekers farms are able to return marginal positive net incomes by implementing only one technology, GI or AHP (e.g. ‘f5’ and ‘f8’, respectively). Furthermore, the proportion of Expansionists farms making losses in 2026 under GI-, AHP- and CT- is expected to rise to 20% if direct support is removed, which is further increased by 20% under Reseed- and EID- scenarios. Under Reseed-, Expansionists lowland farms more than double animal numbers, most likely to offset higher reseeding costs (by 60% and 66.1% in sheep and beef numbers, respectively).

Figure 5.16 shows that farms in the top baseline profitability quartile (Q1) are more susceptible to changes in support payments, showing the largest variations in net income. On average, over half of these beef producers are expected to make losses in 2026. This highlights how the viability of Scotland’s lowland farms ‘post-Brexit’ is heavily reliant on the maintenance of support payments.

Figure 5.16. Farm net incomes in 2026 for different performance quartiles under the baseline scenarios – Lowland farms.



Mixed Farming

ScotFarm used 39 mixed farms included in the FBS 2016. Figure 5.17 illustrates the results when existing levels of direct support are continued. The majority of farms are expected to be profitable in 2026 (Baseline+: 62.5% of Satisfiers and 76.5% of Profit-seekers), except for Expansionists, with 50% of farms estimated to return losses under the baseline scenario. Figure 5.18 summarises the impact of innovations and policy scenarios on mixed farms in different performance quartiles. Some statistical differences between different performance quartiles are verified (Table 5.16). For instance, Satisfiers mixed farms in the top quartile benefit significantly more from both genetic improvement and the range of selected technologies than farms in the third and bottom quartiles.

Figure 5.17. Estimated 2026 farm net income (with direct support) of mixed farms under the baseline scenario and five innovation scenarios (reseeding, EID – Electronic Identification, GI – Genetic Improvement, AHP – Animal Health Planning, and a combined scenario).

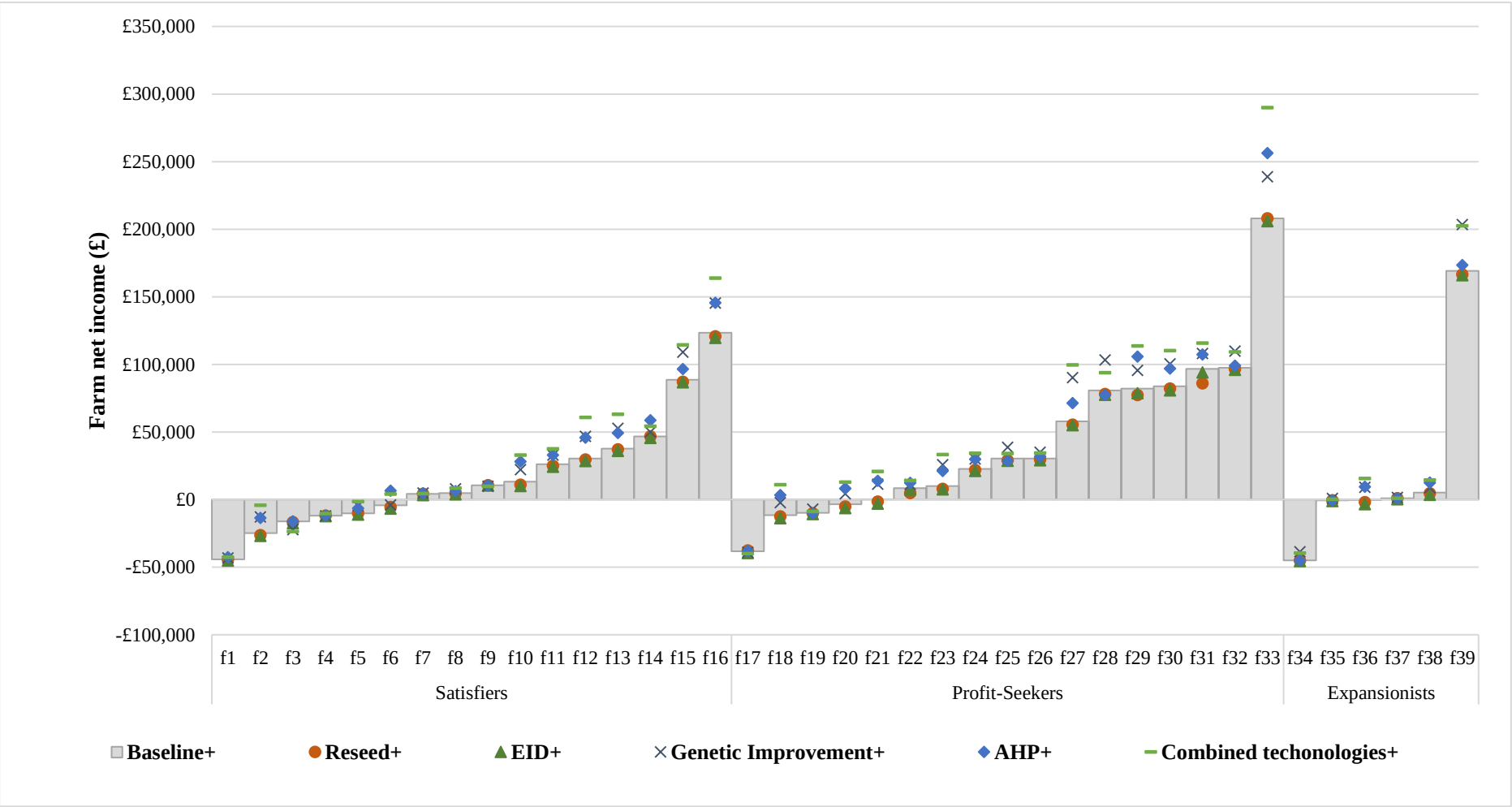


Table 5.16. Estimated difference in farm net income in 2026 due to innovations (with and without direct support; mean $\pm$ SD) for different performance quartiles under five innovation scenarios compared to the baseline scenarios – Mixed farms.

Baseline Net Income Quartile	N	Average Baseline Net Income		Scenario Results – Average Change in Net Income from Baseline									
		+	-	Reseed		EID		Genetic Improvement		AHP		Combined technologies	
				+	-	+	-	+	-	+	-	+	-
Satisfiers													
Top (Q1)	16	£74,100.7 ^{a,b,c}	£11,314.6	-£1,276.1 ± £204.3		-£2,226.7 ± £108.4		£14,994.55 ± £194 ^{a,b}		£12,474.8 ± £1,200.5		£25,925.2 ± £820 ^{a,b}	
2 nd (Q2)		£20,087.2 ^{a,d}	-£25,139.9	-£1,112.7 ± £0		-£1,837.4 ± £0		£7,763.7 ± £0		£9,211.4 ± £0		£15,702.1 ± £786.8	
3 rd (Q3)		-£1,363.2 ^b	-£26,086.8	-£410.3 ± £0		-£1,328.1 ± £10.5		£2,351.85 ± £10 ^a		£4,006.4 ± £0		£5,389.9 ± £290.1 ^a	
Bottom (Q4)		-£24,236.4 ^{c,d}	-£50,505	-£602.4 ±£46.1		-£1,448.8 ± £221		£1,617.2 ± £87.4 ^b		£3,245.2 ± £87.3		£4,069.3 ± £87.3 ^b	
All farms		£17,147.1	-£22,604.3	-£850.4 ± £39.5		-£1,710.20 ± £79.8		£6,681.8 ± £29.1		£7,234.5 ± £278.2		£12,258.7 ± £24.3	
Profit-Seekers													
Top (Q1)	17	£121,461 ^{a,b,c}	£38,029.1 ^{a,b,c}	-£2,176.5 ± £1,681.6		-£2,244.6 ± £136.6		£17,554.5 ± £317.7		£18,463.4 ± £115.7		£34,873.2 ± £115.7	
2 nd (Q2)		£62,766.4 ^{a,d}	-£5,538.8 ^{a,d}	-£2,704.5 ± £0		-£2,778.1 ± £0		£18,152.1 ± £0		£8,786 ± £0		£22,636.3 ± £0	
3 rd (Q3)		£17,874.9 ^b	-£27,034 ^{b,e}	-£1,932.8 ± £91.6		-£2,027.8 ± £438.1		£8,485.2 ± £27.9		£4,979.8 ± £123.2		£10,962.4 ± £0.7	
Bottom (Q4)		-£12,600 ^{c,d}	-£66,827.6 ^{c,d,e}	-£759.6 ± £52		-£1,963.9 ± £202.4		£5,555 ± £623.5		£7,507.2 ± £651.9		£11,260.6 ± £717.3	
All farms		£43,847.6	-£18,371.3	-£449.3 ± £2,380.5		£804.3 ± £4,289		£9,956.5 ± £3,199.7		£9,411.6 ± £730.5		£16,223.9 ± £4,707.8	
Expansionists													
Top (Q1)	6	£87,179.6	£35,647.8	-£1,643.4 ± £0		-£2,413.1 ± £0		£18,781.9 ± £0		£5,774.3 ± £0		£21,320.7 ± £0	
2 nd (Q2)		£920.6	-£18,504.9	-£11.1 ± £0		-£656.7 ± £0		£667.3 ± £0		£0		-£0.5 ± £0	
3 rd (Q3)		-£423.8	-£68,639.4	-£1,298.7 ± £328.5		-£2,803.2 ± £306.7		£9,113.5 ± £531.9		£10,688.1 ± £1,216.1		£16,651.4 ± £1,011.6	
Bottom (Q4)		-£22,744.8	-£58,719.8	£2,162.9 ± £6,576.1		£2,706.4 ± £4,693.7		£8,445.9 ± £6,608.5		£5,358.2 ± £7,577.6		£8,863.4 ± £8,313.8	
All farms		£21,561	-£22,214.7	-£1,209.9± £490		-£1,585.2 ± £51.1		£9,148.4 ± £88.7		£3,706.1 ± £202.7		£10,876.9 ± £168.6	

Note: Values within a row in bold and with different superscript letters are significantly different ($p < 0.1$), following the Tukey post-hoc test.

Key: ‘+’ - with direct support; ‘-’ – without direct support; EID – Electronic Identification; AHP – Animal Health Planning.

Figure 5.18. Difference in mixed farms net income in different quartiles under innovation scenarios compared to the baseline scenarios (mean $\pm$ SD).

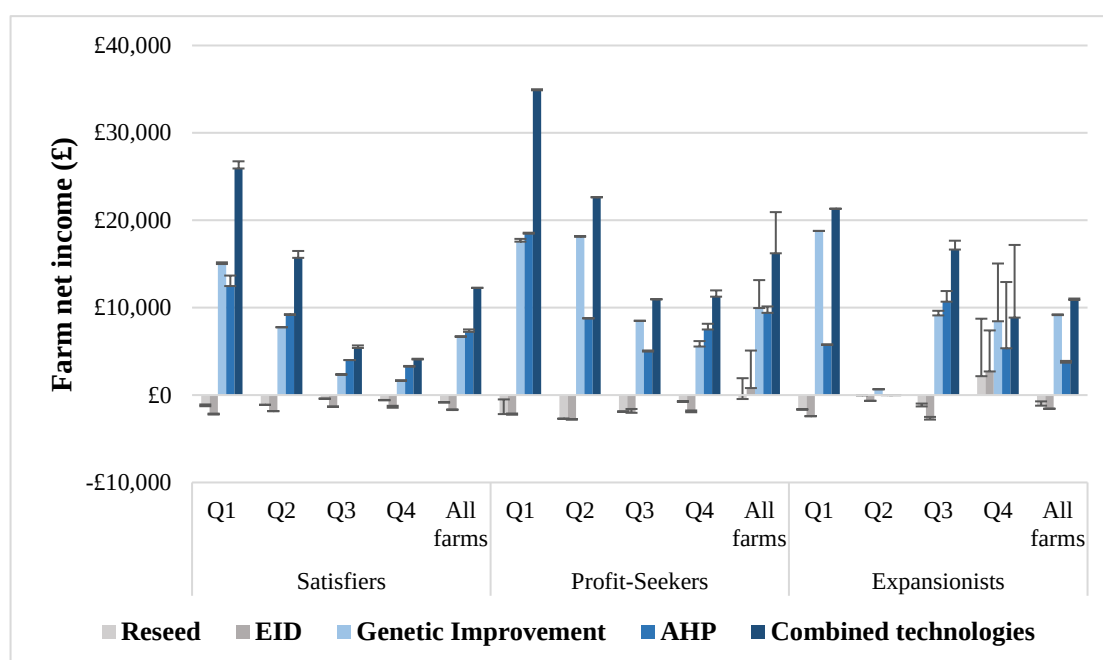


Table 5.17 shows that an average Satisfier and Profit-seeker farm in the top quartile (Q1) receives significantly higher LFA payment than an average farm in the bottom quartile (Q4). These farms also have significantly higher numbers of suckler cows. Generally, top performing farms in each class present larger areas, lower stocking densities, more sheep and are more reliant on support payments.

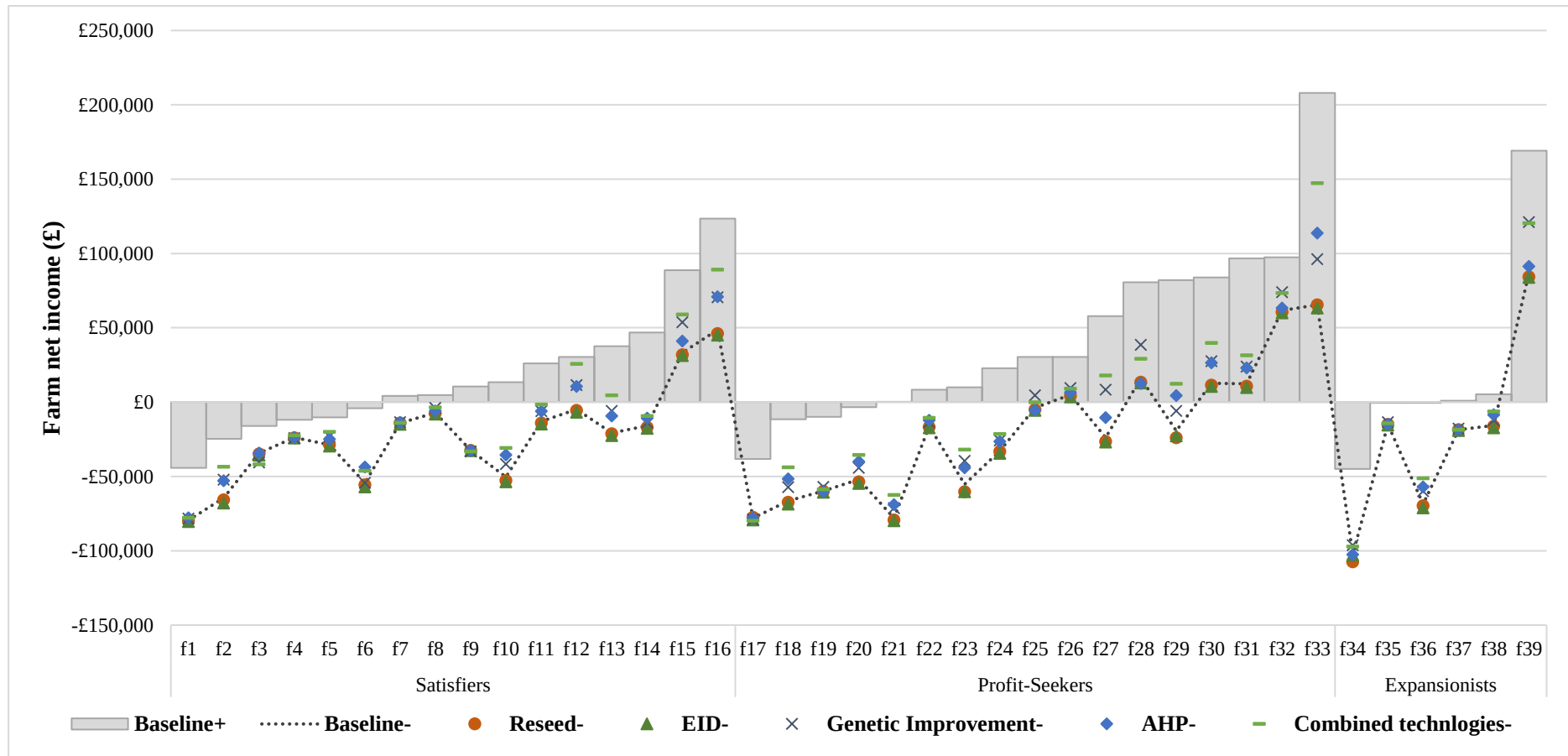
Table 5.17. Characteristics of mixed farms in quartiles based on the baseline farm net income (mean $\pm$ SD). Average of farms in top and bottom 25% groups (*p < 0.01, **p < 0.05, ***p < 0.1).

Farm Input Variable	Average value of Top quartile (Q1)	Average value of Bottom (Q4)
Satisfiers		
Grassland (ha)**	127.4 $\pm$ 55.8	58.8 $\pm$ 9.7
Rough grazing land (ha)	69 $\pm$ 58.5	13.4 $\pm$ 23.7
Family labour unit	1.3 $\pm$ 0.3	1.6 $\pm$ 0.4
Stocking density (LU/ha)	1.1 $\pm$ 0.8	1.4 $\pm$ 0.7
Variable costs (£/LU)	426.1 $\pm$ 168.6	506.2 $\pm$ 66.3
Direct Support Payments*	45,203.5 $\pm$ 2,335.8	21,770.3 $\pm$ 6,297
LFA payments***	7,061.5 $\pm$ 5,132.9	2,023 $\pm$ 1,438.7
Beef (1-2 yr old cattle)	44.8 $\pm$ 48.3	38.9 $\pm$ 37
Suckler Cows**	117.2 $\pm$ 43.7	42.2 $\pm$ 39.8
Ewes	291.9 $\pm$ 227.8	184.1 $\pm$ 122.9
Profit-Seekers		
Grassland (ha)	157.8 $\pm$ 93.7	99.1 $\pm$ 55.9
Rough grazing land (ha)	190.9 $\pm$ 344.9	4.3 $\pm$ 3.9
Family labour unit	1.9 $\pm$ 0.7	1.8 $\pm$ 0.8
Stocking density (LU/ha)	0.9 $\pm$ 0.5	3.1 $\pm$ 3
Variable costs (£/LU)	448.9 $\pm$ 289.8	382.1 $\pm$ 143.4
Direct Support Payments	69,804.2 $\pm$ 34,323	46,982 $\pm$ 12,246.5
LFA payments**	10,493.4 $\pm$ 8,838.7	1,454.8 $\pm$ 1,205.9
Beef (1-2 yr old cattle)**	38.6 $\pm$ 25.3	201.4 $\pm$ 135
Suckler Cows**	117.3 $\pm$ 43.6	49.4 $\pm$ 43.6
Ewes***	136.1 $\pm$ 254.1	111.4 $\pm$ 163.2
Expansionists		
Grassland (ha)	94.7 $\pm$ 79.6	119.6 $\pm$ 128.5
Rough grazing land (ha)	1.5 $\pm$ 2.1	1.1 $\pm$ 1.6
Family labour unit	1.9 $\pm$ 0.4	2.3 $\pm$ 0.3
Stocking density (LU/ha)	1.4 $\pm$ 0.8	1.5 $\pm$ 1.2
Variable costs (£/LU)	555.9 $\pm$ 333.2	792.5 $\pm$ 625.9
Direct Support Payments	43,284.5 $\pm$ 34,014	35,778 $\pm$ 30,798.7
LFA payments	192.5 $\pm$ 272.2	516.5 $\pm$ 730.4
Beef (1-2 yr old cattle)	134.1 $\pm$ 131.7	77.4 $\pm$ 74.4
Suckler Cows	58.5 $\pm$ 82.7	27.5 $\pm$ 38.9
Ewes*	59 $\pm$ 6.4	-

Mixed Farming – without direct support

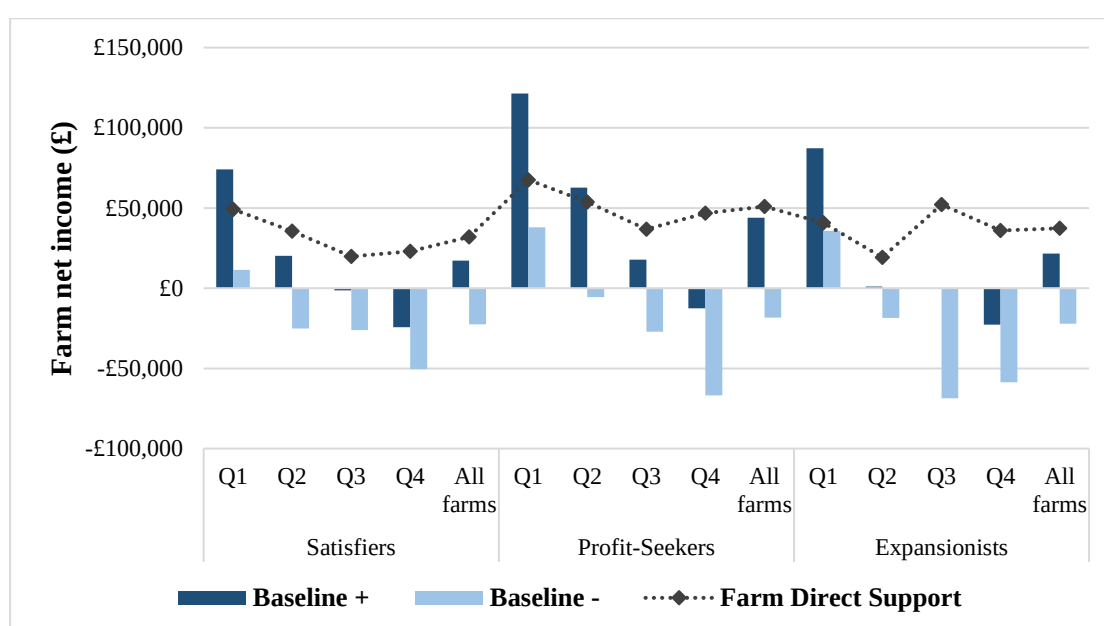
As expected, farm net profitability is estimated to be considerably reduced for mixed farms under all scenarios when direct support payments are removed (Figure 5.19). The lack of support has a pronounced negative effect on these farm systems and farm profitability is often negative. When direct payments are removed the majority of mixed farms remain unprofitable under all scenarios, as determined by ScotFarm. By implementing GI-, AHP- or CT-, some farms (e.g. ‘f12’, ‘f13’, ‘f27’) are able to stay profitable, increasing the proportion of profitable farms when compared to the baseline.

Figure 5.19. Estimated 2026 farm net income (without direct support) of mixed farms under the baseline scenarios and five innovation scenarios (reseeding, EID – Electronic Identification, GI – Genetic Improvement, AHP – Animal Health Planning, and a combined scenario).



Similar to other farm types, farms in the top quartile (Q1) are most vulnerable to the removal of support as they receive higher direct support payments, except for Expansionists (Figure 5.20). Expansionists mixed farms in the third quartile are most susceptible to changes in support payments, being more reliant on direct support as a proportion of their net income when compared to other quartiles (farm direct support: Q1 - £40.7k; Q3 - £52k).

Figure 5.20. Farm net incomes in 2026 for different performance quartiles under the baseline scenarios – Mixed farms.



Mixed farming - herd and flock dynamics

Satisfiers increase beef numbers by 100.1% under GI+ scenario, being the largest difference in animal numbers among mixed farms, whereas under GI- beef numbers decrease by 33.3%. By combining this range of technologies, the optimum solution suggests an increase of 67.7% in beef numbers for these farms, and a 1.3% contraction in the ewe flock. Similarly, Profit-seekers tend to increase beef numbers under GI scenarios by 5.2%-9.1% (under GI- and GI+, respectively). Among Expansionists, the highest variation is verified in the beef herd, which tends to increase over 11% under GI-, AHP- and CT- scenarios, and decrease by 2.1% under both reseeding scenarios (Table 5.18).

Table 5.18. Percentage change in beef and sheep numbers under innovation scenarios compared to the baseline scenarios – Mixed farms.

	Reseed				EID				Genetic Improvement				AHP				Combined technologies			
	Beef		Sheep		Beef		Sheep		Beef		Sheep		Beef		Sheep		Beef		Sheep	
	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-
Satisfiers																				
All farms	-2.2%		-1.3%		12.6%	11.3%	0%		100.1%	-33.3%	0%	-6.3%	0%		0%		67.7%		-1.3%	
Profit-Seekers																				
All farms	-2.6%	-5.2%	-2.1%		0.7%	-0.9%	0%		9.1%	5.2%	0%		0.3%	-0.9%	0%		-7.5%	6.6%	-1.4%	-2.1%
Expansionists																				
All farms	-2.1%		-3.3%		-0.1%	-1.2%	0%		0%	11.2%	0%		0%	11.5%	0%		0%	11.5%		-3.3%

Key: '+' - with direct support; '-' – without direct support; EID – Electronic Identification; AHP – Animal Health Planning.

5.4. Discussion

This study is the first to present modelling results of the adoption of different technological innovations under alternative policy scenarios in Scottish beef and sheep farms. Using FBS data to define and configure representative and individual farms, ScotFarm has estimated impacts across different classes of farmers and farm types. The response to the modelling scenarios was largely consistent across classes of farmers and respective farm types. In general, the combined technologies led to the greatest response in financial performance, followed by GI and AHP, except for LFA beef farms. LFA beef farms are characterised by a high number of suckler cows and calves, which are usually weaned at 6-9 months and then sold. The financial benefits accrued from increasing the number of calves reared through BVD prevention were more substantial among these farms and a significant contributor to their financial performance, when compared to GI. Furthermore, the relative magnitude of response was greater among mixed farms, as these farms' profitability is usually marginal.

The model estimates of economic impacts resulting from the selected innovations are broadly consistent with earlier studies, except for reseeded grassland. Grassland reseeding has been demonstrated to greatly improve grassland productivity, having a positive effect on farm profitability (Creighton et al., 2011b; Shalloo et al., 2011). However, in the model, productivity increases did not automatically lead to improvements in profitability. Even though the benefits of reseeding did not outweigh its costs in the model, other benefits should also be taken into account²¹. After implementing reseeding, some farms reduced the amount of bought-in silage (e.g. Profit-seekers LFA beef farms). As discussed in Chapter 2, grazed grass is the cheapest feed available to all ruminant systems (Finneran et al., 2010), with a relative cost ratio of grazed grass to grass silage and to concentrate of 1:1.8:2.4 (Shalloo et al., 2011). Increasing the quantity of herbage produced reduced the dependence on purchased feed in these farms. By reseeding, only the costs of sward improvement by 'overseeding' (renovation) were considered, which costs up to £24/ha/year (£10/ac; SAC, 2015) and could quickly be recouped in yield benefit. For example, an extra three tonnes of DM per hectare is

²¹ ScotFarm is a system model, meaning that it is based on farm system analysis where all existing farm activities are interconnected (both in physical and financial aspects) and contribute to the optimal objective function that is maximising farm profit. Therefore, an increase, or decrease, in profit due to an innovation represents all the changes in ScotFarm associated with the implementation of the innovation.

reported as the equivalent feed value of three tonnes of concentrates by Quality Meat Scotland (QMS; 2013).

Similarly, the introduction of EID led to decreases in net income. Even though the benefits of EID are well reported in the literature (e.g. EC, 2011b; AHDB, 2015), its high costs and poor reliability of establishment have been identified by farmers as important constraints to wider adoption. In the model, labour saving was assumed to be absorbed within existing labour requirements, with some farms showing reductions on the costs of hired labour when EID was implemented (e.g. Profit-seekers LFA cattle and sheep farms). However, farmers often see the high costs as a barrier and in many cases the cost of investment is prohibitive (e.g. mixed farms). Some calls for financial incentives were recorded by Duckett (2014) and Kyle et al. (2017). Agriculture policy measures to promote innovation such as investment grants have been reported to positively influence the adoption of new technologies (OECD, 2013; Läßle and Thorne, 2019). Such incentives could greatly help maximise the potential benefits of EID in the Scottish beef sector.

The economic benefits of BVD prevention estimated in this study suggest that there is considerable consistency with the findings reported in other studies, given the wide circumstances of the farm systems. For example, by extrapolating the findings of this study, a £17.9 gain per cow²² is estimated due to BVD prevention, which comes within the plausible range of £18-£33 (Stott and Gunn, 2008) and £17.3 per cow (Larson et al., 2012) assessed in earlier studies. However, each study takes a different approach, which is a challenge when trying to find an economic figure of most relevance to determine the economic impacts of BVD prevention. Therefore, there are large uncertainties over the estimation of specific parameters such as biosecurity efficiency, vaccination strategies and herd status.

The genetic gains in growth efficiency modelled are within the scope of what can be achieved through genetic selection (e.g. Amer et al., 2015). Growth rates are moderately

²² In order to assess the economic benefits at the national level, the total number of suckler cows was assumed to be a single national herd and the gains under the AHP+ scenario were determined. The average net income for all the farms under AHP+ was £78,234.6 (SD ± £74,971.1) per year. Considering the total number of suckler cows to be 436,640 in Scotland (Scottish Government, 2016), the average gain per cow per year was estimated at £17.9 (SD ± £17.2).

heritable (Burrow, 2012) providing good opportunities to reasonably improve live weight growth through genetic improvement. However, heritability of weight is higher than that of weight gain (Davis, 1993; McHugh and McGee, 2016). There is a possibility that selecting for weight will lead to an increase in the mature body size of animals, rather than in growth efficiency, which translates into increased feed requirements, as discussed by Ash et al. (2015). Nonetheless, the results indicate that gains in productivity and profitability can be obtained from genetic selection.

The combination of production technologies and practices led to larger increases in productivity and profitability, which suggests that these technologies can have an additive effect. Even though the recorded changes in net income due to innovations are minor, the estimated benefits suggest that for some farms in the study, the farm business could remain profitable without direct support, and there are many possible combinations of technologies that could still be investigated. Similar to the results reported by Laple and Thorne (2019) in Irish dairy farms, this finding reveals that small innovative efforts can reduce dependence on subsidies given a certain level of innovation, hence farmers should be adopting new techniques to remain competitive. Furthermore, associating innovations that target different areas of animal production with a better management of resources could result in wide-ranging benefits for farmers, meaning that innovative farmers could achieve further economic gains by innovating further. This is particularly relevant for farmers in the top performing quartile²³.

However, it is also clear that domestic decisions on direct support have a more significant impact on farm profitability than these technologies. This is verified in all farm types, and the magnitude of estimated reductions in net income is such that the viability of many farms is uncertain if direct support is eliminated without some increase in other type of support and/or alternative income support measures, as also highlighted by Hubbard et al. (2019). As reported by Bradley and Hill (2019) and Swales et al. (2017) in studies also using FBS data, the reductions in net income imply

²³ Less Favoured Areas cattle and sheep, LFA beef, lowland and mixed farms in the top performing quartile return on average £589.7(SD ± £80.2), £643.5 (SD ± £73.3), £443.4 (SD ± £33.7) and £1000.5 (SD ± £16.4) more per hectare, respectively, than farms in the bottom quartile under the baseline scenario.

that many livestock farms would simply cease production. Another option would be some shifting of production from sheep to cattle, as farms seek to benefit from comparatively higher beef prices, such as LFA beef and mixed farms under the CT-scenario. Considering the magnitude of net income reductions from the removal of support payments, it is apparent that the pressure for structural change would be significant (Hubbard et al., 2019).

There is some variation between and within farm types, which most likely reflects differences in farm systems arising, for instance, from structural characteristics (e.g. farm size, subsidy support, livestock prices). In particular, the results suggest that, if farm support payments remain, only an average of 2.6% and 3.7% of LFA farms (LFA cattle and sheep, and LFA beef farms, respectively) become loss making under the baseline scenario. When it comes to lowland and mixed farms, the proportion of farms that become loss making in similar circumstances is much higher, i.e. 13.3% and 37% of farms, respectively. However, 29.1% and 43.1% of LFA farms that were profitable with direct support (LFA beef, and LFA cattle and sheep farms, accordingly) become loss making farms if support payments are withdrawn. This is critical to lowland and mixed farms, where the majority of farms (an average of 62.2% and 78.5%, respectively) is extremely vulnerable to the removal of support as a result of policy change, e.g. due to 'Brexit'. For these farmers, the future looks extremely reliant on the nature and scale of public support available to farming, possibly coupled with a significant reduction in stocking rates on less productive land, as suggested by Silcock (2017).

Within farm type, the variation in impacts across quartiles of performance probably reflects the level of production, with larger top performing farms receiving higher support levels, which leaves them more exposed to support withdrawal even if benefiting from potential efficiency advantages. Overall, economic gains and losses are therefore mainly proportional to farm size. This highlights how farm support payments provide a financial buffer for these farm systems. Given current market and policy uncertainties, the findings of this study are quite relevant, being worth highlighting the positive impact of innovation, which suggests that farmers can reduce 'policy risks' by being more innovative. However, it should be noted that the modelled impacts are based on a number of specific assumptions and do not necessarily represent actual impacts

for individual farms, only revealing the likely direction and where pressures for structural adjustment are most likely to be experienced.

As mentioned before (Chapter 1), the analysis has been confined to all farms producing beef cattle therefore being part of the Scottish beef sector. While in the FBS some farms are single-enterprise specialists, many have two or more different activities. Beef systems are often linked to other enterprises, as they are usually planned to fit a particular farm's circumstance (Hubbard et al., 2019). For instance, livestock and cereal enterprises may co-exist, as may dairy and beef enterprises. Thus, the outputs of many farms include a combination of activities (see Chapter 1 for a review of the FBS farm type classification). ScotFarm was set-up to limit the available production possibility set to beef and sheep production activities currently observed in a farm. The model selects the combination and level of farm activities to maximise net income under each scenario, but only from those activities. However, these farms can have other production activities as sources of income (e.g. cropping) that were not considered in this study. Diversification and off-farm incomes are other sources of income that can also have an impact on the farm financial status (O'Brien and Hennessy, 2006; Barnes et al., 2015). As this study aimed to assess the economic impact of innovations on Scottish beef and sheep farms, it was assumed that farms would be focused on beef and sheep production with no other income generated from alternative activities being included.

This chapter has described the use of LP to model farm-level adaptations under external shocks. The LP approach replicated farmers' responses under a changing farming environment to optimise a single objective - profit-maximisation - attributing similar weights to all activities. As mentioned in Chapter 2, a limitation of LP is the general assumption that all farmers are profit oriented, and farmers may also be interested in pursuing other objectives (e.g. environmental protection and enhancement, lifestyle, future generations). The need to find balance among multiple objectives in farming is well established in the literature (e.g. Gasson, 1973; Defra, 2008, 2011), overcoming this limitation would offer the possibility to improve the present model. This could be attempted in future research, for instance, by using goal programming to incorporate other non-economic factors such as environmental and societal aspects (Romero and Rehman, 1984; Fleskens and de Graaff, 2010). Several studies have also suggested the

use of goal programming when a farmer is seeking an optimal compromise among several objectives (many of which may be in conflict), rather than optimising a single objective (e.g. Wallace and Moss, 2002; Behera et al., 2008). However, while the model presented here may not fully express the objectives of all farmers, it was able to recognise the heterogeneity of farmers' behaviour across a wide range of farms. Furthermore, given the uncertainties in relation to future support payments and trade arrangements, the challenge resides in optimising existing resources and production capacities.

5.5. Conclusions

Using a farm-level model, it was demonstrated how a range of technological innovations can influence the structure and profitability of individual Scottish beef and sheep farms under two different policy scenarios. The technologies covered several areas of animal production from grassland management to animal health planning, and all could provide some sort of benefit, especially when used in combination. However, when direct support is removed, net incomes are estimated to decline in all farm types. LFA beef farms are the least affected with the majority of farms being resilient, as only a smaller proportion of farms are expected to make losses with the withdrawal of direct support payments, whereas LFA cattle and sheep farms show a moderate degree of resilience to the lack of support. In comparison, most lowland and mixed farms are highly vulnerable to the removal of financial support resulting from a potential policy change. These farms require special attention when reforming future agricultural policies. When GI, AHP and CT are implemented the proportion of loss making farms reduces, which indicates that exploring innovative options to improve productivity may indeed help farmers remain competitive and reduce subsidy dependence, in order to adapt to potential changes in economic conditions, all of which leads to the question of what influences Scottish beef farmers to adopt sustainable innovations.

The work presented here has demonstrated that the variation between Scottish beef systems occurs in many dimensions (e.g. structural and socio-economic characteristics, farmers' objectives, farm management choices). Recognising this heterogeneity is important, as different farmers given similar technological options or facing the same agricultural policy tend to respond in different ways. From this analysis, economic

factors appear to have the greatest impact on the adoption of sustainable innovations; however, as shown, the costs and benefits of adopting new farming practices and technologies are not the same across all farms. Identifying the determinants of innovation adoption and the channels through which technological knowledge and incentives may be diffused can help facilitate a move towards more sustainable beef production in Scotland.

6. Chapter 6: General Discussion and Conclusions

In this chapter, the findings of this thesis are summarised in relation to the objectives outlined in Chapter 1. The structure of the chapter is as follows. Section 6.1. highlights the main findings of the thesis and research implications for technology adoption in Scottish beef production systems. Section 6.2. presents a succinct description of the limitations of this research, which links to Section 6.3. where opportunities for further research are discussed. Finally, Section 6.4. underlines some key contributions of this thesis and concluding comments.

6.1. Main findings and applicability

This thesis assessed the performance of Scottish beef production systems under an evolving policy and market context, with a particular focus on the impacts of adopting different farm management technologies/practices on farm-level outcomes and profitability. To achieve this objective an integrated approach was proposed, an approach that captures the heterogeneity of beef production in Scotland and informs the current set of policy decisions related to innovation adoption overarching the agricultural sector. This conceptual framework was applied to beef production systems through three comprehensive applied studies, reflecting the complex and dynamic nature of agricultural production systems.

Chapter 1 presented a background to beef farming in Scotland, describing farm practice, structure and performance across the distribution of farms, together with a discussion of the main policy frameworks that support and shape this production. Economic performance of the sector was analysed using FBS representative data, highlighting the consistently low average net incomes returned by these farmers, and their reliance on support mechanisms. Subsidy support is an important part of farm finances, influencing farmers' decision-making, for instance, in relation to production choices (e.g. input use, labour allocation, investment). Technical performance in terms of average herd sizes and stocking rates was shown to have been dropping since the 1970s, which is not only a result of market pressures, but also a response to the decoupling of support payments in 2005. This analysis has indicated that Scottish beef farmers have been affected by policy and market changes over the years, which is reflected in the way they manage their farm systems, in particular, in the changes they have made to adapt (e.g. reducing

herd sizes). It is important to note, however, that average performance masks important variation and top performing farms reveal higher levels of economic and technical performance. The interdependency of these farm systems, where the behaviour of one farmer has repercussions across the local, or wider global, area was also considered a relevant factor that should be taken into account.

Much of the uncertainty remaining in relation to the potential outcome of ‘Brexit’ negotiations for future trading arrangements and agricultural support post-‘Brexit’ was also discussed in Chapter 1. These significant policy issues are expected to influence the resilience and structure of farm-level production, shaping the future of farming in Scotland. This profile of the Scottish beef sector and the evolving policy context in which beef producers operate, highlights the diversity of farm systems and farm-level production decisions. A diversity that needs to be recognised in order to promote positive behavioural change and remove any potential barriers to improvement.

European farmers, and in particular, Scottish beef producers, are generally considered price takers in a global market with limited influence on meat prices; hence, approaches to improve productivity are usually centred either on increasing output or reducing cost. This can be achieved by adopting sustainable innovations that provide efficient combinations of inputs and outputs at the farm level. An integrated approach capable of taking account of such decisions in light of the significant variation verified among beef farms was therefore required. Against this background, Chapter 2 reviewed the literature on innovation and agricultural systems models, with a new conceptual systems framework being proposed, which focuses on the ex-ante assessment of changing farm practice and agricultural support. This framework captures alternative production decisions and the associated technical and financial performance of the national distribution of beef herds.

In Chapter 3, the behavioural segmentation model proposed in Chapter 1 was outlined. The segmentation model is based on characteristics and determinants of farming style, which were translated into specific farmers’ objectives and attitudes by means of a farmers’ intentions survey. This segmentation model takes into account that actual decisions and in turn, behavioural change, depend on the underlying drivers of decision-making, in addition to the structural and financial opportunities, and constraints, facing

the farm business, therefore acknowledging the heterogeneity of beef farmers. FBS data was used and linked to the behavioural segmentation classes achieved through this study to examine the associated physical, financial and managerial characteristics of each class. The analysis revealed three distinct classes of farmers: Satisfiers, Profit-seekers and Expansionists. Maintaining their way of life and profitability were important objectives to Satisfiers, whereas business expansion was less important. Profit-seekers strongly identified with maximising annual profits and were the class most likely to view enhancing the environment as not important. Finally, Expansionists had diverse objectives but were more likely than the other two classes to be interested in increasing the size of the business and enhancing the environment.

The analysis of farm characteristics associated with each segmentation class concurred with a priori expectations, showing considerable variation with some significant differences. Profit-seekers, corresponding to the largest proportion of the overall sample, operated larger farms, had more labour, livestock and land in crops and grass, reflecting more focused production-led objectives. Higher levels of borrowing, and reliance on subsidies were also verified among Profit-seekers, with these farms performing better as measured by Net Farm Income (NFI) and Management and Investment Income (MII). Apart from Expansionists, farmers did not rate environmental objectives highly. However, all three classes expressed positive attitudes towards environmental stewardship and encouragement of wildlife; this, coupled with the emphasis on profit objectives, suggests a strong potential for policy initiatives such as sustainable intensification. Segmentation proved useful as a means of differentiating between distinct types of farms and farmers, thus providing potential advantages to policy makers, for instance, in targeting policy design and delivery to meet the objectives of each segment. This is particularly relevant for policy objectives that rely on knowledge exchange activities, offering strategies to communicate with different classes farmers.

Chapter 4 assessed the reliability of farmers' intentions, further extending the study presented in the previous chapter. Focusing on farmers' primary objectives for their business stated in 2013, a comparison between farmers' intentions and actual behaviour was performed using FBS farm data to record their actual financial position and performance in 2016. Farmers were categorised into three groups: those that were

accurate, optimistic (i.e. farmers originally overestimating their future production) and pessimistic (i.e. farmers underestimating their future production). The results showed that the majority of farmers overestimated their future production plans, suggesting that stated intentions were not a good predictor of realised objectives. Farmers may plan to improve profitability; however, yields and prices are not fully under their control. This intention-behaviour discrepancy was further analysed by the estimation of two multinomial logistic models to assess the main factors behind farmers' behaviour. The results of the models indicated that, in general, the intention-behaviour gap could only be described by a few farm characteristics currently available in the FBS database. These explanatory variables are, however, important indicators to consider when estimating and modelling farm-level economic and technical performance, as variations in farm characteristics are potential drivers for differences in profitability and productivity. Another finding of the study was that of those farmers planning to maximise annual profits, almost 40% were accurate and increased net farm income, which means that the direction of change was correct. The significance of profit maximising objectives strongly suggests that economic factors will be the strongest influence on the uptake of innovations by farmers. In practice, ongoing assessment of the underlying drivers of farmers' decision-making could help improve understanding of the development, and indeed the heterogeneity of farmers' intentions. However, this is often a time consuming and costly solution.

A key contribution of this thesis was the development of a systems modelling framework that accurately describes the impacts of several farm management practices and technologies, under different policy scenarios across the range of 'actual' beef farms, as presented in Chapter 5. Most models consider hypothetical or representative farm types and have been usually developed for specific applications, agricultural systems or geographic areas. In contrast, the systems model applied in this thesis addresses not only farm and farm type variabilities – from information in the FBS - but also the heterogeneity of farmers' behaviour. Linking the latent class model presented in Chapter 3 to the FBS returns enabled the development of a more realistic model that captures the complexity of a real world situation, and leads to a more comprehensive explanation of farmers' economic behaviour. Combining an optimisation approach with a segmentation model provided a valuable tool to analyse the impacts of alternative policy scenarios.

In order to improve the performance of beef production systems in Scotland, it is therefore important to demonstrate the actual economic and productivity gains that are achievable through the uptake of specific innovative technologies and management practices, across the range of heterogeneous farms. The selection of such technologies and practices was dictated by their sustainability taking into account policy measures and future legislation, as outlined in Chapter 2. The results reported the potential effects on farm output and profitability of improved best practice, which were broadly consistent with the literature. In general, economic gains and losses were proportional to farm size and profitability. The current study thus bridges the knowledge gap about what is currently being accomplished on these farms and what is achievable by implementing specific technologies, given the underlying farm characteristics and policy context.

The systems modelling approach underlined how volatile and changeable market and policy contexts can be, and how challenging it is for beef farmers to adapt their systems accordingly. This analysis also highlighted that beef production has been in part buffered by subsidy support, which is often seen as a ‘social subsidy’ allowing to maintain production levels in remote rural areas. In particular, scenario analysis assessing the potential effects of direct support removal showed that support payments have more significant impacts on farm profitability than these innovations, with the economic viability of many farms being uncertain under such economic conditions. Larger, top performing farms receive higher support levels and therefore appear to be more exposed to support withdrawal even when benefiting scale advantages, such as better efficiency. However, it is also clear that although changes in net income due to innovations are minor, by implementing some of these technologies (e.g. genetic improvement, animal health planning), or the combination of technologies, some farms are able to remain profitable under a policy reform. This reinforces the argument that exploring innovative strategies to improve productivity will help farmers remain competitive and reduce subsidy dependence. Within this context, one important question arises: what can facilitate innovation? As argued by Läßle et al. (2015), although there is a general consensus that innovation is crucial for the development of the agricultural sector (e.g. Spielman and Birner, 2008; OECD, 2013), less agreement exists on how to assess agricultural innovation and on policy measures that encourage innovation.

6.1.1. Research Implications

In the previous section, the main findings of this thesis were discussed, showing how the five chapters relate to one another conceptually and empirically. In this section, broader implications of the empirical findings are investigated, with the purpose of integrating the information provided to foster agricultural innovation in Scottish beef systems. Recommendations to encourage innovation at the farm level are also provided.

Implication 1: Recognising farmers' heterogeneity and potential innovation adopters

As argued by Doole and Pannell (2011), farmers' classifications can be used to better understand how heterogeneity in biophysical and socio-economic characteristics affects the costs and benefits of adopting new technologies. Heterogeneity across farms plays therefore an important role in explaining differing rates of innovation adoption (van Grieken et al., 2019). More specifically, the innovation literature suggests that key characteristics for identifying likely adopters of innovative technologies and practices include profit orientation (e.g. Rogers and Shoemaker, 1971; Mariano et al., 2012), larger farm sizes (e.g. Diederer et al., 2003; Prokopy et al., 2008), higher levels of agricultural support (e.g. Finger and El Benni, 2013; Toma et al., 2018), and higher availability of labour (e.g. Ghadim and Pannell, 1999; Diederer et al., 2002). In addition, higher levels of education attainment, in particular agricultural education (e.g. Läßle et al., 2015, 2017), active information seeking (e.g. Foltz and Chang, 2002; Reichardt et al., 2009) and positive investment behaviours are also described as positively influencing innovation adoption (e.g. Diederer et al., 2002; Toma et al., 2018). Economic factors have therefore the greatest impact on technological uptake.

Findings of this thesis point in the same direction. Thus, Profit-seekers with the primary objective of maximising annual profits, with higher farm business revenue, NFI, total net investments and heavier reliance upon subsidies are more likely to adopt these innovations first. This finding is supported by the established body of literature that highlights that innovation adoption behaviour is inherently connected to the farm's financial and economic behaviour (e.g. Adrian et al., 2005; Mariano et al., 2012), in part because higher income farms are more likely to support costs related to technology adoption (van Grieken et al., 2019).

Profit-seekers are also characterised by higher education levels in an agriculturally related subject, and by operating larger farm sizes with higher stocking density and labour availability when compared to other classes - characteristics also matching the abovementioned determinants of innovation adoption. In particular, a stronger profit orientation shown by highly focused production-led objectives, together with a higher number of employees are usually associated with larger farms, which have a higher probability of being technology adopters (Diederer et al., 2002; Mariano et al., 2012; Toma et al., 2018). Furthermore, the positive effect of agricultural education may be reflective of the farmer's awareness of new technologies and practices that increases through agricultural education, and of the perceived usefulness of information sources (Lin, 1991; Läpple et al., 2015; Sauer and Latacz-Lohmann, 2015). Thus, more educated farmers such as Profit-seekers are more likely to have been exposed to more information, and to spend more time accessing and selecting the information most fitting for their business (Läpple et al., 2015; Toma et al., 2018). As such, these farmers are generally more effective in translating innovation into sustainable efficiency gains. As highlighted by Läpple et al. (2017), the fact that these already 'better performing' farmers present a higher probability of adopting new technologies may be a cause of concern, as innovations could contribute significantly to support more marginal farmers in making progress and catch up. However, several studies have identified such farmers as being less likely to engage with innovative technologies when compared to Profit-seekers (OECD, 2001; Toma et al., 2018; Läpple and Thorne, 2019).

At the policy level, recognising these differences between farmers' classes can help improve the cost-effectiveness of interventions that foster innovation adoption, increase farmers returns and meet specific policy objectives, for instance, for sustainable agricultural production (Barnes et al., 2019). As discussed in Chapter 3, engaging particular classes of farmers can lead to more targeted policy delivery within the sector. That is, to encourage the use of innovative sustainable technologies, identifying the most likely adopters would be a good starting point, avoiding the costs implicated in targeting farmers who are less (or not) likely to adopt first; this, in turn, may positively influence neighbours' adoption decisions. Given recent policy challenges, more effective measures targeted at different farmer types, which take into account their divergent needs, can help facilitate a positive change in farm practice, which may benefit beef farmers in transitioning away from direct payments.

Implication 2: Identifying the benefits of innovation efforts

The considerations expressed above lead us to question how much a typical Scottish beef farmer would gain from being more innovative. From a systems perspective, the relative advantage for the average farm of adopting the selected innovations was minor across all classes and respective farm types. However, focusing particularly on Profit-seekers (as they are more likely to adopt these innovations first), in total, 33.3%, 44.4% and 64.2% of these farmers could increase net income by more than 15% by implementing genetic improvement (GI+), animal health planning (AHP+) and the combined technologies (CT+), respectively. More specifically, the majority of lowland, mixed and LFA beef farms (60%, 70.6% and 84.9% of farms, accordingly) would be able to achieve such increase by taking up the combined package of technologies.

This ‘profit incentive’ becomes even more relevant when direct support is removed, with the proportion of farms benefiting by more than 15% due to GI-, AHP- and CT- increasing to 77.8%, 79% and 92.6%, respectively, as a result of a reduced net income. This is particularly critical to LFA cattle and sheep farms, where 97% of farms achieve a 15% increase in net income under the CT- scenario, compared to 42.3% of farms when direct payments are in place, hence highlighting the heavy dependence of LFA cattle and sheep farms on direct support. Overall, comparing the proportion of farms that become loss making under similar scenarios (GI-:43.6%; AHP-: 43.3% and CT-: 38.2%, respectively) with the baseline scenario (Baseline-: 54.9%), shows that these farmers could clearly benefit from innovation efforts, in view of the uncertainties regarding future support payments and markets, and there are several combinations of technologies that can be trialled. In line with Ridley and Hill (2018) and Läpple and Thorne (2019) work, these findings indicate that, in general, adapting current farming methods and being more innovative will enable farmers to improve profitability, reducing subsidy dependence, particularly if associated with the production of public goods.

Implication 3: A positive attitude towards innovation needs to be fostered

While farm and personal characteristics may positively influence the adoption of new technologies, farmers have different motivations to adopt innovations, which are usually influenced by personal preferences and circumstances. Even though Scottish farmers may be described as slow to adopt innovations, the majority of farmers agreed

with the statements ‘To farm successfully it is important for me to keep up-to-date with new farming methods’, and ‘It is important for me to try new varieties or breeds (crops/stock)’, which can be broadly considered as proxies for innovation behaviour. More specifically, Satisfiers and Expansionists showed higher probabilities of moderately agreeing with the relevance of keeping up-to-date and of trying new varieties or breeds than Profit-seekers, though opinions were divided in relation to the latter. Given these farmers’ characteristics, this finding may be surprising, as it seems likely, they would be slow adopters of technology. However, having lower incomes may help Satisfiers and Expansionists recognise the need to innovate in order to boost productivity and remain competitive, even if they lack the necessary financial liquidity or resources to actually implement innovations. This positive attitude towards innovation should be encouraged in order to increase the likelihood of adoption.

In many cases, having a higher (net) income is a requirement for adoption, some innovations are more costly to adopt and even though several technologies may be interesting for more than economic returns (e.g. environmental benefits) - and thus, not only to profit-oriented farmers – they might be more difficult to adopt by smaller farms (Toma et al., 2018). While this does not automatically imply causation, there is some uncertainty as to whether lack of profitability constrains innovation, or whether lack of innovation constrains profitability (Islam et al., 2013b). These findings are relevant to policy as they provide indications of the factors affecting the process of agricultural innovation adoption, suggesting ways of targeting specific innovation information and incentives to beef producers, therefore building a potential driver of behavioural change.

Implication 4: Targeting innovation information and incentives to beef producers

On the topic of knowledge exchange, Holloway and Lapar (2007) and Läßle et al. (2017) explain that farmers’ adoption decisions and characteristics may also have positive effects on neighbours’ adoption decisions, i.e. the adoption of one farmer induces adoption decisions of others due to direct communication among farmers, hence facilitating technology diffusion. These neighbourhood effects are especially significant for less costly and reversible decisions (e.g. reseeded, milk recording). Similarly, Pannell et al. (2006) emphasizes the relevance of geographic proximity and social networks for adoption decisions.

Communication is greatly encouraged among Scottish farmers through the support of knowledge transfer events, farmer discussion groups, organisation of open days, among others (Scottish Government, 2015). There is a general consensus that these knowledge exchange activities are essential to encourage innovation adoption, consisting of a collaborative process between different ‘agents’ such as farm systems, supply chains and economic systems, policy environments, extension and societal systems (Birkhaeuser, Evenson and Feder, 1991; Klerkx et al., 2012). More specifically, knowledge exchange activities have been actively implemented by the Scottish Government, by financially rewarding farmers for participating (e.g. Monitor Farm Network, Farm Advisory Service, Beef Efficiency Scheme; Scottish Government, 2015). These activities are strongly focused on technology knowledge transfer of innovative technologies and best practices to support a sustainable development of the agricultural sector, and have been quite effective in guaranteeing farmers’ participation, which is expected to have a positive effect on the uptake of innovations.

Engaging in knowledge exchange activities may help farmers recognise the relative advantage (i.e. perceived net benefits of adoption) and the trialability (i.e. how easy it is to test and learn about the innovation before adoption) of specific technological improvements, that according to Pannell et al. (2006) are the two broad attributes of innovations that drive its adoption (or non-adoption). Additionally, by supporting the participation of a wide-ranging group of farmers in these activities, efficiency gains within the sector can be achieved through improvements by ‘frontier’ farmers and ‘catching up’ advances of less productive farmers (Kimura and Le Thi, 2013; cited by Läpple et al., 2017). As significant regional differences were found in this study²⁴, efforts should be made to avoid the concentration of knowledge exchange activities in more productive regions with higher agricultural potential, hence not including farmers in disadvantaged regions, which according to Cary (1993) has detrimental effects on the productivity of farming and balanced rural development. In line with this, Genius et al. (2014) reported that in order to guarantee widespread diffusion of information, extension agencies should be situated strategically near to target farms in remote areas. However, as pointed out by Läpple and Hennessy (2015), some might argue that the overall efficiency of the sector may decrease in the long-term if less efficient farmers

²⁴ Satisfiers were over-represented in the Highlands and Islands, whereas Profit-seekers and Expansionists were mostly located in South Western Scotland.

are able to stay in production, a perspective that might be worth further attention in the future.

Furthermore, education and more general policy measures to encourage innovation, for instance, investment grants have also been described as positively influencing the adoption of new technologies (OECD, 2013; Läpple and Thorne, 2019). Training, education and skills are recognised as important drivers of best practice and performance. In this sense, attention should be given to the delivery of education and proper training on implementation and usage of technologies, and on their combined impacts. As argued by several authors, policy makers need to realise that investing in (higher) education is as essential as supporting technology adoption at the farm level in order to support a successful structural change in the agricultural sector (Läpple et al., 2015; Sauer and Latacz-Lohmann, 2015; Toma et al., 2018). Although the uptake of innovations may not be the first choice for all farm businesses, the costs associated with adopting specific technologies (e.g. EID) can be a barrier to some. This justifies the need for innovation grants, or other incentives, to help Scottish beef farms purchase new technology, within the acknowledgement that such budgets are finite.

Implication 5: Encouraging a step-change in agriculture by combining economic and environmental benefits

Sustainability has been a key aspect of the debate surrounding efforts to increase beef production, with sustainability credentials becoming increasingly important. While innovation adoption can contribute to economic performance and lead to a more efficient beef sector, other dimensions of sustainability also need to be accounted for. For instance, productivity improvements also entail environmental implications such as increasing pressures to reduce negative externalities (e.g. GHG emissions). Thus, action is required throughout the sector to increase beef production while simultaneously lowering environmental impacts, where the uptake of sustainable agricultural innovations plays an important role. As pointed out in Chapter 3, while the majority of farmers framed their objectives from a profit-based perspective, both economic and environmental concerns were important across all classes of farmers, which is promising, especially, from a policy perspective. It should be noted, however, that profit seeking farmers will also be motivated to consider more sustainable practices to avoid

penalties for negative externalities – ‘polluter pays’ principle – or, indeed receive ‘public money for public goods’ (H. M. Treasury, 2013).

While a commitment has been given to retain subsidy support for the duration of this parliament (House of Commons Library, 2018), estimated to be until March 2022, the UK Government has confirmed that important changes in policy are looming. An intention to move from support for agricultural activities towards directing public money to the provision of public goods, particularly to environmental improvements, has been signalled (Bateman and Balmford, 2018). In light of the results of the modelling exercise presented in Chapter 5, guaranteeing financial viability while encouraging a more productive and sustainable industry is expected to be a particular challenge for policy makers in Scotland (Swales et al., 2017; Moxey and Thomson, 2018). As mentioned, one way to help address this is to implement sustainable technologies that increase productivity and profitability, while providing a net improvement in environmental public goods (Bateman and, 2018), either directly (e.g. reseeded pastures for improved sward nutrient value and/or diversity), or indirectly (e.g. improving animal nutrition to optimise productivity and reduce the environmental footprint of livestock systems; Dicks et al., 2018). Thus, adopting sustainable best practices is a sensible option if these are to be recognised as public goods and paid for, for instance, through environmental and management contracts (Ridley and Hill, 2018).

In particular, farmers should be encouraged to link the provision of public goods to marketing of produce, for example, by diversifying products and adding value. This should give them an advantage when marketing their products across the world. As argued by Moxey and Thomson (2018), encouraging the delivery of public goods will require not only support payments, but also accompanying information, advice, training and investment grants to improve all ecosystems services in the most cost-effective way, e.g. livestock production, biodiversity levels, climate change mitigation, etc.

Overall reflections

Subject to the degree of liquidity of the farm, in addition to the optimisation of existing resources and production capacities, investing in sustainable innovations, agricultural education and knowledge exchange appears to be the key for sustainable and competitive beef production in Scotland. However, as highlighted by Sauer and Latacz-

Lohmann (2015), it should be noted that technological change might not necessarily lead to immediate productivity improvements, as there might be a time lag between an investment in innovation and an actual increase in the productivity of the farm.

Based on this research, it is apparent that informed action is clearly needed to promote more sustainable beef production in Scotland, and approaches such as the work reported here can offer some guidance on how to encourage positive behavioural change in these systems. Accordingly, understanding the biophysical and socio-economic heterogeneity of Scottish beef systems has provided important information in relation to how farmers might respond to specific information, technologies or policies. These considerations should not be viewed in isolation, as similar challenges certainly exist in other areas facing similar constraints. A summary of recommendations to foster innovation adoption in Scottish beef farms is provided as follows:

- i.** The heterogeneity of farming styles and farmers needs to be recognised
- ii.** Acknowledging this heterogeneity helps improve the cost-effectiveness of interventions that encourage innovation adoption
- iii.** Profit-seekers are more likely to adopt first when compared to others - it would be beneficial to engage this class of farmers first; this, in turn, has the potential to positively influence the adoption decisions of neighbouring farmers
- iv.** While lacking the necessary financial liquidity or resources to adopt, Satisfiers and Expansionists still recognised the need to innovate in order to improve productivity and remain competitive – this positive attitude towards innovation should be fostered
- v.** Although the relative advantage of adopting the selected innovations was minor, farmers can benefit from innovation efforts, and there are several combinations of innovations that can be explored – the net benefits of adoption need to be estimated and communicated
- vi.** The role of innovation in helping farmers remaining competitive and reducing subsidy dependence to adapt to potential changes in economic conditions should be emphasized among farmers
- vii.** Knowledge exchange activities, and collaboration between farmers and other ‘agents’ need to be actively promoted

- viii.** Efforts should be made to avoid the concentration of knowledge exchange activities in more productive regions, supporting their distribution across Scotland
- ix.** Access to education, proper training and innovation grants (or other incentives) should be targeted
- x.** In addition to innovation investments, existing resources and production capacities should be optimised
- xi.** A step-change in agriculture where farmers combine the provision of public goods and economic objectives should be supported, helping farmers transitioning to a new agricultural policy; this will require information, advice, training and investment grants to improve all ecosystems services
- xii.** Farmers should be encouraged to be more business-oriented, and link the provision of public goods to marketing of produce; this should give them an advantage when marketing their products in future markets.

6.2. Limitations of the research

While this thesis provides a comprehensive assessment of beef production in Scotland, a few limitations exist that must be taken into consideration. Some of these are data limitations, whereas others relate to the methods employed.

The FBS provides a consistent panel dataset of beef farms with sufficiently detailed production and financial information to realistically describe production at the individual farm-level; furthermore, this is representative at a national scale for policy analysis. However, besides the farm-level data available in the FBS, additional ‘representative’ information was required for a few inputs, coefficients and parameters; these were taken from the literature (e.g. Farm Management Handbook; SAC, 2015, 2017) and expert knowledge. This information, together with the assumptions behind the benefits and costs of each innovation were generalised across farm types, except for calving, lambing and survival rates that were adjusted according to farm type. As such, while there will be considerable variation across ‘actual’ farms based on farm management and other factors, some of the heterogeneity in production performance is not observed due to these data limitations. More detailed data and assumptions for each specific farm type would most likely highlight some variability on the effects of these innovations on different farm types. For instance, a solution would be using experimental data based on field trials to provide a detailed biophysical description of

the production process, and the real effects of adopting different farm practices and technologies upon experimental conditions.

Another potential data limitation of the study is related to the FBS under-representation of ‘very small’ farms, i.e. farm businesses with both less than 0.5 SLR and 25,000€ of output (equivalent to £21,315). However, based on findings from the literature, larger farms are more likely to take up technologies, therefore this potential bias is considered to be irrelevant to the findings of this study (similar arguments are made by Toma et al., 2018). Along with this limitation, ScotFarm is based on farm-level data collected for only one year. Thus, the results depend on the performance of farms in that specific year. While the output baseline applied here describes 2015/16 production, there may have been some variation in farm performance in the intervening period. Further work could therefore look at the effects of these innovation and policy scenarios in a ‘longer run’ situation by allowing survey baseline data to change, for instance, by extending this work to a panel data model.

Although this study has made best use of the available data, it is recognised that there are weaknesses in the approach taken to assess innovation adoption. Due to the focus of this study, and to the widely unknown reference conditions of technology adoption in Scottish beef farms, it was assumed that farm systems could easily adopt innovative technologies and practices, not facing constraints in terms of access to capital or complementary technology (e.g. machinery) that might be required for their implementation. In addition, any technologies already available in the farm were not taken into account. Furthermore, the practices and technologies selected to estimate the potential impacts of innovation adoption at the farm level might be considered as only capturing part of the overall farm innovation activity.

As there has been little research on the actual technological improvements adopted by the distribution of beef farms, and on farmers’ innovation behaviour, the collection of more detailed data both on the level of innovation on farms, and on farmers’ intentions towards innovation over time would enable a better evaluation of the degree of farm ‘innovativeness’ (Läpple et al., 2015) and reliability of farmers’ intentions, providing interesting angles for future research. While primary data collection would be the most appropriate approach for a more comprehensive innovation assessment (e.g. surveys,

interviews), expanding the present set of innovations to include other sustainable options would contribute to the continuous update of the model to take account of new developments, which would also allow further significant research questions to be addressed. Examples include investigating the relationship between innovation and profitability, and the link between levels of agricultural subsidies and innovation.

As previously discussed, ScotFarm assumes profit maximising behaviour of farmers, and farmers' behaviour may also be motivated by other factors including environmental stewardship, lifestyle, future generations, etc. At the beginning of this study, the significance of such motivations was unclear and an area that needed further investigation. In Chapters 3, farmers' objectives for the business were assessed, which emphasized the importance of profit maximisation for most farmers. Even though the approach applied here may not fully capture the objectives of all farmers, it is able to identify the heterogeneity of farmers' behaviour across a wide range of farms and has been applied in other studies at a similar scale of analysis, as detailed in Chapter 2. Furthermore, in light of current uncertainties in relation to future support payments and trade arrangements, the challenge resides in optimising farm resources and identifying the best combination of management strategies.

Despite these data limitations, the approach taken here to estimate policy responses through an assessment of performance for the distribution of beef farms accounting for the range of innovations and evolving policy context, as far as possible, is deemed to be well represented, as suggested by favourable calibration results²⁵, being more appropriate than the traditional approach using representative farm types.

6.3. Future research perspectives

The findings of this thesis illustrated the financial and productivity gains that can be achieved through the adoption of alternative innovations at the farm level, in relation to specific assumptions about their potential benefits and costs, which are representative at national level. These findings represent an important contribution to the literature on innovation and open several potential avenues and directions for future research, as described below.

²⁵ The model base year outcomes were compared to actual FBS data (2015/16).

From the farmers' perspective, the actual effects of adopting these innovations are mostly unknown and, at least in part, subject to external factors such as costs, market prices and policy settings, which makes implementing changes a risky investment. As beef farms operate amid such variability, an extension of ScotFarm could include an element of risk, for instance, through the development of probabilistic outcomes for yield effects (for both beef and crop production) and associated costs over time. In addition to providing estimates to inform farmers, such a tool could increase the understanding of the innovation adoption process and related risks by those involved in agricultural research, development, extension and policy. This is an interesting topic of research as some innovations may contribute to reduce yield variability over time, for instance, by improving best practice. Attention should be given to differences in risk attitudes, management and optimisation objectives, which would require a more detailed assessment of the distribution of beef farms.

While this thesis shows that given a limited set of resources some technological improvements can indeed have a positive impact on economic performance, other aspects of sustainability should also be considered. To be able to analyse whether an economic improvement is 'sustainable', the potential economic and environmental effects should be compared. In the modelling exercise of Scottish beef and sheep farms, efforts were made to avoid overstocking and utilisation of grazing land increasing beyond sustainable levels, with the number of animals on farm being constrained over a threshold of maximum number. By implementing this specific 'herd management strategy', the land condition could be maintained and the number of animals limited to a farm's holding capacity. However, the environmental implications of beef production and the impacts of innovation efforts on the environment are also important avenues for future research, as well as the dynamic effects over time.

The analysis of the beef production systems presented here could therefore be extended to perform a Life Cycle Assessment (LCA) of the environmental outputs of Scottish beef farms, e.g. GHG emissions. LCA is an established and standardised approach to assess environmental impacts across the life cycle of a production system and has been broadly applied to livestock production systems (e.g. Edwards-Jones, Plassmann and Harris, 2009; Yan et al., 2011). This integrated assessment would enable the evaluation of farm-level economic and environmental performance of the distribution of Scottish

beef farms under alternative scenarios, using nationally representative data from the FBS. In particular, identifying and describing the trade-offs between increased GHG emissions and economic activity arising from agriculture sector expansion due to innovation would be an area of interest, as farm systems are being increasingly required to account for their environmental footprints, with environmental regulations becoming more stringent. Understanding these trade-offs can trigger and support decision-making. Furthermore, this methodology could be used to propose different scenarios of an optimised environmentally sustainable beef production in Scotland, by quantifying trade-offs between scenarios and farm-level indicators of sustainability (e.g. farm income, GHG emissions per unit of output and permanent grassland).

All these estimates could be aggregated using a spatial microsimulation model (e.g. Simulation Model of the Irish Local Economy [SMILE]; O'Donoghue et al., 2013) to assess national-level uptake of farmers' innovative behaviours in Scotland. A spatial microsimulation model such as SMILE would be capable of aggregating responses at the farm level and map them spatially to the national level, providing a framework for spatial policy impact analysis. This framework could improve understanding of the impact of social networks on innovation at the national policy level. Within this context, peer interaction is a well recognised element of the innovation adoption process (Rogers, 2003), being, however, rarely addressed in adoption studies. As mentioned, some studies report that the likelihood of a farmer adopt a new technology increases if a neighbour has already adopted the technology (e.g. Holloway and Lapar, 2007). Peer effects can be highly significant from a policy perspective, as they may provide positive multiplier effects in the adoption of technologies (Läpple et al., 2017). These can be assessed, for instance, via spatial proximity.

Following this line of thought, Läpple et al. (2017) using recent geo-coding of the FBS returns for Ireland calculated the Euclidian distance between farms, and applied this information to construct spatial weight matrices to perform a spatial analysis of the Irish dairy sector. A significant neighbourhood effect was reported in the uptake of milk recording, implying that farmers' adoption decisions are affected by their peers. These authors argue that policy makers could pursue such positive multiplier effects, for instance, by increasing farmer interaction through knowledge exchange activities. Thus, a better understanding and recognition of the spatial effects and regional

differences across Scotland in terms of adoption behaviour may be a good strategy to promote adoption of technological improvements, for instance, by facilitating ‘knowledge spill overs’, i.e. fostering activities to deliver knowledge that spills from neighbours to their neighbours and so on through communication.

6.4. Concluding remarks

Sustainable agriculture has become increasingly important, stemming from the acknowledgment that current agricultural productivity increases will eventually lead to the use of natural resources beyond their regeneration capacity (OECD, 2012). An increasing population and rising awareness of the detrimental effects of farming on the environment and society as a whole, has contributed to the realisation of the need to maintain more sustainable production methods (OECD, 2014). Currently, it is widely acknowledged that innovation is essential to move towards sustainable intensification of the agricultural sector, with farmers being under an increasing pressure to accomplish a sustainable productivity growth (Leaver, 2010). Farming in a compatible manner with the societal values coupled with environmentally friendly and multi-attribute production has therefore become essential, where the uptake of innovative practices and technologies plays an important role (Salois, 2015; Läßle et al., 2017).

To address this challenge, this thesis has focused on the question of how sustainable agricultural innovation may be delivered at the farm level in a Scottish context. Fostering innovation requires a better understanding of the innovative behaviour of farmers, i.e. it requires recognition of the different farmer types who would be the most likely innovation targets. Accordingly, the underlying drivers of farmers’ behaviour and, in particular, what influences Scottish beef farmers to adopt sustainable technologies were assessed, which led to further work analysing the impacts of innovations at the farm level under alternative policy scenarios. Specific technologies and practices with the potential to sustainably increase productivity and profitability of beef farms were identified. These innovations build on existing knowledge, focusing on different areas of beef production, and have been an integral part of the discussion and research investment around sustainable intensification.

In line with previous studies, the findings from this analysis suggest that Profit-seekers with higher net incomes are more likely to adopt innovations first, which may be an area of concern for policy making, as sustainable innovations could support less profitable farmers such as Satisfiers and Expansionists improving performance. However, these farmers are usually reported as having a lower probability of adopting innovative technologies when compared to profit-oriented farmers. Furthermore, the outcomes of the modelling exercise indicate that all sustainable innovations could provide some sort of benefit to the farm systems, especially when used in combination.

While the analysis of the farm-level production systems points towards the potential benefits of innovation, when direct support is removed the vulnerability of these farm systems and their heavy reliance on subsidy support is revealed. This was verified among all farm types, and the estimated reductions in net income are such that the viability of many farms remains uncertain. Particularly, most lowland and mixed farms appear to be highly vulnerable to this policy scenario, demanding special attention when reforming agricultural policies. Even though these considerations need to be closely investigated by decision-makers on an individual basis, the adoption of particular innovations allows some farms to stay profitable, hence reducing the proportion of loss making farms under a potential policy change. This highlights the positive impact of innovation, indicating that farmers can reduce ‘policy risks’ by being more innovative, which is in line with previous studies of innovation adoption (e.g. Läpple and Thorne, 2019). These findings are particularly relevant for policy makers interested in encouraging sustainable and competitive farming through innovation, providing not only indications of the aspects influencing innovation adoption, but also suggesting ways of targeting information and incentives to producers, building a potential driver of behavioural change.

Some recommendations arise as a result of these findings. First, the fact that ‘one size fits all’ approach is challenged further demonstrates the importance of acknowledging the heterogeneity within the beef sector. Carefully planned communication, which is targeted at each farmer type, can help foster a positive change in farm management practices (Garforth et al., 2004; Hyland et al., 2015), thus encouraging innovation adoption. Second, farmers and policy makers need to realise that knowledge exchange activities which actively encourage farmer interaction may be as important in fostering

innovation as supporting technology acquisition at the farm level. Within this context, social learning is considered an essential part of innovation adoption by farmers, and several studies have validated that peer effects are important for innovation uptake choices (Läpple et al., 2015). Knowledge exchange activities should therefore be promoted, and efforts should be made to avoid their concentration in more productive regions with higher agricultural potential. Finally, agricultural education and general agricultural policy measures to encourage innovation such as investment grants appear to also positively influence the adoption of new technologies (Läpple and Thorne, 2019). Supporting and improving access to agricultural education may reinforce the links between education, research, extension and farmers, resulting in the acquisition of knowledge adjusted to farmers' needs, which may contribute to drive innovation in the agricultural sector. Furthermore, subject to the viability of each individual farm business, initiatives that improve access to credit may be useful to facilitate innovation.

The analysis presented in this thesis can also play a key role in justifying government support for agricultural innovation that should be tailored and targeted to specific segments of farmers in order to fit divergent needs. The impacts associated with the adoption of some of these innovations can be relevant and may, in some cases, provide the main motivation for government intervention (e.g. EID). Considering recent policy and market uncertainties, this thesis has provided insight and suggestions on how to support sustainable growth given the manifest challenges facing the sector. Thus, the findings of this research support the literature that aims to help preparing the Scottish beef sector for the substantial change and challenges that may be associated with a policy reform. Regardless of focusing on Scotland, the analysis reported here and resulting recommendations are also relevant to other agricultural sectors.

In summary, this thesis outlined a set of innovations able to deliver progress towards sustainable intensification across the range of heterogeneous beef farms in light of recent policy developments, providing farmers, policy makers and researchers with information on the potential effects of adopting feasible and sustainable innovations at the farm level, contributing to the current debate on innovation in agriculture. Rather than elaborating a plan for a sustainable intensification strategy, or a predictive tool for farmers and policy makers, the challenge was to develop an integrated approach for the analysis of beef production in Scotland which was able to highlight important

considerations that may influence the uptake of innovations in these farm systems. The technological alternatives incorporated in the LP model are regarded as opportunities and were included with the purpose of identifying a spectrum of possible future development paths, their likely consequences, and the problem areas to be expected in the future.

Recently, ambitious growth targets for the Scottish beef sector have been established on the concept of productivity growth through knowledge exchange within the sector (e.g. Beef 2020 report, Ambition 2030 growth strategy; Scottish Government, 2014; Scotland Food and Drink, 2018). This will require increased emphasis on continuing innovation in order to achieve such targets, which opens important avenues for future research. In this sense, together with data on the actual innovations adopted across the distribution of beef farms, this study could be extended to provide guidance on which technological improvements might be more useful to promote through knowledge exchange activities, education, awareness-raising and incentives, as different sets of innovations may be more suitable for different farm systems. Thus, this research emphasizes the need for further studies that examine the current level of ‘innovativeness’ among Scottish beef farms to determine the reference conditions of technology adoption in these farm systems. Moreover, studies exploring relationships that may have been insufficiently investigated, but appear to be relevant to assess the effects of innovation efforts (e.g. risk attitudes, trade-offs between environmental and economic aspects and peer effects) also describe promising directions for future research.

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