

# UPTAKE OF AGRICULTURAL INNOVATIONS IN SCOTTISH BEEF FARMS: A REVIEW OF CONCEPTS, CHALLENGES AND SCIENTIFIC APPROACHES

Sub theme: Technology (robotics, other new technologies, traditional farm equipment)

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## Abstract

*This paper reviews the literature on the uptake of agricultural innovations in general, and more specifically in beef cattle farms, with a specific focus on how these innovations may be relevant in Scottish beef farms. The paper is intended as a literature review, representing a forerunner to a more comprehensive study of the national level uptake of innovative technologies in Scottish specialist beef farms.*

*There are several definitions of innovation available in the literature, with many of them stemming from the ideas of Schumpeter, according to whom economic development is driven by innovation. From a farm-level perspective, innovation is seen as the main driver of agricultural productivity growth. The decision of whether an individual will adopt a specific innovation, and the time frame associated with that decision, has been the main subject of research across several disciplines (e.g. economics, sociology). Since Griliches (1957) pioneering study on farmers' decisions to adopt an innovation, the subject has been extensively studied. Agricultural economists have been focussed on understanding and modelling farmers' adoption decision-making, with several theories and models being developed over time. These are particularly valuable for informing policies and programs designed to encourage innovation uptake.*

**Key words:** *agricultural innovations, innovation uptake, beef cattle, Scottish beef farms*

## 1. Introduction

Innovation is essential to promote growth of output, rural development and enhance productivity (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).

Before examining how innovation disperses and distributes within a population, it is necessary to accurately define the term 'innovation'. There are several definitions of innovation available in the literature, many of which stem from the ideas of 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 factors of production (inputs) to produce products (outputs; Schumpeter, 1939). In this sense, as knowledge of new and more efficient methods of production becomes available technology changes.

Technological change is the main driver of productivity growth, being encouraged by demand-pull and/or technology-push factors (Dosi, 1982). Technological change results in an improvement in efficiency of production, which ultimately increases overall economic growth (Link and Siegel, 2003). From an economic perspective, it corresponds to a shift 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. Thus, in agriculture, as in other sectors, technological change has been the starting point for increasing productivity and promoting development.

Innovation and an understanding of how innovation can lead to technological change is therefore an important area for agricultural research. We normally distinguish between 'adoption' and 'diffusion' of innovations, although there is some overlap between both concepts. Lionberger (1960) described adoption as the full-scale incorporation of a new idea, product or practice into a farmer's on-going operation, through repeated and continuous use, usually 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). Note that an innovation may be new, or indeed, 'innovative' but fail through lack of adoption and hence diffusion. Understanding the factors influencing adoption and diffusion are therefore clearly of great importance, for instance to inform and refine agricultural policy interventions, in particular those aimed at promoting knowledge transfer and innovation adoption (Pannell et al., 2006).

This paper represents an initial survey of the literature supporting a more comprehensive study of the national level uptake of innovative technologies in Scottish specialist beef

farms. It aims to improve our understanding of the innovation and diffusion process through a systematic review of the literature on the uptake of agricultural innovations in general, and more specifically with respect to beef cattle farms, with a specific focus on how these innovations may be relevant to Scottish specialist beef farms. We start by providing an historical overview of the innovation adoption and diffusion literature, which is followed by the contributions of previous empirical studies important to our research project. Finally, a few examples of agricultural innovations and policy implications of such studies are discussed.

## **2. Material and methods**

A review of the scientific literature to date was the starting point for identifying agricultural innovations relevant to Scottish specialist beef farms. Databases (Web of Science, CAB Abstracts, PubMed and Scopus) were searched for English language studies addressing agricultural innovations. Key words such as ‘agricultural innovation’, ‘agricultural technology’, ‘innovation uptake’, ‘innovation adoption’, ‘innovation diffusion’, ‘precision livestock farming’ and ‘livestock production’ were used as major descriptors, combined with ‘beef cattle’ and ‘Scottish beef farms’. In this paper ‘innovation’ and ‘technology’ are used interchangeably, as in most studies of diffusion of technological innovations these terms have usually been applied as synonyms.

To gain insight into the uptake of innovations in Scottish specialist beef farms, a comprehensive range of innovations was selected and classified according to their main areas of application in the farm business, namely production, environment and management (Table 1). Even though the selected innovations might fall into several of the aforementioned areas, a distinction was made to simplify the methodological treatment. Care was taken to choose appropriate innovations for the farming system under study; selected innovations were most likely to be known by most farmers. Further studies aimed at compiling a final list of relevant technologies to the future of Scottish specialist beef farms are still underway (spring 2017).

Table 1. Agricultural innovations' main areas of application in the farm business.

Innovations		
Production	Environment	Management
Breeding	Soil and grassland management	Enterprise management
Herd health, welfare and nutrition	Conservation of natural resources	Direct marketing
Herd monitoring	Mitigation of environmental impacts	Value-added products

### **3. 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 (epidemic models), anthropology and education, in the 1920s, 1930s and 1940s (Rogers, 1995; 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 (Freeman, 1994). By the late 1950s and mid-1960s, other economists started contributing to the literature. In fact, the seminal contribution of economics to technology adoption and diffusion literature was in agriculture (Griliches, 1957; Griliches, 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, 1963b) dedicated himself to the study of industrial innovations' diffusion, by integrating economics into the epidemic models.

Griliches (1957), by fitting data to a 'logistic curve', demonstrated that differences in the time and rates of adoption in a region could be explained by economic variables, such as profitability of entry into production of hybrids by seed producers, and profitability of adoption by farmers. Mansfield (1961, 1968) applied more complex models of diffusion, also originating an S-shaped diffusion curve including variables regarding uncertainty surrounding the innovation, in addition to profitability (Sunding and Zilberman, 2001).

Several other approaches to the process of diffusion arose over time. The 'equilibrium approaches' (e.g. 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 (e.g. more recently this approach has been taken by Karshenas and Stoneman, 1993). 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.

### **4. Empirical studies of innovation adoption and diffusion in agriculture**

Lindner (1987) classified 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. Cross-sectional studies aim to identify why some producers adopt an innovation while others reject it, corresponding to the majority of empirical studies of adoption (e.g. Marra, Hubbell and Carlson, 2001; Khanal and Gillespie, 2013, Ghimire and Huang, 2016). Temporal studies are mostly concerned with the determinants of the timing of adoption, i.e. why some producers 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 being 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, allowing the estimation of adoption patterns over time (e.g. Abadi Ghadim and Pannell, 1999; Abadi Ghadim, Pannell and Burton, 2005; Holden and Quiggin, 2016). 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 studies 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. Dinar and Yaron, 1992; Marsh, Pannell and Lindner, 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). Most studies examine the pattern of diffusion of one particular innovation, though farmers may consider adoption of multiple innovations. A few studies consider uptake of different innovations such as a system for drying chicken manure, the use of ultrasound to exterminate insects (Diederer et al., 2003), or the introduction of innovative changes in products or production processes (VanGalen and Poppe, 2013). These studies, based on the Farm Accountancy Data Network (FADN) dataset in the Netherlands, allowed monitoring of innovation adoption in the Dutch agrifood business sector. Another

example is the study performed by Ash et al. (2015), in which the production and financial implications for northern Australian beef enterprises of a set of technology interventions (e.g. genetic gain, nutrient supplementation) were assessed.

Following a different approach, some studies derive a single measurable index to measure adoption of multiple innovations, either by performing a sum of dummy variables<sup>1</sup> (e.g. Boz et al., 2011; Singh, Singh and Kumar, 2014; Karafillis and Papanagiotou, 2011), or by calculating adoption indexes (e.g. Fita, Trivedi and Tassew, 2012; Ariza et al., 2013), or expert-weighted indexes (e.g. Läpple, Renwick and Thorne, 2015).

Table 2 outlines the major factors that influence the adoption of an agricultural innovation and their hypothesized effect on innovation behaviour.

Table 2. Major factors influencing the adoption of agricultural innovations and hypothesized signs.

Factors	Hypothesized sign	References
Farmer's characteristics		
Age	-	Boz et al., 2001 (+) Diederens et al., 2003 Ariza et al., 2013 Khanal and Gillespie, 2013 Läpple, Renwick and Thorne, 2015 Ghimire and Huang, 2016
Marital status	+/-	Läpple, Renwick and Thorne, 2015
-		<u>(+)</u>

<sup>1</sup> Dummy variables take the value 0 or 1 to indicate the presence or absence of an innovation on a farm.

Experience	+	Foster and Rosenzweig, 1995 Carletto et al., 1996 Marsh, Pannell and Lindner, 2000 Marra, Hubbell and Carlson, 2001 Abadi Ghadim, Pannell and Barton, 2005 <u>Fita, Trivedi and Tassew, 2012</u>
Education level	+	McWilliams et al., 1998 Marra, Hubbell and Carlson, 2001 Fita, Trivedi and Tassew, 2012 Ariza et al., 2013 Khanal and Gillespie, 2013 Ghimire and Huang, 2016
Agricultural education	+	Läpple, Renwick and Thorne, 2015
Wealth	+	Boz et al., 2011
Off-farm job	+/-	Fernández-Cornejo et al., 2005 (+) Khanal and Gillespie, 2013 (-) Läpple, Renwick and Thorne, 2015 (-) <u>Ghimire and Huang, 2016 (-)</u>
Farm-related business	+	McWilliams et al., 1998
Risk aversion	-	Abadi Ghadim, Pannell and Barton, 2005
Attitude regarding innovation	+	Diederer et al., 2003
Farm resources		
Farm size	+	McWilliams et al., 1998 Marra, Hubbell and Carlson, 2001 Diederer et al., 2003 Khanal and Gillespie, 2013 Läpple, Renwick and Thorne, 2015 <u>Ghimire and Huang, 2016</u>
Market position	+	Diederer et al., 2003
Solvency	+	Diederer et al., 2003 (-)
Credit/Loan	+	Boz et al., 2011 Läpple, Renwick and Thorne, 2015
Farm profitability	+	Byerlee and Polanco, 1986 Cary and Wilkinson, 1997 Boz and Akbay, 2005 Areal et al., 2011 Keelan et al., 2009 Toma et al., 2016
Extra farm labour	+/-	Abadi Ghadim, Pannell and Barton, 2005 (+)
Extra hired labour	-	Abadi Ghadim, Pannell and Barton, 2005



Institutional characteristics		
Participation in Agricultural Innovation Networks	+	Ariza et al., 2013
Number of market actors the farm is involved with in innovation activities (suppliers, clients, other farms and consultants)	+/-	Carletto et al., 1996 Boz et al., 2011 Fita, Trivedi and Tassew, 2012 Ariza et al., 2013

#### 4.1. Measuring agricultural innovation in Scotland

With regard to Scotland, there is a relevant body of Scottish studies applying the concept of Agricultural Innovation Systems (AIS), which recognizes innovation as a dynamic social multi-stakeholder process involving the contribution of a variety of stakeholders and institutions (Klerkx, Mierlo and Leeuwis, 2012), including farmers. AIS provide a suitable framework that requires an understanding of the structural and functional circumstances in which technologies are applied (Morris et al., 2006). Within this framework, innovation dynamics, drivers, enabling factors or barriers can be examined and better understood. These studies have focused on: (1) stakeholder views of innovation performance, drivers and barriers in specific agrifood sectors (e.g. Borthwick, Barnes and Lamprinopoulou, 2014); (2) innovation policy frameworks across a number of countries, including Scotland, Netherlands and New Zealand (e.g. Lamprinopoulou et al., 2012); and (3) the dynamics of technology uptake in several sectors, such as uptake of genetic selection technology (Islam et al., 2013b), animal health planning (Islam et al., 2013a), cattle electronic identification (Duckett, 2014) and Nitrogen Use Efficiency techniques (Barnes and Borthwick, 2013). However, a lack of significant studies referring particularly to the uptake of innovations in the Scottish beef sector was identified.

#### 5. Selection of agricultural innovations

Even though innovation can be considered as an outcome of AIS, where research and industry contribute to farm-level innovation, actual innovation only takes place when farmers implement a new practice (Ryan et al., 2014). As a result, the role of farmers as innovators, the value of local knowledge, and the topic of farmer's experiments have been attracting more attention (Bentley et al., 2010; Brunori et al., 2013).

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, 2001). Furthermore, profitability is a major concern to farmers. Farmers need innovations that will increase efficiency and provide competitive edge (Sumberg, 2005), a process that needs to be continuous. Farmers must therefore keep up with technological developments to stay in business (Cochrane, 1979; Fuglie and Kascak, 2001).

As previously mentioned, different kinds of technologies focus on different ‘domains’ of the farm business (e.g. production). A few examples of the reviewed innovations will be further discussed (Table 3).

Table 3. Agricultural innovations and their likelihood of widespread uptake in Scottish specialist beef farms.

Innovations		
Production	Environment	Management
Estimated Breeding Values (EBVs) <sup>***</sup>	Global Positioning System (GPS) on tractor <sup>***</sup>	Key Performance Indicators (KPIs) <sup>***</sup>
Herd health, welfare and animal biosecurity plans <sup>***</sup>	GPS soil sampling/mapping <sup>*</sup>	Knowledge Exchange groups <sup>**</sup>
Electronic Identification (EID) <sup>**</sup>	Monitor and control on-farm energy use <sup>*</sup>	Food certification and assurance schemes <sup>*</sup>

<sup>\*\*\*</sup>Very likely to be adopted

<sup>\*\*</sup>Somewhat likely to be adopted

<sup>\*</sup>Very unlikely to be adopted

## 5.1. Production technologies

### 5.1.1. Estimated Breeding Values (EBVs)

EBVs assign numerical figures to an animal based on certain selection traits, which then indicate the predicted genetic merit of the animal for that trait, offering the opportunity to enhance the productivity, profitability and competitiveness of the Scottish livestock industry. Even though adoption of EBVs has been reported as slower in beef and sheep sectors (Vipond, 2010; Scottish Government, 2016), those involved in EBVs’ development and promotion believe that its uptake is on the increase (Islam et al.,

2013c). Additionally, a variety of complementary advances may encourage adoption, such as 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.

### **5.1.2. Herd health, welfare and animal biosecurity plans**

Here we refer to the development and application of herd health, welfare and animal biosecurity plans to improve health status of the herd and ultimately enhance livestock productivity and animal welfare. Herd health planning highlights the risks for the herd and provides a programme to manage these risks. One such example is the Scottish ‘Sheep and Suckler Cow Animal Health Planning System (SAHPS)’, a web based health planning system that allows farmers and their 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).

Several solutions to facilitate the uptake of animal health planning in Scotland were identified by Islam et al. (2013a), such as simplifying health planning systems, improving collaboration and communication between actors involved, and increasing and standardising data recording.

### **5.1.3. Electronic Identification (EID)**

Animals are individually identified with a microchip in either ceramic bolus, ear or pastern tags, enabling individual performance measurement. With EID the recording and monitoring of on-farm performance becomes easier, contributing significantly to an improved management of the herd (e.g. immediate access to animal data that can help with management decisions; AHDB, 2015a). The low adoption rates of cattle EID in Scotland can 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 (Duckett, 2014).

## **5.2. Environmental technologies**

### **5.2.1. Global Positioning System (GPS) on tractor and GPS soil sampling/mapping**

GPS-based applications in precision farming can be used for field mapping, soil sampling, farm planning, tractor guidance, crop scouting, variable rate applications and yield mapping (Mohapatra and Singh, 2012), which can help productivity (Kalkhan,

2011). Precision soil sampling, data collection and analysis facilitates localized variation of chemical applications and planting density to fit particular areas of the field, allowing an effective use of expensive resources (Neményi et al., 2003).

### **5.2.2. Monitor and control on-farm energy use**

This innovation consists of monitoring and controlling resource use efficiency on farm and associated environmental performance. Some examples of broad indicators that can be used are: (1) energy use; (2) energy efficiency; (3) use of renewable energies. Different software may be used to calculate these indicators allowing benchmarking of the farm environmental efficiency over time and/or against similar enterprises (Scottish Natural Heritage, 2010).

## **5.3. Management innovations**

### **5.3.1. Key Performance Indicators (KPIs)**

KPIs estimated from farm records can assist farmers in making informed decisions, in detecting areas of strength and weakness and in implementing changes that may increase the profitability of the farm business (e.g. calving period, kilogram (kg) of beef reared by weaning per cow put to bull; ADHB, 2015b).

### **5.3.2. Knowledge Exchange groups**

This innovation consists of attending and contributing information to industry led knowledge transfer groups, allowing the continuation and development of existing community led initiatives such as the Monitor Farm Programme, the Planning for Profit Initiative and the QMS Grazing Groups (Scottish Government, 2014).

### **5.3.3. Food certification and assurance schemes**

Food assurance and certification schemes help to provide consumers and businesses with guarantees that food has been produced to particular standards (e.g. geographical location; Food Standards Agency, 2012). The main aim of these schemes is to differentiate included products, in order to obtain an increased market price and a marketing advantage. Examples of these schemes are Quality Meat Scotland (QMS) and Protected Geographical Indication (PGI).

## **6. Policy implications**

Innovation adoption and diffusion studies are highly relevant in terms of policy-making as they determine the constraints on innovation uptake, such as insufficient inputs, credit, or marketing infrastructures, in a given population. Additionally, these studies provide a realistic understanding of the results that can be expected from technological change.

It is of major importance for policy makers to have a complete understanding of the adoption decisions of farmers, so they have a proper knowledge basis for formulating policies to change farmer's practices, as they cannot foresee the wide range of responses farmers may present to those policies (Kaine and Higson, 2006). This view is also supported by Doss (2006, p. 210) who stated "without basic descriptive information on who is using the technologies and who is not, it is difficult to know how to formulate policies aimed at improving agricultural productivity". Thus, the measurement of innovation allows not only the assessment of the performance of innovation systems, but also the effectiveness of innovation policies in terms of their aims, providing valuable information that can lead to a better designing and formulation of potential policies. However, one should bear in mind that farmers will adopt innovations that positively contribute to their economic goals. If an innovation is not adopted in the long term, it is because farmers are not completely certain that it advances their goals sufficiently in order to outbalance its costs (Pannell et al., 2006).

## **7. Conclusions**

This paper has provided an overview of significant concepts, theories and empirical studies from the literature on agricultural innovation as well as a starting point in the identification of relevant innovations to the future of Scottish specialist beef farms, with several examples being highlighted. Further studies are being carried out to compile a final list of technologies that will help assessing the national level uptake of innovative technologies in Scottish specialist beef farms.

It is widely accepted that adoption and diffusion of innovative technologies are of major importance in the process of economic growth. From a farm-level perspective, innovation is seen as the main driver of agricultural productivity growth. Thus, farmers require innovations that increase efficiency and provide competitive edge within their policy and market context.

Agricultural economists have been particularly concerned with understanding and modelling the processes and consequences of farmers' adoption decision-making. Several theories and models have been developed over time, which are useful not only to assess performance of innovation systems, but also to deliver supporting information that can help designing and formulation of policies aimed at encouraging innovation uptake.

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**Acknowledgements:**

This research was supported by the Scottish Government funded Research Programmes and the University of Nottingham. We also acknowledge all of the experts involved in the research project for their extensive contribution.