Factors affecting the adoption of Agri-IoT in Ireland

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Declaration

I declare that the work described in this dissertation is, except where otherwise stated, entirely my own work, and has not been submitted as an exercise for a degree at this or any other university. I further declare that this research has been carried out in full compliance with the ethical research requirements of the School of Computer Science and Statistics.

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Abstract

Recent technological developments in Low Power Wide Area (LPWA) networks are providing powerful options for previously unfeasible remote device connectivity use cases. Smart Cities and industrial automation are prime targets for LPWA enabled IoT applications however agriculture, a sector that has struggled to benefit from the rapid development of the internet and smart tech, will also be profoundly impacted.
Agri-IoT, a sub-category of IoT concerned with agriculture, can be seen as a key enabler of precision farming which has been highlighted by the EU as critical to EU farming competitiveness. Connectivity coverage over expansive, rural and lightly populated farms has always been a barrier to utilising such smart technology. With the technology enablers now a reality, the question now becomes what are the other factors influencing adoption. A review of current LPWA network options and Agri-IoT technologies available in Ireland was carried out. A survey of Irish farmer's awareness and attitudes towards Agri-IoT products was conducted and analysed in respect of Technology Acceptance theory to determine the main factors affecting the adoption of Agri-IoT in this country. Interviews with both Agri-IoT users and non-users were held to gain a deeper understanding of the factors involved. The primary drivers to adoption were found to be increased competitiveness through both time savings and increased productivity. The primary barriers to adoption were found to be initial purchase cost and difficulty to maintain. Farm size and type along with Agri-IoT familiarity and social influence factors were also determined to impact on adoption rates. Regulation and government incentive programs are likely to drive further adoption of the technology. It was also identified that more work needs to be done to increase ICT skills in the farming community to allow the advantages of Agri-IoT to be realised.

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Abbreviations

Agri-IoT	Agricultural Internet of Things
LPWA	Low Power Wide Area
IoT	Internet of Things
EIP-AGRI	European Innovation Partnership for Agricultural Productivity and Sustainability
EU	European Union
TAM	Technology Acceptance Model
MIT	Massachusetts Institute of Technology
RFID	Radio-frequency identification
EPOSS	European Technology Platform on Smart Systems Integration
IP	Internet Protocol
IPv6	Internet Protocol Version 6
IETF	Internet Engineering Task Force
M2M	Machine-to-Machine
RTK	Real Time Kinematic
TAMS	Targeted Agricultural Modernisation Scheme
VRT	Variable Rate Technology
GPS	Global Positioning System
IoT	Internet of Things
PA	Precision Agriculture
AMS	Automated Milking System
EID	Electronic Identification

1 Introduction

The application of IoT technology to agriculture has the potential to transform farming practices, making them more productive, precise and sustainable. However it is predominantly larger farms in developed countries that have implemented IoT with many smaller farms yet to do so (Teagasc 2016). Two of the major obstacles to mass deployment of IoT in agriculture are high device cost and limited device power. With long range coverage, low power consumption and ultra-low cost devices, Low Power Wide Area (LPWA) communication technologies are particularly well suited for agriculture and provide a number of opportunities (Sinha, Wei et al. 2017). Development and rollout of LPWA technology is occurring at a rapid pace around the world and recently work has started on such networks in Ireland. With the potential of such technologies to profoundly impact how the Irish agriculture industry operates, this paper is motivated by a need to look at IoT adoption factors in the Irish context from the primary farmer's perspective and aims to understand the forces involved.

1.1 Context of Study

Numerous studies have been completed on the introduction of IoT technology to smart cities, industrial processes and even the Agri-foods supply chain however for such a large field of study relatively little research has been conducted on the application to primary agriculture. In a systematic literature review Talavera, Tobón et al. (2017) found 72 papers, between 2006 and 2016, dealing with the application of IoT to primary agriculture. The majority of these studies were conducted in America, India or China and involved large-scale farms, operations such as vineyards or olive plantations that do not occur in Ireland or focused on irrigation solutions that are not a focus for Irish agriculture. In addition these surveys deal with the application of the technology and very little analysis of factors affecting adoption by the farmer is conducted. This study will look at the specific factors affecting Agri-IoT adoption in the Irish context.

1.2 Background

Advancing technology, growing populations and environmental concerns require a new approach in agriculture. Ireland has the capacity to contribute to reducing world food and nutrition insecurity but to do this will require the widespread adoption of existing and new practices by the greatest number of producers and agri-food actors (Teagasc 2016) Recent technological developments in Low Power Wide Area (LPWA) networks are providing powerful options for previously unfeasible remote device connectivity use cases. Fig 1.1 highlights the unique characteristics of this technology. LPWA networks are designed to enable long-range coverage, low power and low cost IoT device connectivity via lean network architectures and simple communication protocols. They aim to provide low data rate connectivity to massive amounts of sensors in a variety of settings, underground, in tanks, in machinery and infrastructure or monitoring animals and plants.

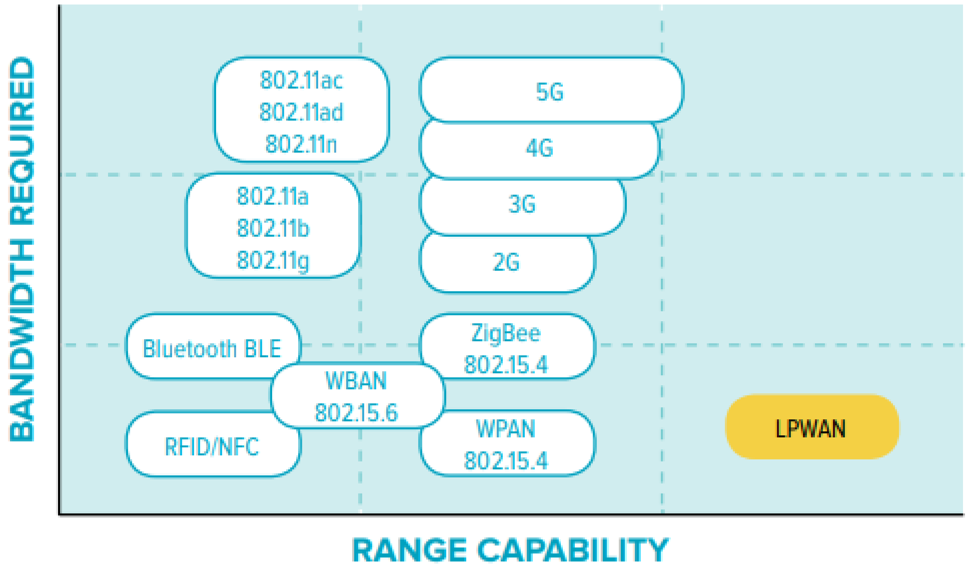

Fig 1.1 LPWAN Range & Bandwidth (Labs 2016)

This research is interested in the adoption of Agri-IoT technology by Irish farmers. It endeavours to understand the forces at play in Irish farmers choosing to adopt or ignore available Agri-IoT technology capabilities. It will describe the current state of Agri-IoT technology and explore the particular factors involved when Irish farmers choose to use Agri-IoT technology or not. This paper aims to explain the cause and effect relationships driving these technology adoption behaviours. Technology acceptance theory will be tested using primary data collected from a survey using deductive reasoning.

1.3 The Research Question

The primary research question is:

"What are the factors affecting the adoption of Agri-IoT technology in Ireland?"

Secondary questions include:

What is the current state of LPWA networks in Ireland?
What Agri-IoT sensor options are available to Irish agriculture currently?
What awareness is there in the farming industry of Agri-IoT capabilities?
What are the barriers to Agri-IoT adoption in Irish agriculture?
What are the drivers to IoT adoption in Irish agriculture?

1.4 Why This Research Is Important

Agriculture plays a major part in the Irish economy and needs to compete against strong global players. Emerging technologies such as IoT and LPWA are being adopted by developed countries to increase competitiveness. While research has been carried out on the application of IoT technologies to the agri-food supply chain, little research has been carried out on its application to primary farming. Furthermore primary farming studies tend to focus on large scale American farms making it difficult to relate the findings to Irish interests. Brexit has resulted in a reduced Common Agricultural Policy budget and more penalties for non-compliance with EU environmental rules. This twin impact puts pressures on farm margins and increased focus on making farms more eco-friendly. The advent of lower priced Agri-IoT systems allowing smarter more targeted use of resources and greater control over farm waste could be a timely solution.

1.5 To whom It Is Important

This paper provides insights into the developing role of IoT technology in Irish farming and as such would be of interest to Irish agriculture policy makers and researchers.
Irish farmers in 2018 are coming to terms with an agricultural industry rapidly modernising. An improved understanding of the factors affecting the adoption of Agri-IoT in Irish agriculture can help steer targeted farmer training and incentive programs.
The results of this research can also inform Agri-IoT system manufactures on issues

stopping farmers from using their products and allow them to better align their product ranges with the needs of the Irish agriculture industry.

1.6 Scope

The scope of this study includes all factors impacting on the adoption of Agri-IoT technology in Ireland. This includes both the macroeconomic and technical factors affecting the adoption of the technology by the agri-foods industry and the specific factors affecting the take up of the technology by Irish farmers themselves.

1.7 Timeframe

The study was conducted between September 2017 and June 2018. A proposed survey and interview system was submitted to the Trinity ethics board on Thursday January 25th and ethical approval was received on Friday February 23rd. The survey was conducted from Monday March 19th until Monday May 7th. Interviews were held from Sunday May 6th until Thursday May 10th. The final paper was submitted Monday June 11th.

1.8 Chapter Roadmap

Chapter 1 introduces the context that this study is undertaken in and the background on the subject matter. It defines the main research question and the sub-questions that the study aims to answer. An outline of the need for this study is given and parties that will benefit from the research are described. Research scope, timeframe and then document structure are summarised.

Chapter 2 first provides an overview of IoT in general, then outlines the Agri-IoT concept and introduces the various Agri-IoT sensors and applications. It describes the drivers and barriers to Agri-IoT adoption listed in the literature. It then looks at Technology adoption theory and the specific case of technology adoption in the agricultural setting.

Chapter 3 outlines the methodology used in this study to answer the research question. It expands on the objectives of the study and describes the methodology to be used. It then details the research instruments. A review of the ethical considerations of the study is given. The techniques used to analyse the study findings are summarised. Lessons learnt during the study are given flowed by a description of limitations identified with this study.

Chapter 4 reviews the research findings and analysis. It briefly describes the survey execution and then provides insight on the demographics of the surveyed population. It interprets the results of the survey and identifies factors involved in Agri-IoT adoption. Findings for the interview stage are then analysed.

Chapter 5 provides a conclusion on the study, providing an answer to the research question and outlines future work that could be undertaken in this area.

2 Literature Review

The aim of the literature review is to identify previous research conducted on this topic to provide insight on how to best answer the research question. It begins with a general review of the IoT paradigm, its impact on the world's economy and developments in connectivity options that are of particular interest to the agricultural industry. It then introduces the specific sub-topic of IoT in agriculture, Agri-IoT, outlining sensors and applications used in that field. The drivers for adopting Agri-IoT are then given followed by identified barriers. To understand how technology is adopted by people a review of adoption theory was undertaken. Finally the literature was reviewed for previous studies that attempted to identify the factors in agricultural technology adoption

2.1 IoT.

2.1.1 IoT Introduction

The Internet of Things (IoT) concept has been present in the literature in various forms from the late 1980's (Weiser 1991) but was popularised by MIT's Auto-ID centre in the early 2000s with the first public reference to it in a November 2001 MIT white paper (Brock 2001). It was initially associated with Radio Frequency Identification (RFID) tags for Supply Chain Management but has since expanded into market segments such as connected home, infrastructure & utilities, manufacturing, healthcare, transportation, retail, wearable's and drones (Pappageorge 2015).

Semantically the phrase means "a world-wide network of interconnected objects uniquely addressable, based on standard communication protocols" (EPOSS 2008). In more rigorous terms the IoT was defined by the ITU-T as "A global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies". Physical things can be sensed, actuated and connected such as the surrounding environment or industrial robots. Virtual things can stored, processed and accessed such as multimedia content and application software (ITU-T 2012).
The ongoing development of the IoT network has been compared to the initial development of electricity systems in the early 1900s. Specialised, expensive and isolated systems eventually became the standardized, pervasive commodity that is the electrical grid today. Like the electricity running through those electrical grids, data runs through IoT

systems, available to be tapped into whenever and wherever it's required (Lucero 2016). Metcalfe's Law explains that the value of a network is the square of the number of users it has. The explosive success of the internet is often explained by this law and in a similar fashion the continual addition of objects to the IoT network makes it exponentially more useful (Kevin Ashton 2001). To cater for such large numbers of uniquely addressed objects, the internet protocol (IP) addressing scheme was updated to version 6 (IPv6) in July 2017. Developed by the Internet Engineering Task Force (IETF) it provides for 2^{128} or about 340 trillion, trillion, trillion addresses, this is enough to unique identify every grain of sand on the planet (Graziani 2014).

An example IoT architecture is shown in Fig 2.1 (Popović, Latinović et al. 2017). Any number of environment measurements can be taken by a variety of sensor types and transported over connectivity mechanisms to the cloud. A range of advanced analytics, storage and data visualisations are made available by scalable cloud platforms.

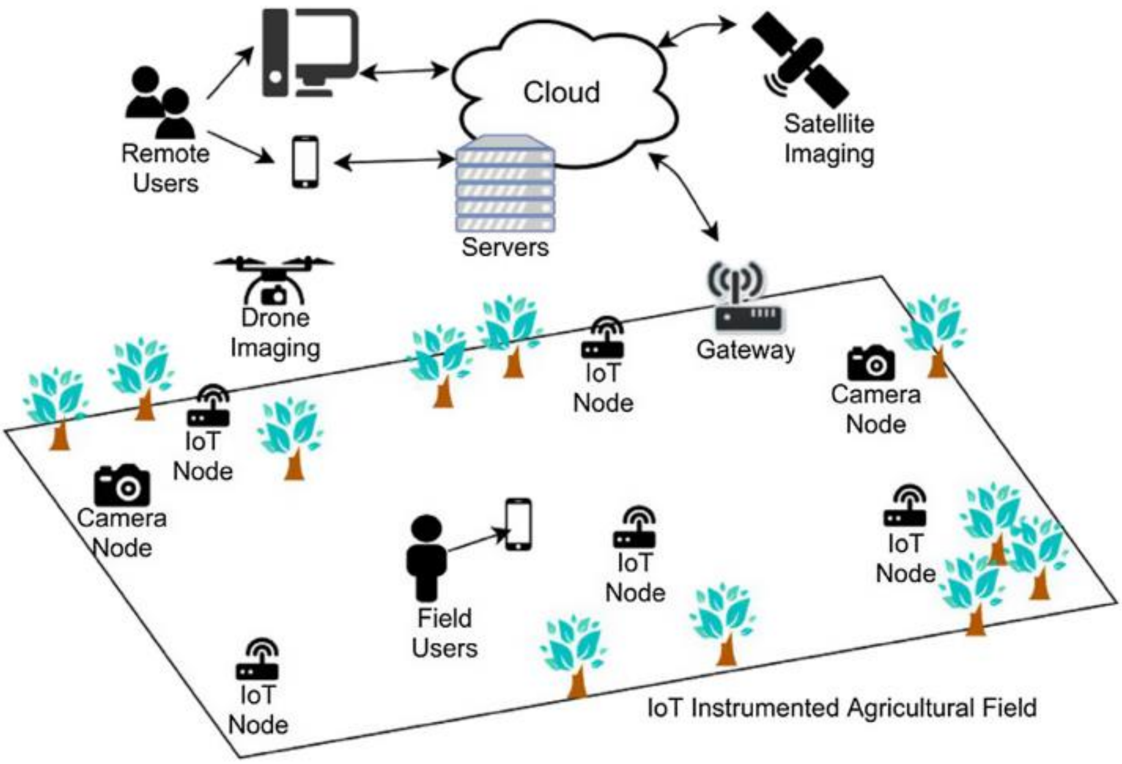

Fig 2.1 IoT Instrumented Agricultural Field (Popović, Latinović et al. 2017)

2.1.2 IoT Impact

In 2015 there were 15.4 billion IoT devices in the world and there are predicted to be 30.7

billion in 2020 and 75.4 billion in 2025. The expected economic impact of IoT technologies by 2025 is estimated to be between a conservative $2.7 trillion and an optimistic $6.2 trillion per year (Al-Fuqaha, Guizani et al. 2015).

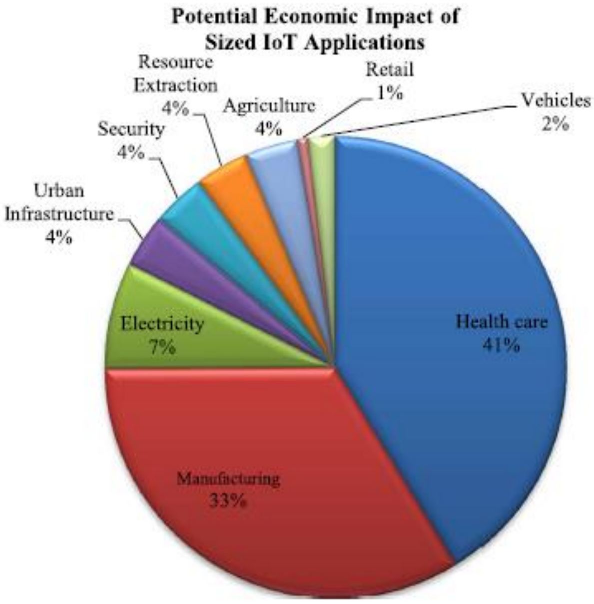

Fig 2.2 Potential Economic Impact of IoT (Al-Fuqaha, Guizani et al. 2015)

Fig 2.2 gives an overview of the expected economic impact of IoT on different industries. The top three area's impacted by IoT are expected to be Healthcare, Manufacturing and Electricity. Efficiencies gained from self-monitoring health devices, remote monitoring of patients with chronic diseases and tackling drug counterfeiting are seen as huge areas of growth for healthcare. For manufacturing, real-time tracking of supply chains, machinery and assembly lines can reduce downtime and increase precision generating productivity gains. The precise, real-time tracking of electricity grid usage via smart meters can help manage load, avoid outages and improve efficiencies. While agriculture is not expected to be as impacted by IoT as the top three sectors it is still expected to create $100 billion in economic value per year by 2025 by helping to optimise farm resource usage and the early detection of pest and disease outbreaks (Manyika 2013).

2.1.3 IoT Connectivity

One of the most critical elements of the IoT system is the ability of the device to communicate remotely. There are three main connectivity options for IoT.

Standard public mobile network

A number of public mobile network variations are currently in operation such as the 2G, GPRS, 3G, 4G and LTE-A standards. All provide the ability for remote devices to connect with the cloud. None of these systems were designed specifically with IoT requirements in mind however and do not efficiently transport many of the IoT use cases. The ubiquitous GSM or 2G mobile phone technology has catered to the Machine-2-Machine (M2M) industry for decades however it is approaching its end of life and mobile phone operators are starting to turn such networks off as the architecture is now quite dated (Fingas 2017). 3G/4G cellular networks were designed to transport human voice, support web browsing and high capacity video streaming/document download functionality. Such devices are power hungry, require complex electronics to communicate and are not efficiently designed for the low bandwidth, intermittent communication needs of IoT.

Short-range mesh network

These involve connecting the remote device locally, between 10cm and a couple of 100 metres, and require a close proximity between the sensor and the network. Ideal for manufacturing plants and logistics in warehouses but often not suitable for the large coverage footprints involved in agricultural use-cases.
Short range technologies include WiFi, RFID, ZigBee, Bluetooth Low Energy (BLE) and Z-Wave.

Low Power Wide Area (LPWA)

LPWAN networks were specifically designed to handle IoT communication needs over long distances with low power usage and requiring only simple, low cost remote devices. Examples include proprietary systems such as SigFox and LoRa or standardized open systems such as the 3GPP’s LTE-M, NB-IoT

The benefits that LPWAN technologies bring to IoT over regular cellular networks are discussed by Raza, Kulkarni et al. (2017) and include:

- Low power usage with a greater than 10 year battery life.
- Low device unit cost.
- Massive device density supported by a single base station
- Extended coverage, +20 dB antenna sensitivity allowing long range and underground applications
- Optimised, efficient data transfer

GSMA (2016) also details the additional functionality provided by the licensed LPWA technologies, LTE-M and NB-IoT:

- Secured connectivity and strong authentication
- Flexible licensed frequency band use

LPWA networks are critical for farm IoT applications as they provide widespread rural coverage enabling applications such as machinery/animal tracking and monitoring. Also farm applications need to have low maintenance requirements over a protracted period of time, devices may be in grain silos, oil tanks, implanted in an animal or installed on remote farmland over a period of years in often harsh conditions.

Narrow Band IoT (NB-IoT) was standardised as part of 3GPP Release 13 in June 2016 and has been launched by a number of operators worldwide. Market research from Analysys Mason showed that a total of 85 new LPWA networks were launched in 2016, up from 29 in 2015 (Xylouris 2017). Vodafone Ireland announced a NB-IoT nationwide rollout in August 2017 (Kennedy 2017, August). VT-Networks Ireland launched a nationwide SigFox network in 2016 providing solutions for tracking for farm assets and security sensors for gates amongst others. Pervasive Nation is a nationwide LoRa testbed platform setup by CONNECT and funded by Science Foundation Ireland (Doyle 2017).

2.1.4 Agri-IoT Introduction

There are many terms currently used to describe IoT in agriculture, some overlap in meaning and some describe specific use cases. Examples are smart farming, precision agriculture (Pierpaoli, Carli et al. 2013), precision livestock farming (Wathes, Kristensen et al. 2008) or the Internet of Farming Things (Teagasc 2016).
Kamilaris, Gao et al. (2016) describe a common agricultural IoT framework called Agri-IoT that incorporates all the components of the above terms, namely ground, animal, drone or satellite sensor data, social network information, weather forecast data and government alerts in one system. This paper will use the term Agri-IoT as described by Kamilaris, Gao et al. (2016) to reference all IoT devices used in agriculture.

2.1.5 Agri-IoT Sensors

A wide range of commercial off-the-shelf Agri-IoT sensors have been developed, a selection are listed below in Fig 2.3

Area	Measurement	Examples
Soil	moisture, temperature, nitrogen, pH, matric potential, salinity	Libelium
Liquids	Level, quantity, Temperature, Pressure, water quality, Photosynthetically Active Radiation (PAR), mineral/salt content, dissolved oxygen, pH, Ammonia, Nitrate, Chloride	Stevenswater
Environment	Temperature, Rainfall, Humidity, Solar Radiation, Atmospheric pressure, wind speed, direction	Climatronics
Plant	Photosynthesis, chlorophyll, leaf wetness	Growtronix, PlantLink
Animal	Machine vision camera's, microphone acoustic monitoring, calving & fertility	MooCall, Smatex
Location	Asset tracking, GPS or Real-Time Kinematic (RTK) precision agriculture	Topcon, Trimble
Security	Passive Infrared (PIR) motion detectors, perimeter security	VT Networks

Fig 2.3 Examples of Agri-IoT sensors

In addition a number of cheap, generic IoT enabled boards are also available for end-users to assemble Agri-IoT systems themselves. Examples are Arduino and Raspberry Pi kits.

2.1.6 Agri-IoT Applications

Ojha, Misra et al. (2015) list a variety of real world Agri-IoT applications including:

- Irrigation management systems
- Farming systems monitoring
- Pest and disease control
- Controlled use of fertilisers
- Animal movement monitoring and control
- Ground water quality monitoring
- Greenhouse gas monitoring
- Asset tracking
- Remote control and diagnosis

2.2 Agri-IoT Adoption Drivers

There are a number of both international and local factors driving the adoption of Agri-IoT by Irish agriculture. While feeding growing populations and environmental protection may not be on the agenda for every farmer it is behind a global drive to make farming more productive and efficient while at the same time less impactful on the environment.

2.2.1 Growing population

One of the major drivers for Agri-IoT use is the need to feed a growing population with a greater variety of food products on the same land area. The global population in 2017 was 7.6 billion with an additional 83 million people being added each year. This is expected to increase the global population to 8.6 billion in 2030 and 9.8 billion in 2050. At a local level, Ireland with a current population of 4.7 million, is expected to grow to 5.2 million by 2030 and 5.8 million by 2050 (United Nations 2017). The challenge of rising populations over the last number of decades has always been answered by agricultural innovation, from the adoption of steam to tractors, fertilisers to genetically modified crops, technology has always allowed farmers to do more with less. Tom Vilsack, then United States Secretary of Agriculture, is quoted as saying that in 1940 an American farmer produced enough food for 19 people but that by 2010 this had increased to 155. This indicative measurement compiled by the USDA until 1970 and since then by the American Farm Bureau Federation shows the magnitude of farm yield increases achieved (Sullivan 2014).

An analysis of US farm output 1948 – 2015 by the United States Department of Agriculture shows US agricultural output grew by 170% while two major inputs declined, labour (down 75%) and land farmed (down 24%) in the same time period (Sun Ling Wang 2015).

In analysing this output growth Sun Ling Wang (2018) looked at the Total Factor Productivity (TFP) measure which compares agricultural output to agricultural inputs including capital, land, labour, and intermediate inputs such as chemicals and energy. This shows that while there were declines in labour and total area farmed, these reductions were offset by increases in intermediary goods (fertilisers, pesticides) up 134% and capital inputs (machinery, farm buildings) up 78% leaving overall farm inputs up only 7% over the period.

These figures highlight how technology has allowed farm yields to increase while keeping farm inputs basically steady. The study does not predict a slowdown in productivity in the short term but a reduction in the technology pipeline could impact productivity towards

2050. An analysis of global yield increases from the Food & Agricultural Organization (FAO) of the United nations shows that year on year increases from the three most dominate human dietary crops are falling, with wheat and rice now at 1% and maize at 1.6% yield increase/year (R.A. Fischer 2009). It is also noted that a continuous linear increase in yields, following the pattern of the last forty years, will not be sufficient to meet food, feed and fuel needs into 2050. More efficient and precise management of farm inputs using Agri-IoT technologies will be required. Slowing productivity with increasing demand puts obvious pressures on food prices and food security which in turn affects the poorest segments of society as daily food requirements become unaffordable.

2.2.2 Environmental Sustainability

When asked for his thoughts on whether a US withdrawal from the Paris climate agreement would collapse the deal, Ban Ki-Moon, general secretary for the United Nations is quoting as saying “We don’t have plan B because there is no planet B” (Ki-Moon 2016).

Many of the benefits from the Green (or Third) agricultural Revolution between the 1930s and the 1960s came from widespread application of pesticides and fertilisers in a blanket manner across varying farm and crop types (Barrera 2011). This lead to issues with environmental damage and increased input costs with plateauing productivity. More accurate and insightful identification of specific farm needs along with variable rate application technologies allow farmers to apply only what is needed while still achieving productivity gains. This allows yields to increase in a sustainable way.

Climate Smart Farming (CSA) is farming that sustainably increases productivity, resilience, reduces/removes greenhouse gases, and enhances achievement of national food security and development goals (Cees Leeuwis 2013). Agri-IoT can help to implement CSA by using sensors to direct the use of pesticides and fertilisers. It can also be used to record field treatments at the meter scale, track application levels from operation to operation and transfer all recorded information with the harvested products which will assist with the enforcement of environmental protection legislation (Zhang, Wang et al. 2002).

2.2.3 Competitiveness

As a small, open economy we are particularly reliant on exports to drive growth and job creation. With over 80% of Irish food production being exported, Ireland requires a continued focus on competitiveness in its global marketplaces to succeed. Farmers must adopt, and be encouraged to adopt, the latest technologies and processes to increase sustainable productivity which will result in increases to farm level profitability (DAFM 2015)

A development paper from the Department of Agriculture, Food and the Marine, Food Wise 2025, set major sustainable intensification targets on the Irish agri-foods sector. These include increasing the value of agri-food exports by 85% to €19 billion and increasing the value of primary production by 65% to almost €10 billion while at the time acknowledging that environmental protection and economic competitiveness are equal and complementary, one will not be achieved at the expense of the other (DAFM 2015). To achieve these growth targets while also abiding by our environmental targets will require the adoption of emerging technologies such as Agri-IoT (Teagasc 2016).

Agri-IoT technology can improve crop yields, optimise inputs and improve quality through techniques such as autonomous guidance, yield mapping, nitrogen sensors and soil sampling (Zarco-Tejada, Hubbard et al. 2014). For instance, economic savings on nitrogen fertilisation using variable rate technology (VRT) in Germany range between 10€/ha and 25€/ha depending on the field size, benefits grow if more complex systems are adopted, which could lead to additional returns of 18-45€/ha for winter wheat (Zarco-Tejada, Hubbard et al. 2014).

Automation will play an increasingly significant role in helping producers achieve high levels of production with lower cost to the environment in 2035 (Teagasc 2016). Automation can already be used to save time and reduce labour for such tasks as animal identification, feeding, milking, oestrus and birth detection, harvesting and cleaning (Hamadani and Khan 2015).

The on-going renegotiation of trade agreements between Ireland's largest agricultural produce export market, Britain, and the EU, places even greater emphasis on ensuring Ireland's competitiveness in global markets.

2.2.4 Animal Health

One of Irish agricultures key sales points is naturally grown, safe food products. Under the government's 2020 Innovation plan research should be focused on promoting and enhancing the already high standards of animal health and welfare and plant health present in Irish agriculture (Teagasc 2016). One of the key investment areas identified by Bord Bia's 2015 Sustainable healthy Agri-Food Research Plan was to develop early warning data/surveillance sensor systems and improved diagnostics for the rapid recognition and control of new and endemic infectious diseases of livestock (Bia 2015). Low-cost cameras, microphones and telemetric sensors such as pedometers, heart rate, body temperature and activity monitors are now available that together with analysis software can be used to assess the health of all animals on a farm on a continuous basis. The advantage of such systems is that health information can be collected without the stress of animal disturbance or handling (Wathes, Kristensen et al. 2008).

Animal identification systems provide an efficient means for farmers to tailor operations to the needs of each individual animal. This allows for instance medical history to be accurately recorded or changes in behaviour such as activity levels, milk production or gait, that could indicate the on-set of sickness or lameness, to be identified (Hamadani and Khan 2015).

Automated feeding systems can reduce stress in animals as food is readily available on demand, this also means lower ranking animals are able to take advantage of more and better feed (Grothmann, Nydegger et al. 2012).

Calving is a precarious time for farmers and cows alike on a farm with a difficult un-assisted birth causing trauma for both cow and calf. Agri-IoT sensors provide a means for 24/7 monitoring of the cow in the lead up to a birth and gives the farmer sufficient notice to take action if needed reducing instances of calf or cow death, milk loss or infection (Hamadani and Khan 2015).

Modern farming is intensifying and the individual attention farmers were once able to give their animals at low stocking rates is no longer achievable. Automated sensory technology can replace the eyes and ears of farmers but thought must be given to the bioethical impacts of such systems (Wathes, Kristensen et al. 2008). An analysis of automated milking systems (AMS), which allow cows to present for milking voluntarily, looked at such ethical aspects as motivation to be milked, grazing and dominance. Results showed improvements in cow welfare due to increased behavioural freedom but noted that there should be governance over how such systems are installed and operated to ensure animals are properly treated (Millar 2000).

2.2.5 Government Regulation & Incentives

It is likely that there will be increasing policy interventions in relation to food production and consumption as governments seek to improve public health, promote healthy aging and address issues such as sustainability.

There is currently a legally binding mandate for a 20% cut in Greenhouse Gas (GHG) emissions in all EU countries based on 1990 levels. This is to be achieved by 2020 with a

follow on program to set reduction targets towards 2030 (Teagasc 2016). In a similar vein EU directives on water quality control the availability of pesticides for crop protection. Biotechnology has a crucial role to play in this integrated approach through the use of new techniques of molecular biology and networks of sensors (Teagasc 2016).
EU regulation (EC) No 21/2004 required electronic identification (EID) tagging for lambs born after 31 December 2009 to address traceability and help implement sustainability initiatives. There were however exemptions for sheep going straight from farm of origin to slaughter meaning the system was not in widespread use in Ireland. On May 2nd 2018, the EID system was announced to be extended, requiring all sheep sold from October 1st, 2018 to be electronically tagged. EID tags use RFID chips to encode identification information and can be read using an RFID reader. EID tags cost about €1 more than regular tags while a handheld reader can cost about €500. Both tags and readers are to be included in the TAMS incentive programme (Quinn-Mulligan 2018).

Targeted Agricultural Modernisation Scheme II (TAMS II) is an Irish government initiative aimed at making Irish agriculture more competitive by encouraging farmers to adopt new technology and implement best practice processes. It provides grant aid for farmers to purchase Agri-IoT technology such as GPS guidance, automatic milking and EID tagging systems among others. It is co-funded by the EU and the exchequer with a total allocation of 395m until 2020 (DAFM 2018)

Teagasc proposes to develop a National Digital Farming Test Bed (NDFT) to support Irish farmers in dramatically improving their efficiency and sustainability through the widespread use of ICT (Teagasc 2016). This would allow pre-commercial testing of both public and private Agri-IoT sensor technologies allowing collaborative development of Agri-IoT systems between technology innovators and end-user farmers.

2.3 Agri-IoT Adoption Barriers

There are a number of issues hindering the adoption of Agri-IoT by the Irish farming community.

2.3.1 Cost

In an agricultural market where gross margin and profitability are getting tighter, farmers are looking for technologies that reduce cost without decreasing production (Zarco-Tejada, Hubbard et al. 2014). Cost will be an important factor in Agri-IoT as the average

Irish producer is operating on a much smaller scale farm than larger American type systems. In America the average farm size is 175.6ha (NASS 2014). In comparison the average Irish farm size is 32.5ha while the average standard output of an Irish farm is €35,912, these figures drop to 27.1ha and €23,013 for border midland & West farms (CSO 2013). Irish farmers will only invest in these new systems if they come at an affordable price. The investment costs can be substantial. For example Heege (2013) gives a of range of between €10,000 for a lightbar guidance system to about €40,000 for a RTK-GPS based automatic guidance system.

There can also be substantial financial challenges after the initial purchase. Steeneveld, Hogeveen et al. (2015) show that after investment in Automatic Milking Systems (AMS) in Holland the total capital costs increased significantly from €9.72 to €13.97 per 100 kg of milk. This increase was due to significant increases in depreciation on buildings and expenses on machinery and equipment.

Electronic identification (EID) tags, like those to be made mandatory by the Irish government this October, cost about €1 more per tag than regular tags while a handheld reader can cost about €500, more advanced readers can be in the thousands. For the smaller Irish farm with maybe 100 sheep the advantages of such a system are hard to justify as there is no real financial gain to be seen at the primary producer level (Quinn-Mulligan 2018) Costs don't relate just to the Agri-IoT device itself, other costs include information costs, expenses involving data processing software, learning and maintenance costs (Zarco-Tejada, Hubbard et al. 2014).

2.3.2 Return on Investment

Immature systems have not yet been proven to provide definite return on investment and difficulty in determining ROI is often cited by end-users as a key barrier to adoption (Lucero 2016).

Steeneveld, Hogeveen et al. (2015) found that although a significant increase in milk revenues was observed after investment in Automatic Milking Systems this was likely due to an increase in milking frequency and profit after operating costs did not increase.

ROI case studies and analysis are complicated and results from different countries and agricultural sectors differ greatly. Studies from Denmark showed no economic effect of sensor based fertilizer redistribution, possibly explained by the fact that the application rate was already near optimal. In cases of very heterogeneous fields with areas of low yield variable rate applications are much more successful (Zarco-Tejada, Hubbard et al. 2014). In a similar Australian study, precision agriculture soil sampling and variable rate application technology was found to reduce the volatility low quality soil zones had on ROI (Tozer 2009).

2.3.3 Training

Appropriate training is crucial to help farmers understand the use and applicability of Agri-IoT systems (Brewster, Roussaki et al. 2017). According to AIOTI (2015) 71% of EU farmers still operate primarily of practical experience giving lack of time to learn as one of the main reasons. Also farmers appreciate in-field demonstrations, free trials, support services related to the use of new technologies, as they promote the perception that the use of a technology is easy (Pierpaoli, Carli et al. 2013)
Previous research on the adoption of GPS Guidance systems has shown that although general education was not a determinant factor, experience with other precision agriculture techniques was a strong indicator of adoption of new GPS Guidance systems (Banerjee, Martin et al. 2008).

2.3.4 Robustness

Agri-IoT devices will be exposed to harsh environmental conditions and need to work for extended periods of time without maintenance. They need to continue to operate correctly in high solar radiation, extreme temperatures, rain or high humidity, strong winds, vibrations, tolerate water submersion, dirt and be robust against physical impacts from farm machinery or animals. They need to remain active for extended periods on battery power as mains power or frequent battery replacement is not an option for open field deployments (Tzounis, Katsoulas et al. 2017)

2.3.5 Interoperability

Standards are required to allow interoperability between different device manufactures and to provide confidence to end-users that they won’t end up buying into a technology that becomes obsolete by a rival (Al-Fuqaha, Guizani et al. 2015).
Atzori, Iera et al. (2010) in his seminal paper on IoT states that one of the central issues facing IoT is making full interoperability between inter-connected devices possible. Due to the broad nature of the IoT paradigm however there are multiple standardisation bodies involved such as the ITU, Machine-to-Machine (M2M) Workgroup of the European Telecommunications Standards Institute and the Internet Engineering Task Force (IETF).

Brewster, Roussaki et al. (2017) has stated that it is not the lack of standards that is the problem but rather too many standards. Lucero (2016) gave fragmented supply chains and ecosystems and diverse standards and technologies as two of the critical barriers to Agri-IoT adoption.

2.3.6 Privacy & Security

Agri-IoT devices are likely to be placed in large open areas without supervision for long periods of time making them susceptible to theft, damage or physical tampering. There will need to be adequate security mechanisms put in place to detect and counter such activities. Due to the connected nature of Agri-IoT devices they are also at risk of hacking or information acquisition threats. Sufficient encryption features are required to deal with this while not raising the cost or complexity of the remote device. (Tzounis, Katsoulas et al. 2017)
Atzori, Iera et al. (2010) stress that the extent to which everyday objects become information security risks, the IoT could distribute those risks far more widely than the internet has to date, this is also true for Agri-IoT.

2.4 Technology adoption theory and prediction

Numerous studies have looked at how technology is adopted by people. A number of models have been proposed since Davis (1989) outlined his Technology Acceptance Model (TAM) constructs of Perceived Ease of Use (PEU) and Perceived Usefulness (PU). The Unified Theory of Acceptance and Use of Technology (UTAUT) was developed by Venkatesh (2003) to combine the prediction capability of eight separate models.
UTAUT is used in this paper to help categorise the factors affecting the adoption of Agri-IoT by Irish farmers as it combines the prediction theory of eight previous models and also incorporates the effect social aspects and facilitating conditions have on technology acceptance. A definition of the terms used is given below.

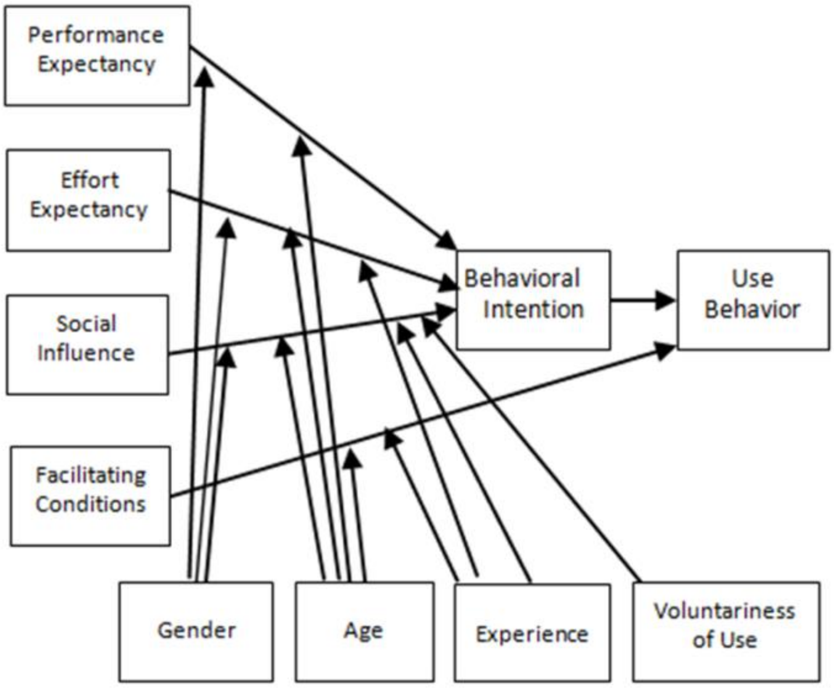

Fig 2.4 UTAUT Model (Venkatesh 2003)

Performance Expectancy

Performance expectancy (PE) is “the degree to which an individual believes that using the system will help him or her to attain gains in job performance”
This construct is the strongest predicator of intention and is significant in both voluntary and mandatory settings. The influence of performance expectancy on behavioural intention will be moderated by gender and age in particular for younger men. This construct grew from perceived usefulness in TAM, extrinsic motivation in MM, job fit in MPCU, relative advantage in IDT and outcome expectations in SCT.

Effort Expectancy

Effort expectancy (EE) is “the degree of ease associated with the use of the system”. This construct is the measure of difficulty entailed in use of a technology, which is an important predictor of behavioural intention. The construct is moderated by gender, age and experience. In general, the influence of effort expectancy on behavioural intention is expected to be most relevant to females based on age and experience. This construct grew from perceived ease of use in TAM, complexity in MPCU and ease of use in IDT.

Social Influence

Social influence (SI) is “the degree to which an individual perceives that important others believe he or she should use the new system”. This construct reflects the individual’s perception of how their peers and others whose opinions they value influences of their adoption of technology. General theory suggests that females are more sensitive to the opinions of others with the effect declining with experience. The social influence construct is moderated by gender, age, voluntariness and experience. This construct grew from subjective norm in TRA, Social Factors in MPCU and image in IDT.

Although only an indicator, it highlights that the farmer's social group are discussing the technology and its potential uses. UTAUT details how this has an influence on technology acceptance. In voluntary contexts social influence plays a role in creating perceptions about a technology, internalization and identification mechanisms. Only important in early stages of adoption

Facilitating Conditions

Facilitating conditions (FC) are "the degree to which an individual believes that an organizational and technical infrastructure exists to support use of the system". This construct reflects the individual's perception of the support that an organisation has in place for the use of technology. If performance and effort expectancies are present then the impact of facilitating conditions will not be significant in predicting intention. Empirical evidence shows that if individuals find support and assistance in the organisation this will increase behavioural intention. The moderators of facilitating conditions on behaviour are experience and age. This construct grew from perceived behavioural control in TRA, facilitating conditions in MPCU and compatibility in IDT.

2.5 Technology adoption in agriculture

Given the variety of structures and processes in farming, technology adoption in the industry is a complex topic with many variables. Prokopy, Floress et al. (2008) conducted a broad meta-level analysis of farm technology adoption and found characteristics and attributes such as education levels, capital income, farm size, access to information, positive environmental attitudes, environmental awareness and utilisation of social networks as all positively associated with the adoption of new technology practices. Pierpaoli, Carli et al. (2013) reviewed the existing literature on precision agricultural technology adoption and looked at adoption factors which lead to and sustained successful adoption, termed ex-post, and factors involved in setting attitudes to adoption, termed ex-ante. The factors were combined into three groups, competitive and contingent, socio-demographic and financial.

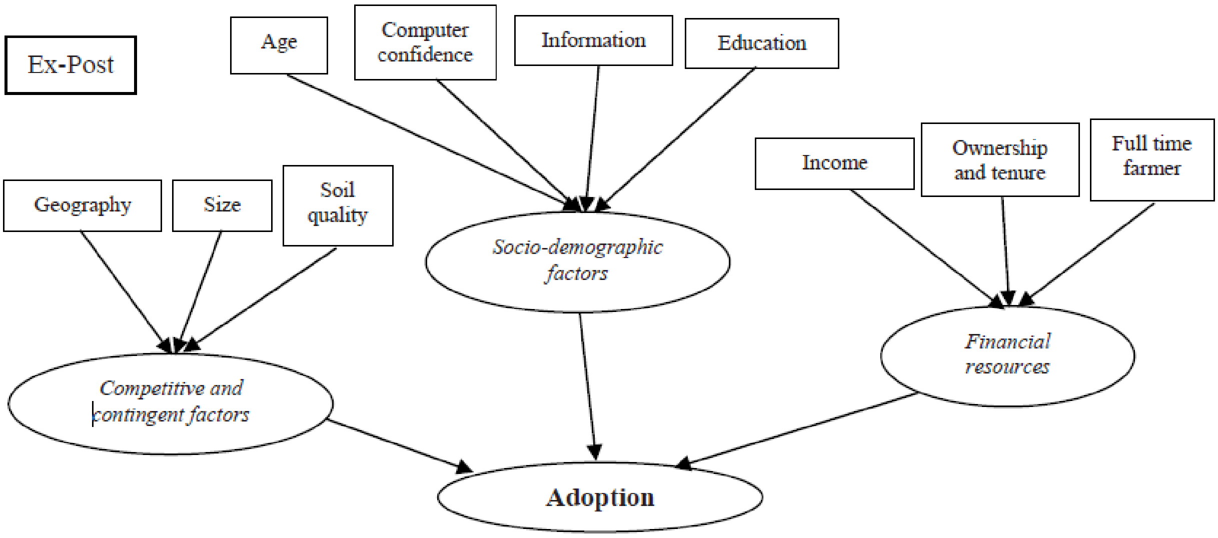

Fig 2.5 Drivers of adoption – Ex-Post (Pierpaoli, Carli et al. 2013)

The primary ex-post factors included farm size, improved cost/benefit ratio, income, land ownership, education, computer literacy, access to information and advice on technology and location. Age was found to have a variable effect on adoption. In some cases young farmers were seen to adopt more, in some cases there was no correlation and in other older farmers were found to be the strongest adopters.

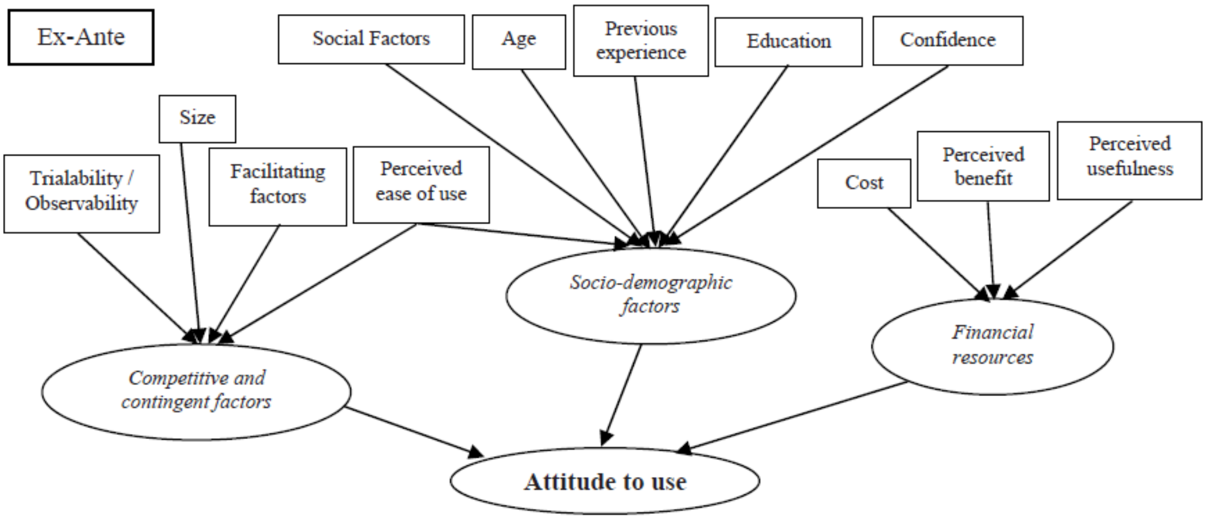

Fig 2.6 Factors affecting attitude to adopt – Ex-Ante (Pierpaoli, Carli et al. 2013)

The main ex-ante factor identified by the literature review was increased profitability. Secondary factors included ease of use, low perceived cost and bigger and more profitable farms are more likely to adopt.

The adoption of new technology and management systems in general by Irish farmers has traditionally been low with cost and complexity making such investments only suitable for large-scale operations (Teagasc 2016). There is a lot of available literature on factors affecting the wider adoption of IoT and the adoption of IoT methods to the agriculture supply chain (Lin, Lee et al. 2016) and (Ramundo, Taisch et al. 2016) but not to the primary agriculture segment.

Many studies that do look at adoption of Agri-IoT systems by the primary farmer are focused on large scale American operations, findings from these studies are useful but cannot be directly applied to the smaller Irish farm context.

For example Banerjee, Martin et al. (2008) looked at the adoption of GPS guidance, section control and Auto-steer for cotton farmers in America but no such studies have been done on Agri-IoT technologies in Ireland. His findings indicate prior usage of technology on the farm as a strong indicator of future use. Farmers with large farms, high yields or young, affluent farmers were also more likely to adopt. College education was not correlated with use. Similarly Velandia, Edge et al. (2016) looked at Automatic Section Control (ASC) with automatic guidance on cotton farms in Tennessee. ASC is a variable rate application technology, targeting only specific areas of a field for treatment. The study found that younger farmers and farmers with larger farms were more likely to adopt ASC with AG.

Research from (Lima, Hopkins et al. 2018) discusses the adoption of electronic identification technology by commercial sheep farmers in England and Wales. Only 87 out of 406 farmers had adopted the technology. It identified three factors blocking the acceptance of the technology in the farming community. These were:

- External pressure and negative feelings
- Usefulness
- Practicality

No studies were found on adoption of IoT technologies by Irish farmers however Howley, O. Donoghue et al. (2012) studied whether farm characteristics influenced Irish farmers decision to use artificial insemination (AI) technology. They used a 15 year dataset from the Irish National Farm Survey. Cost was the primary barrier to adoption, older farmers and part-time farmers were also less likely to use AI. Farmers with higher gross margins or ones that participated in a farm advisory programme such as Teagasc were more likely to use the technology.

3 Methodology and Fieldwork

3.1 Introduction

This chapter describes the research design for this study. It outlines the main research objective and describes the related sub questions that impact on our understanding of the objective. It explains the research methodology chosen to structure the research and to best answer the research question. It details other approaches considered and provides arguments for the final choice. It describes how the research instruments were developed, from what sources data was taken and how the data was analysed. It also summarizes the lessons learnt during this process and clarifies some of the limitations uncovered during the design and implementation of the methodology.

3.2 Research Questions and Objectives

The primary objective of this research is to gain an understanding of the factors affecting the adoption of Agri-IoT farming in Ireland. The emerging Agri-IoT industry is multi-faceted and the dynamics advancing and hindering its adoption are expected to be both complex and varied across agricultural sectors. Results are expected to detail these opposing forces and describe how they are acting on the different agricultural segments.
Secondary areas of interest for this research are to:

- Explore the Agri-IoT technology currently available to Irish farmers
- Gauge Irish farmer's awareness and attitude towards Agri-IoT
- Determine the current level of Agri-IoT use in Ireland
- Develop recommendations on how Irish agriculture can maximise the benefit from this new technology in the future.

3.3 Research Methodology

3.3.1 Philosophy

A research philosophy can be used to provide direction for the research study. Two research philosophies were considered for this study, that of positivism and interpretivism. Positivists believe in an observable objective reality and search for regularities and causal relationships in data to create law-like generalisations (Gill and Johnson 2010).

Interpretivists believe that reality is socially constructed, that data collected from humans represents the participants interpretation of the world and its collection is also subjected to the researchers own experience of reality. This reality is also constantly being shaped and changed by the interactions of humans.

Pragmatism asserts that concepts are only relevant where they support action (Kelemen and Rumens 2008). It accepts that there are multiple ways in which reality can be understood and that the most important perspective is the one that helps to answer the research question. Pragmatism allows the use of both quantitative based positivism to analyse objective survey results and an interpretive philosophy to make sense of subjective, socially constructed meanings involved in semi-structured interviews. This study adopts the research philosophy of pragmatism as the best way to answer the research question.

3.3.2 Approach

With a deductive approach data is used to test a theory, in other words the research moves from theory to data. Technology Acceptance theory was used to guide the design of the survey however the point of this research is not to validate this theory but rather to focus on gaining new insight on farmer adoption issues.

With an inductive approach data is used to develop theory. In other words the research moves from data to theory. In this study the research data will be used in conjunction with studied technology acceptance theory to identify the factors affecting the adoption of Agri-IoT adoption in Ireland, in a way this is formulating a new theory on Agri-IoT adoption in Ireland. We can say this study will use inductive inferences to answer the research question.

An abductive approach moves back and over between the two, data is used to develop a theory and the theory is then tested with data. Topics about which there is a wealth of information in one context but far less in the context being researching may lend itself to an abductive approach enabling the researcher to modify an existing theory (Saunders, Lewis et al. 2012).

3.3.3 Methodological Choice

A full literature review of both academic and industry sources was performed to understand the current body of knowledge gathered on the topic. However, to discover the factors affecting the adoption of this technology it is necessary also to ask the users, the farming community themselves. This requires primary data collection techniques.

As there was little prior research available on Agri-IoT a survey strategy was selected to allow the widest reaching collection of data possible. The survey involved a combination of objective and subjective questions. Objective attributes such as farmer age and farm size were requested along with questions on the subjective personal perspective of the farmers, such as opinions and attitudes to the new technology. As discussed by Saunders, Lewis et al. (2012) a distinction needs to be drawn between quantitative hard numbers and data based on opinions, sometimes referred to as 'qualitative numbers'. The survey collects both factual attributes of Irish farmers and their descriptive opinions on Agri-IoT.

A quantitative survey is very useful to gather facts and objective data but other factors such as attitudes and perspectives on technology adoption can be hard to collect in such a manner. A follow-up interview with survey participants was also selected as a second phase of primary data collection. This was used to expand and enrich the data collected in the survey and allow further exploration of factors highlighted by the wider reaching survey. This study then uses a mixed methods approach combining a quantitative survey with qualitative semi-structured interviews. Data collection involves two sequential phases, the first phase is a quantitative survey followed by a qualitative interview phase. As this is quantitative research followed by qualitative research it is known as a sequential explanatory research design. There are four criteria defining how the quantitative and qualitative components are mixed in the research. These are mixing stage, level of integration, timing and relative status. This study can be defined to be using a partially integrated, double phase and sequential mixing method.

3.3.4 Strategy

Initially an experimental strategy to study Agri-IoT in action on a farm was envisaged. However after consulting with IoT network providers and reviewing the available hardware/software options this was deemed to require more time to setup than the masters research timeframe provided and also would have resulted in a limited understanding of the wider topic given its focus on a particular device's performance in a specific farming sector.

Another approach considered was a case study strategy as this would allow an in-depth analysis of the wider national Agri-IoT picture. Although there are volumes of research on the development and application of IoT in a general sense, the body of knowledge available on IoT in the agricultural industry is relatively underdeveloped. Likewise while there are a lot of studies surrounding technology adoption generally, little prior research was found on technology adoption by farmers and even less on the adoption issues surrounding emerging technology like Agri-IoT in the Irish context. Given the lack of secondary data available on the specific topic of Agri-IoT in the Irish context a case study strategy was also ruled out.

While some insight was gained by initial informal conversations with interested parties and industry experts, a wider view of the situation on the ground was missing. A survey strategy was seen as the best option to assess the situation under the time and resource constraints imposed by a part-time postgraduate study. It is acknowledged that a depth of understanding is a penalty of such an impersonal quantitative survey approach. Follow-up semi-structured interviews were seen as a way to mitigate this.

Survey participants were Irish farmers known to the researcher, email distribution groups such as Macra na Feirme and online farming community groups such as boards.ie Farming & Forestry and Facebook's Irish Farming Discussion Group. Farmers known to the researcher were also asked to invite other farmers to participate. This is a non-probability sampling method known as snowball sampling.

The survey was developed on the Qualtrics platform. It consists of 28 Yes/No, multi-choice, ranking or Likert scale questions. There was one open-ended question. The survey contains logic to separate participants into different question streams based on whether or not they use Agri-IoT devices. It is expected to take between 10 and 15 minutes to complete on either smartphone or computer.

3.4 Research Instruments

3.4.1 Survey

From the literature review it was identified that attributes such as farm size, farmer age, internet access etc. could be determinants for Agri-IoT use. It was decided to pose these as questions in the online survey. Some ethical questions were raised over privacy and a compromise on data granularity and ethical considerations was found. This resulted in for instance, age brackets being used instead of specific age and farming county instead of exact farm location. A review of the established Technology Acceptance theory also lead to questions being designed to uncover attributes such as performance expectancy, effort expectancy, social influence and facilitating conditions. Questions were also included on farmer's awareness of Agri-IoT as an emerging technology. One open ended subjective question allowing the farmer to express any other thoughts on the matter was also included. Care was taken to express questions unambiguously and without bias.

Checks were also incorporated into the survey to exit if a participant did not agreed to the presented consent terms or was not a fulltime or part-time farmer.

The questions developed for Agri-IoT users versus non-users were of a different nature so a fork was developed in the survey to separate these two streams once this was identified.

The survey was tested for readability and clarity by friendly users before being sent out to participants. Feedback from this stage highlighted confusion over the new term Agri-IoT. Although it was outlined in the participant information at the start of survey, users often skipped over this. An extra paragraph was included just before the question on whether or not the participant was an Agri-IoT user or not. This provided the required clarity just as the participant needed to decide.

The last question of the survey asked participants if they would be willing to answer further questions on the topic as part of a follow-up phone interview. If the participant answered ‘Yes’ they were directed to a form to fill out their name and contact phone number. Otherwise they were thanked for their participation and exited the survey.

3.4.2 Interview

A follow-up semi-structured interview was prepared to further explore the factors highlighted in the survey. A semi-structured interview is non-standardised and the exact flow can vary from interview to interview dependent on the participant. Six leading questions for Agri-IoT users and six for non-users were prepared.

For Agri-IoT users the questions involved:

- A description of Agri-IoT devices used and
- Reasons for investment,
- Expectations versus reality,
- Benefits and drawbacks
- Degree to which they would recommend to friends
- Hopes for future development

For non-Agri-IoT users the questions sought to determine:

- Reasons for not investing
- Availability of information on topic
- Internet access concerns
- Thoughts for future investment

- Thoughts on the industry in general using this technology
- Hopes for future development

Once the online survey was completed the total number of candidates for phone interviews was collated and divided into Agri-IoT users and non-users. Due to time limits it was felt six candidates, three selected randomly for each group, would be interviewed. This would provide a balance between the two perspectives.
One of the benefits of mixed methods research is the ability to use the different streams of primary and secondary data to triangulate the results thereby ensuring consistency in the research conclusions.

3.5 Ethics

As the farmer survey and interviews required human participation, ethical approval for both had to be sought in advance from Trinity's ethics committee. A research proposal outlining the academic rational for the research and the methodology to be used was created. Also participant information and consent sheets were developed and submitted along with the online survey and interview questions. The survey developed ensured participant anonymity, no personally identifiable information was collected such as name, address or IP. Also no sensitive information was requested such as income or exact farm size. All survey and interview participation was voluntary and participants were advised that they could withdraw at any time. The full ethics pack was reviewed and signed off by the research supervisor in advance. The application form with required documentation was submitted for ethical approval to the School of Computer Science and Statistics Research Ethics Committee (SCSS REC) online application website on Jan 25th. The initial REC review on Feb 2nd requested two minor amendments involving clarification on interview recording and removal of a redundant warning on epilepsy. A corrected application was resubmitted Feb 5th and full ethical approval was granted on Feb 23rd.

3.6 Analysis Techniques

Once the survey collection was completed on Monday May 7th the data was imported into SPSS for analysis. Results were interpreted visually via clustered and stacked bar charts. This highlighted the main attributes and demographics of the surveyed population. Results for various attributes were contrasted between Agri-IoT and non Agri-IoT users. Spearman's rank-order correlation was used to identify any associations between Agri-IoT use and a range of farmer attributes such as age or farm type. The multiple response nature of Likert table questions such as Q15 also required specific SPSS multiple response variable functions for analysis.

Although all survey data was anonymised, the county level location of participants was coded and displayed visually on a map through PowerBI. This confirmed a broad, nationwide distribution of the online anonymous survey.

The data was also processed in Excel to visualise the % difference seen in advantages and disadvantages for Agri-IoT users and non-users.

3.7 Lessons Learned

Difficulties accessing farmers and securing their attention and time to conduct the survey meant the level of effort required to accomplish that was underestimated within the limited resources available to a part-time study.

There were initial difficulties describing the emerging technologies, such as LPWA communications, clearly in the survey. Relevant examples of the technology proved much more useful that technical jargon.

Feedback from survey participants included complaints about excessive information at the start of the survey which was off putting or demotivation. This is likely to have lowered the survey participation rate.

Development of surveys can be difficult without prior experience of implementation, data analysis or categorisation and the write up process. The learning curve is steep.

It can be hard to strike a balance between asking enough questions to answer and verify your research question and not put too much burden on your survey and interview volunteers.

3.8 Research Limitations

The snowball sampling method used by this study does not allow results to be projected on the general farming population.

It had been hoped more candidates, both Agri-IoT users and non-users would agree to follow-up interviews. However of the 112 survey participants, only six provided the necessary contact information and only four were available to complete the interview. Of these four, three were Agri-IoT users and one was a non-user. This biased the available interview information towards the experience of Agri-IoT users and limited the insight gained from the non Agri-IoT perspective.

4 Findings and Analysis

4.1 Introduction

This chapter will discuss the main findings and analysis from both the survey and interview stages of this study. First a summary of the survey execution is given with participation totals and initial data analysis. This is followed by a review of the demographics identified in the survey population. The third section provides an assessment of the survey findings under the UTAUT criteria detailed in the literature review. Finally the chapter looks at the interview execution and details findings from both using and non-using Agri-IoT farmers.

4.2 Survey Execution

The survey was distributed on Monday March 19th using an anonymous Qualtrics web link in email, WhatsApp groups and via posts on online forums. The survey was closed to responses on Mon 7th May. The results were extracted from the Qualtrics platform in SPSS .sav format and imported into SPSS for further analysis. 112 responses in total were received. Three participants did not fit the survey criteria outlined in the initial questions, they were thanked for their participation and were automatically exited from the survey. A further thirty participants completed the survey but had various levels of incomplete information, these were removed during the initial analysis. This left seventy-nine valid responses to be analysed. Some recoding of variables had to be performed such as Likert scales not using integers 1-5 and counties entered in the free text field without capital letters or with spaces included. Of the seventy-nine valid responses 32 were Agri-IoT users with 47 non-users. The data was also processed in Excel and PowerBI for visualisation and spatial analysis.

4.3 Demographics

To understand the significance of survey data relating to the Agri-IoT adoption factors it is important to first understand the demographics of the survey population. The data is analysed through three criteria:

1. Age, Location and Farming Type
2. Farm Type and IoT device

3. Farm size

4.3.1 Age, Location and time spent farming

Due to the snowball sampling method and the nature of the online survey a wide distribution was achieved across the country. There is some skewing of responses towards the denser farming areas of the south and south-east.

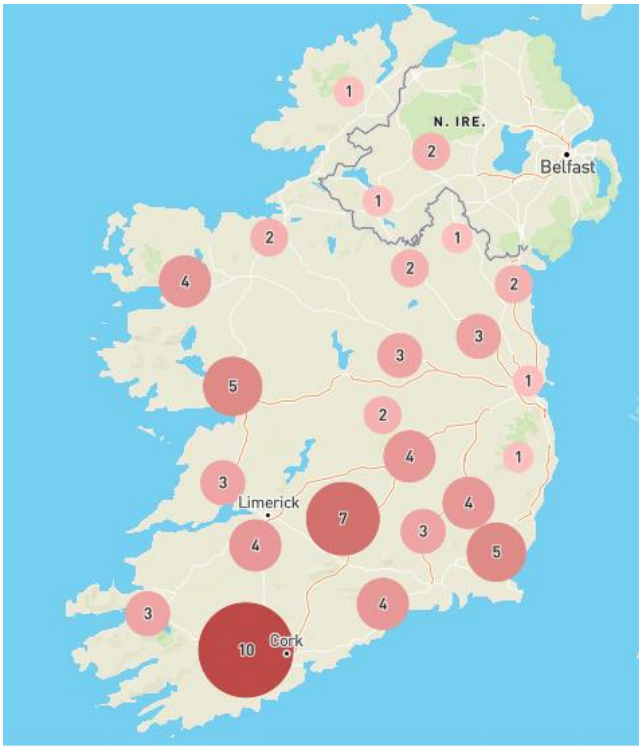

Fig 4.1 Location of participants who completed the survey

The 2013 Farm Structure Survey published by the Central Statistics Office (CSO 2013) showed 73,300 or 52.7% of farmers were over the age of 55. However the respondents to this study's online survey were predominantly in the younger 25-40 bracket. This is due to two factors, farming friends of the researcher who were asked to complete the survey are in this bracket and likewise friends of theirs also fit this demographic. Secondly the survey was posted to online farming discussion forums which are more likely to be used by younger, more technology capable farmers. It is also interesting that a much larger number of farmers in the 25-40 bracket are part-time farmers. In all other brackets fulltime farmers either equal or exceed part-time farmers.

The online distribution method enabled a broad distribution but limited the survey to a smaller segment of farmers. To conduct the survey on the ground or with posted surveys would be beyond the time and resource limits of this study. It is likely that the 25-40 year old online farmer demographic does have more knowledge of Agri-IoT but as this survey is attempting to identify both the drivers and barriers of the technology this is beneficial. Also it can help to identify what the younger generation of farmers will do with this technology in the coming decades. It is acknowledged however that the results from this study cannot be generalised to the broader, older farming population.

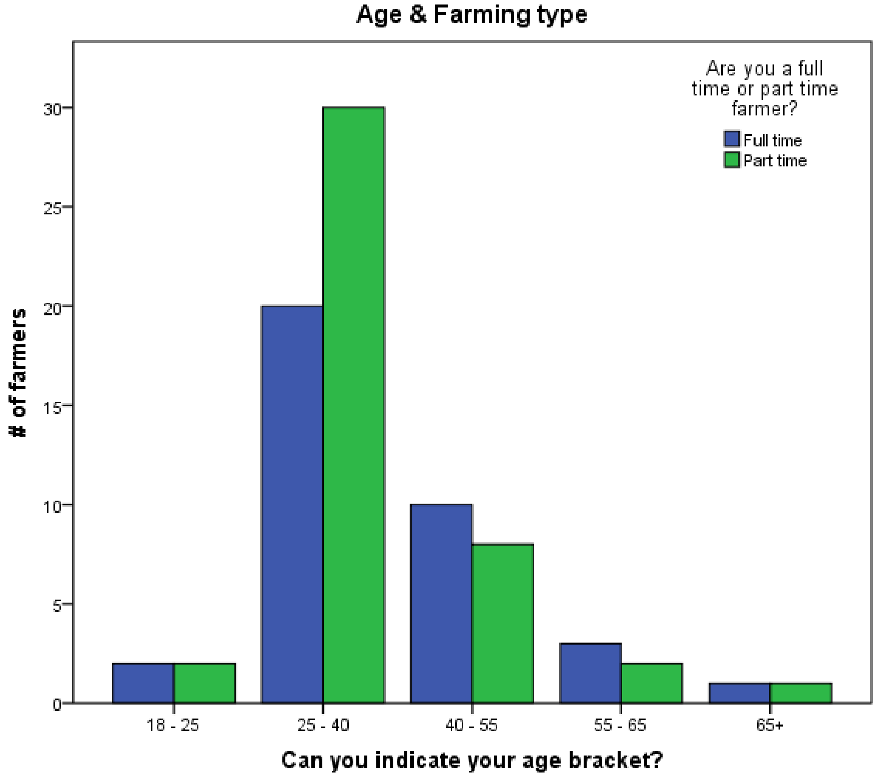

Fig 4.2 Age & Time spent farming

4.3.2 Farm type and device usage

Although Agri-IoT usage is seen across all farm types some sectors have adopted the technology more than other. All six tillage farmers surveyed were using Agri-IoT sensors, particularly temperature sensors but also GPS guidance and security devices. Dairy also has high usage with 45% of total dairy respondents using the widest variety of devices including GPS guidance, tank monitoring, animal health and grass measurement. For both Mixed (Cattle and Sheep) and Cattle categories the calving alert solution ‘MooCall’ and GPS guidance systems were prevalent although the overall penetration rates for Agri-IoT in these categories was lower at 42% and 31% respectively.

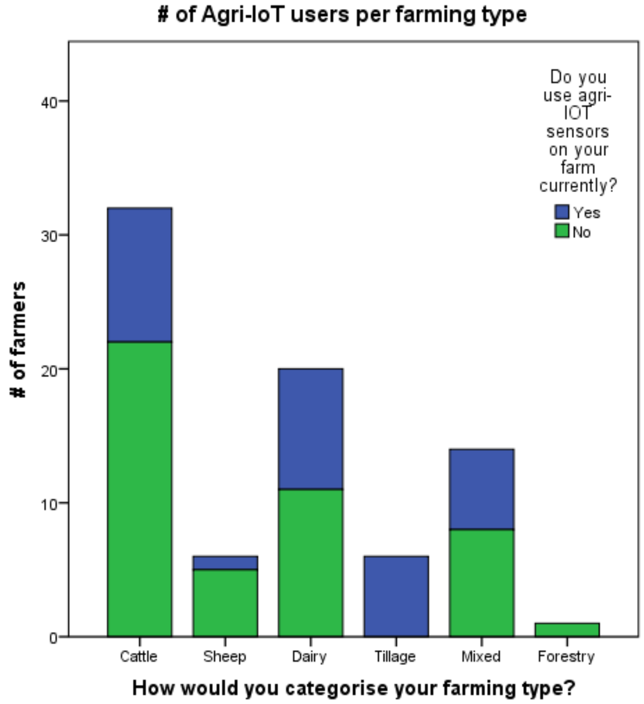

Fig 4.3 Number of Agri-IoT users per farming type

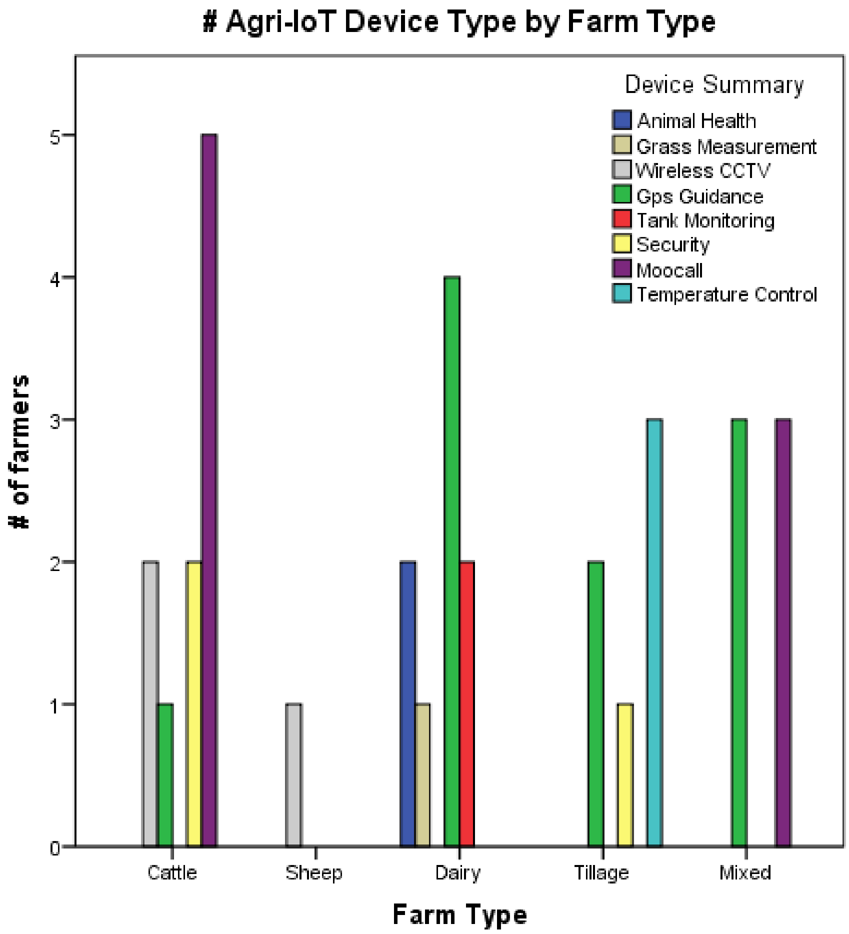

Fig 4.4 Agri-IoT Device type by Farm Type

4.3.3 Farm size

From the literature review it was expected that farm size would play a role in determining Agri-IoT usage and this carries through in the survey results with 67% of farmers on farms greater than 250 acres using Agri-IoT compared with only 27% of farmers on farms less than 40 acres. The correlation between farm size and Agri-IoT use is statistically significant using Spearman rho and is negative in sign indicating that as farm size grows Agri-IoT tends to go 'Yes' which is coded as a 1. Other factors such as full or part time farmer, farm type, farmer age or internet speed were not shown to be a determinant of Agri-IoT usage. However other participant attributes such as familiarity with Agri-IoT technology and social interactions regarding Agri-IoT correlate significantly with Agri-IoT usage.

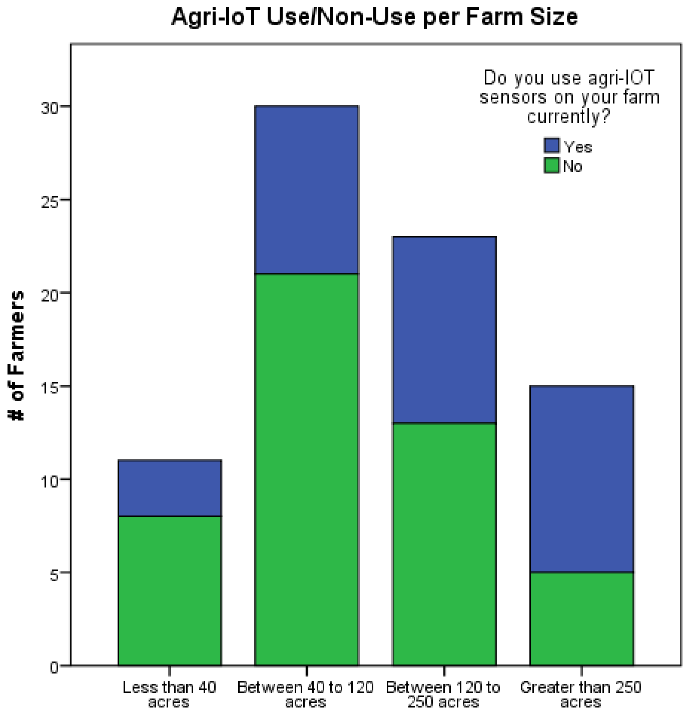

Fig 4.5 Agri-IoT use/Non-use per Farm Size

Correlations

		Can you give an indication of your farm size?	Are you a full time or part time farmer?	Can you indicate your age bracket?	How would you categorise your farming type? - Selected Choice	Are you happy with the speed of the internet available on your farm?	How familiar are you with the usage of agri-IOT sensors on Irish farms?	In the past 3 months how often did you hear people talking about agri-IOT sensor usage on Irish farms?
Spearman's rho	Do you use agri-IOT sensors on your farm currently?	-.268	.073	-.080	-.184	-.113	.625	.660
		.017	.520	.484	.105	.323	.000	.000
		79	79	79	79	79	79	79

Fig 4.5 Correlation of farmer attributes versus Agri-IoT use

4.4 Agri-IoT Adoption Factors

4.4.1 Performance Expectancy v Performance Experience

One of the strongest motivators for new technology adoption identified by Venkatesh's UTAUT model was performance expectancy. This is defined as the degree to which an individual believes that the system will help him or her to attain gains in job performance. Agri-IoT device users were asked to identify the top three advantages from their on-the-ground Agri-IoT usage experience, this is termed performance experience. Non-users were asked to list what they perceived as the top three advantages of Agri-IoT usage, this will be listed as performance expectancy. The figures below are the percentages of all user or non-user farmers that gave that category as an advantage.

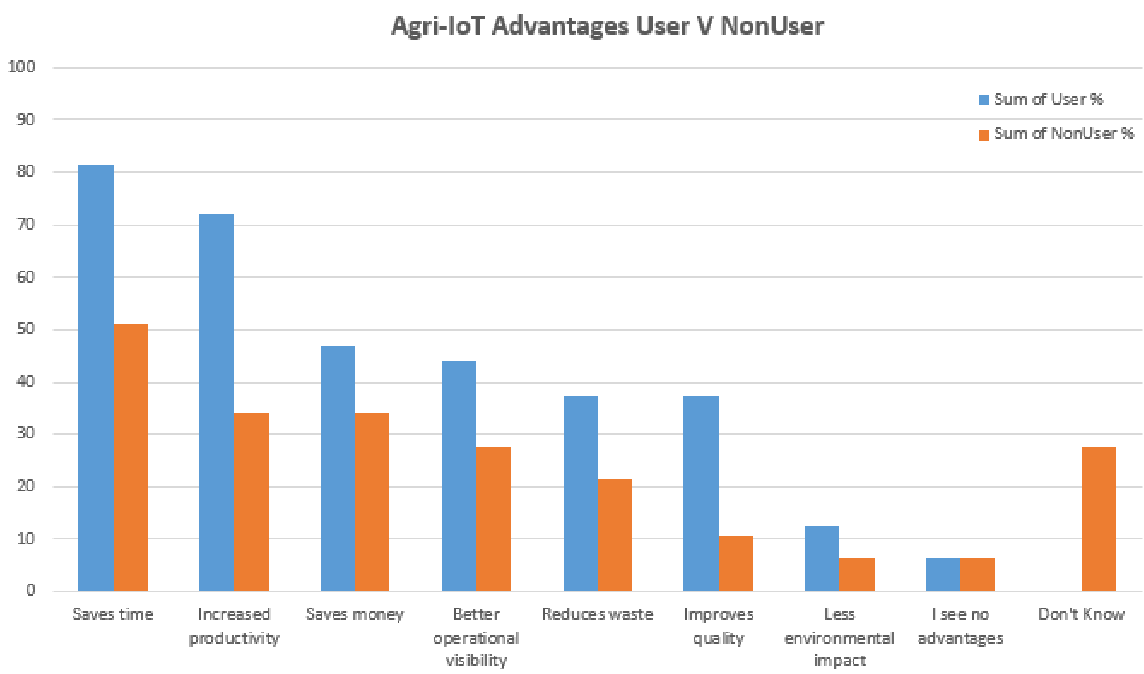

Fig 4.6 Agri-IoT Advantages User V Non-user

Saving time and increasing productivity were listed as the two biggest advantages of Agri-IoT by active users with 80% of all Agri-IoT using farmers listing time saved as an advantage and 72% also stating increased productivity. In general non-users have much lower expectations of Agri-IoT performance, scoring lower on all categories. Two categories show a clear separation between performance experience and performance expectancy. Over 70% of users see increased productivity as an advantage of Agri-IoT devices while only 35% of non-users would expect the same. Likewise 38% of users listed improved quality as an advantage while only 11% of non-users would expect this as an advantage. It is also clear that a major barrier to adoption of the technology is under informed farmers, with 28% of non-users stating they didn't know what the advantages of such technology would be.

4.4.2 Effort Expectancy v Effort Experience

The second primary motivator for technology adoption outlined by Venkatesh's UTAUT model is effort expectancy. This is defined as the degree of ease associated with the use of the system. Agri-IoT device users were asked to identify the top three disadvantages from their Agri-IoT usage experience, this can be viewed as effort experience. Non-users were asked to list what they perceived as the top three disadvantages of Agri-IoT usage, this will be listed as effort expectancy.

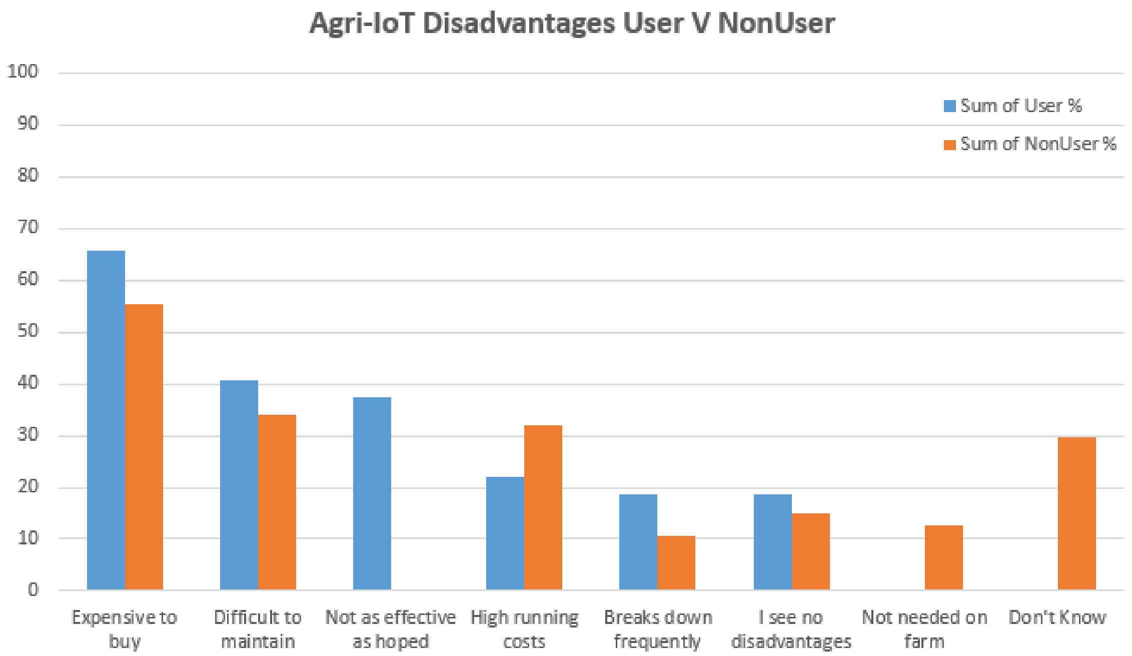

Fig 4.7 Agri-IoT Disadvantages User V Non-user

'Expensive to buy' was the main disadvantage given by both users and non-users with 66% of Users and 55% of non-users listing this as a disadvantage. With marginal profit margins especially on smaller scale Irish farms this is a significant real and perceived barrier to adoption of the technology. The expected and experienced effort to maintain Agri-IoT systems is quite closely matched with a substantial 40% of active users giving this as a disadvantage highlighting a need for simpler and more robust Agri-IoT systems but also for farmer training in how to operate and maintain this new technology. High running costs is expected to be a disadvantage by non-users to a greater extent than reported by actual users indicating a perceived barrier that may not actually be as much of a problem as thought. A large number of active users express a disappointment with their

Agri-IoT system not being as effective as hoped, this can be down to a combination of technology hype, newly developed immature platforms and over selling of system capabilities by sales teams.

When non-users were asked specifically why they hadn't yet bought an Agri-IoT device they largest response cited lack of information regarding the technology following that non-users indicated not needing such a system but also waiting for them to improve.

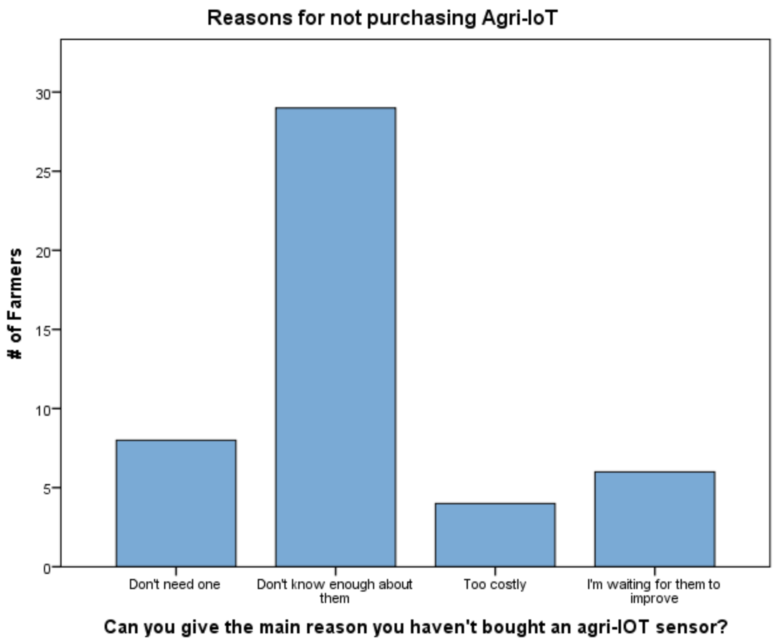

Fig 4.8 Reasons for not purchasing Agri-IoT device

4.4.3 Social Influence

Social influence is defined as the degree to which an individual perceives that important others believe he or she should use the system. From the survey data it's clear that Agri-IoT users have far more interactions with others about Agri-IoT technologies than non-users. A significant 75% of active users state hearing others talking about Agri-IoT devices "a few times" to "very often" in the last three months while 89% of non-users only heard people talking about Agri-IoT "Once or Twice" or "not at all" in the same time period. This is also bore out statistically with frequency of social interactions regarding the technology a significant determinant of Agri-IoT use.

In turn Agri-IoT users are very likely to recommend the use of such devices to friends with 78% "extremely likely" or "somewhat likely" to recommend such devices to friends.

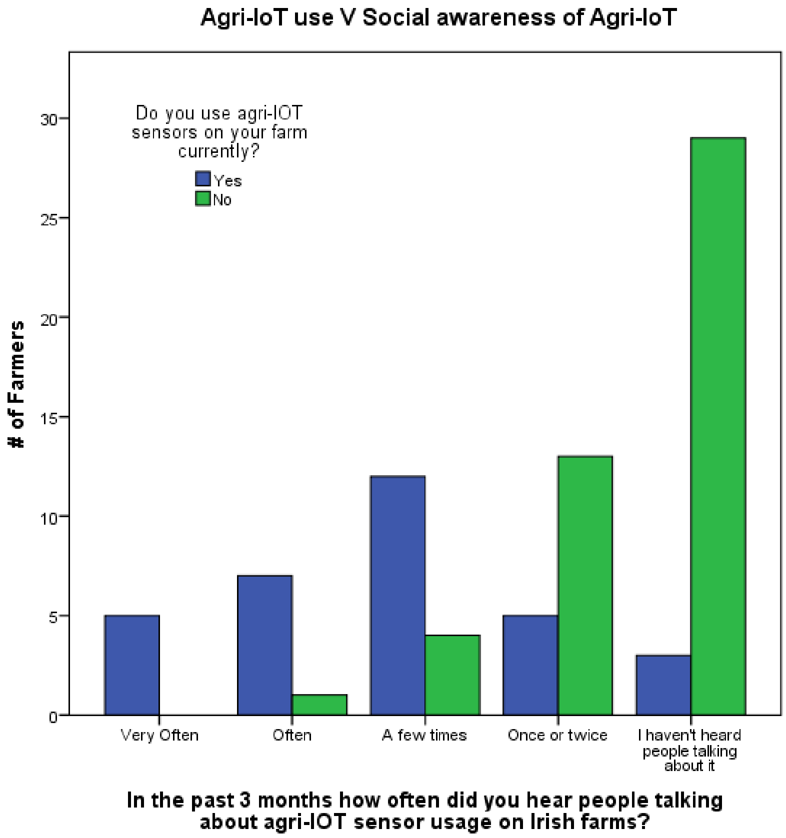

Fig 4.9 Agri-IoT use V Social Awareness of Agri-IoT

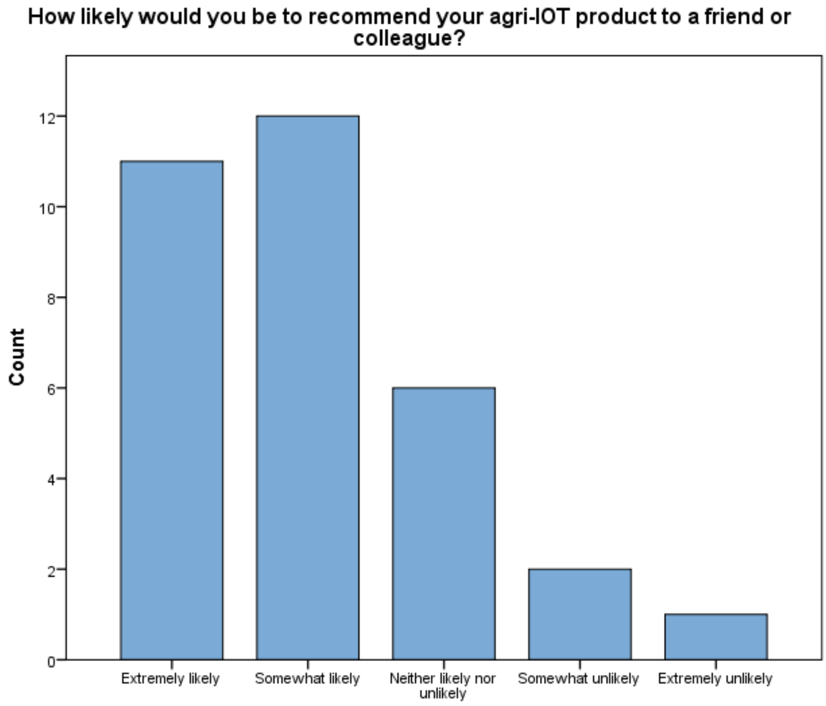

Fig 4.10 Likelihood of recommending Agri-IoT product to friends

4.4.4 Facilitating Conditions

Facilitating conditions is defined as the degree to which an individual believes that the organizational and technical infrastructure exists to support use of the system.
Agri-IoT systems work over a number of connection mediums but associated Apps, training and support documentation are often only available through regular internet connections. Internet connectivity satisfaction in farmers may drive or hinder the adoption of Agri-IoT. The survey results show the majority of both users and non-users being 'somewhat happy' with their internet connection. At the same time 1 in 5 give a 'Very unhappy' rating which is likely to diminish their overall satisfaction with Agri-IoT.

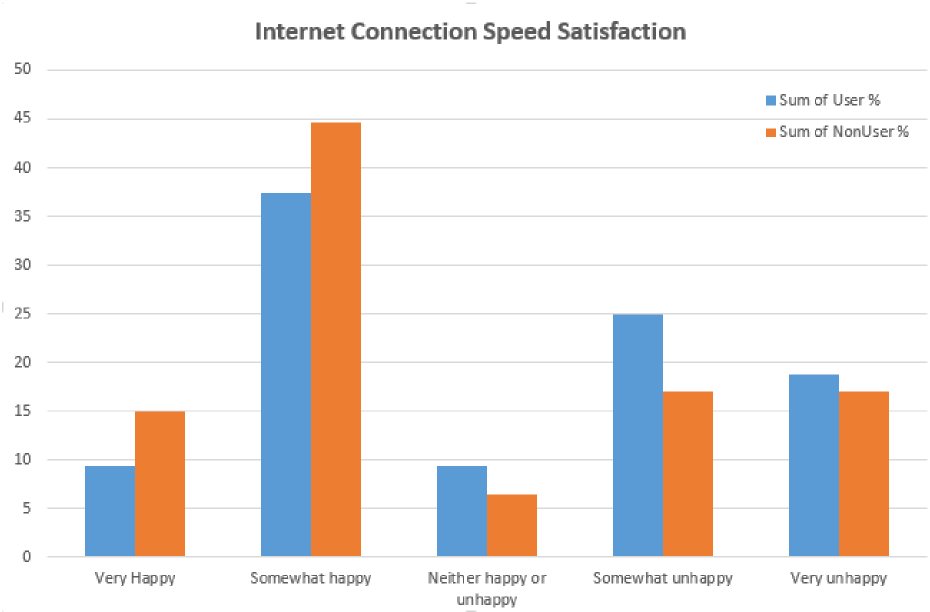

Fig 4.11 Internet Connection speed Satisfaction

The results from the survey show a majority of farmers, both users and non-users feel they don't get enough info on the technology. Any major new technology introduction requires education and training for new users. In companies the benefits of new technologies often have to be clearly demonstrated and then introduced to teams in a well thought out, coordinated manner and any unexpected costs or failings identified and managed. Effectively educating end-users about a new technology is a critical step in technology introduction. This lack of information is clearly felt amongst non-users with 83% stating they probably don't or definitely don't get enough information.

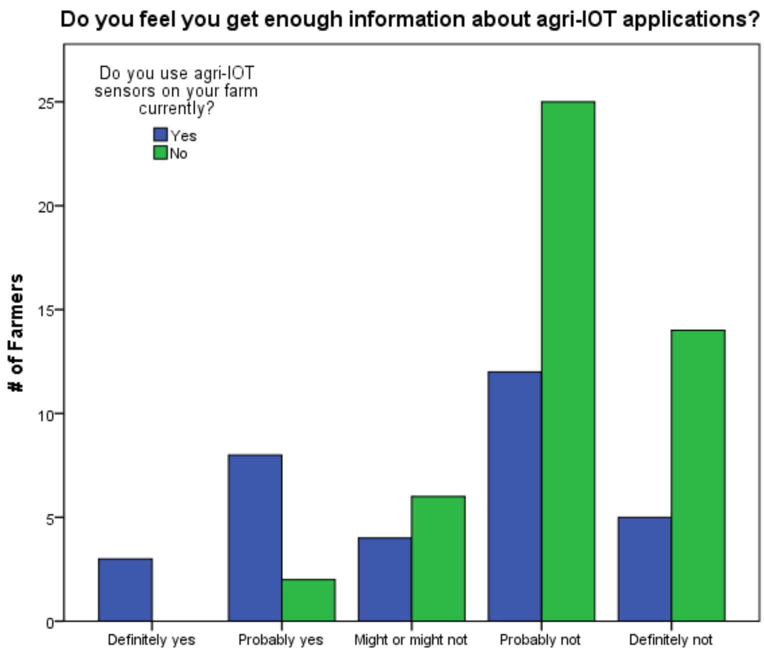

Fig 4.12 Are farmers sufficiently informed about Agri-IoT applications

Survey participants were also asked their thoughts on what they saw developing in this area in the next two years. While current users are more enthusiastic about future developments, farmers overall are expecting better Agri-IoT systems to be available in the future. This is likely to be stalling investment currently as farmers wait for more mature platforms to be made available.

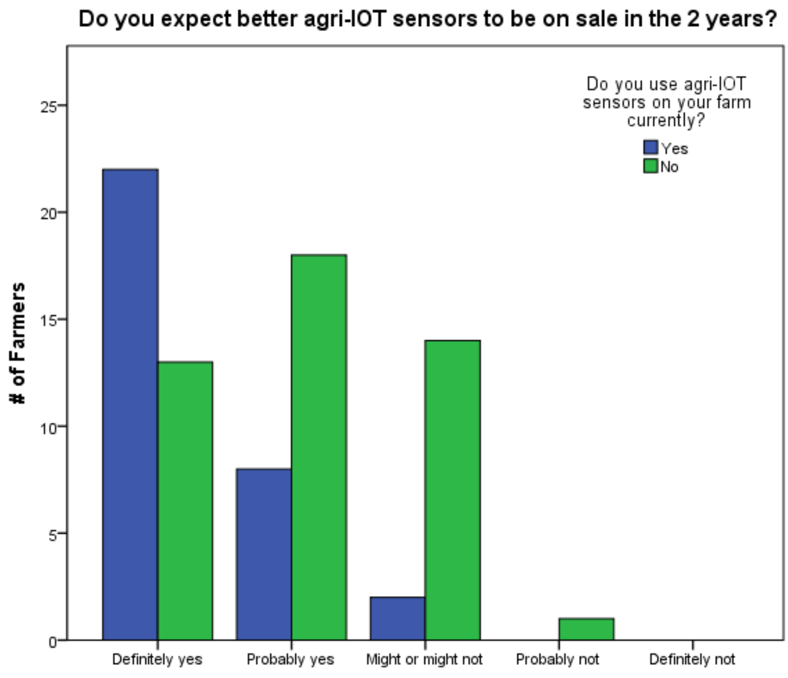

Fig 4.13 Expectation of better products in next 2 years

4.4.5 Moderators

Venkatesh's UTAUT model also details four moderators that influence whether a particular technology is adopted or not. These are age, gender, experience and voluntariness. These moderators are not investigated by this paper. The primary intent of the research is to identify the macro drivers and barriers to technology adoption and not the more subtle impact of the moderators. Also due to the relatively small size of the survey dataset, realistic coverage of gender, age and experience is insufficient to allow interpretable results. The age range of this survey was particularly clustered in the 25-40 age bracket. Also, as Agri-IoT is a new technology, experience may have a negligible impact or would be difficult to accurately measure. As Agri-IoT is an optional technology on farms voluntariness does not factor in this study. Although ~87% of farmers are currently male the differences in technology adoption between male and female farmers would be interesting to study. It is not expected to be a macro driver or barrier to the adoption of the technology however.

4.5 Interview Findings

Six survey participants were contacted for follow-up interviews. Four interviews were completed. The summary details of the four interviewees are listed in table …

Participant	Full/Part-time	Age Bracket	County	Type	Size	Agri-IoT User
A	Fulltime	40-55	Kerry	Dairy	120-250	Yes
B	Part-time	40-55	Waterford	Sheep	< 40	No
C	Fulltime	55-65	Carlow	Tillage	> 250	Yes
D	Fulltime	25-40	Tyrone	Dairy	> 250	Yes

Fig 4.14 Interview participant breakdown

The interviews were conducted over the phone and averaged about 30 minutes in length. Notes were taken by the research during interviews and are given in full in Appendix C.

Six questions specific to users of Agri-IoT devices were asked of three Agri-IoT using farmers. The questions were designed to further explore what Agri-IoT devices were being used, what lead the farmer to adopt the technology and what the experience has been like. Particularly indicative and insight notes from each question are given followed by further analysis of the combined responses.

1. Picking a sensor you use regularly, please tell me what it does and how long you have been using it?

   "GPS guidance in tractor is used to map fields and apply fertilizer in exact quantities. Accurate guidance removes need for manually placing markers on fields for guidance and minimizes wasted fertilizer"

   "I've been using a Sigfox enabled remote temperature sensor to monitor a grain silo for years"

GPS guidance, temperature sensors, weight measurement and security devices were described with multiple Agri-IoT devices being used on two of the farms. All three respondents had been using Agri-IoT devices for some years.

2. What were the main reasons that lead you to invest in the technology?

   "Reduces the manual effort to check grain silo temperature, increases the measurement frequency from fairly infrequently to hourly"

   "More efficient usage of ventilation fans as system is connected to local weather station with defined temperature trigger"

Reducing workload by automating tasks and increasing profitability were the primary drivers to adoption identified.

3. Were your expectations meet?

   "My expectations were exceeded, excellent return on investment"
   "Some initial fluctuations in coverage but were sorted out and has worked well and very consistently since"
   "Commercial products are massively overpriced and will not provide any return on investment, Everything I use I build myself."

The cost/benefit performance of GPS guidance system savings was better than expected and it was noted that incentive schemes such as TAMS should further encourage farmers to adopt. It was clear however that for other system the learning curve was steep and the initial cost for off-the-shelf systems was often too high to fully justify the benefit. Many such systems use subscription based annual charging giving little room for savings over time. It was mentioned that a number of do-it-yourself (DIY) options were available for much lower prices.

4. Does it make farm work harder or easier? If so, in what ways?

> "GPS guidance removes the need for me to manual mark fields for fertiliser spreading while retaining accuracy, saving me time and money"

> "Overall yes it saves time and effort on the farm however some concern that connection fees are going to go up. Sales pitches are often for large scale systems and don't have individual end-users in mind"

Clearly the GPS guidance system proves more accurate, reducing costs and labour. Likewise the temperature sensors and farm security devices provide constant data and confidence while freeing up the farmer to worry about other issues.

5. Would you recommend the product to friends? Please explain your reasons?

> "GPS guidance gives a good return on investment as savings on fertilizer can add up quickly. I would recommend that to anyone I talk to"

> "I would recommend these devices but they can be hard to get used to, system needs to be very robust and easy to operate"

> "I wouldn't recommend commercial off-the-shelf systems. Would be better to train farmers on how to build and operate such systems themselves"

Again the GPS guidance system appears to be the strongest use case, showing a strong reference likelihood. Concerns were expressed about the learning involved for other systems, espicailly the DIY systems. Grappling with the system setup may not be suitable for all farmers' skill sets. Training here would be beneficial.

6. What do you hope to see happen in this area in the future?

   "The addition of automatic tractor steering to GPS guidance will be even more beneficial" "Once farmers start using these devices they won't go back, so likely to see large scale adoption in next few years."

   "New NB-IOT networks to provide better options and pricing schemes"

   "Farmers to become more computer savvy and be able to tailor IoT systems to their specific farm needs.

Automatic tractor steering technology is seen as complementary to GPS guidance. Cheaper and more tailored connectivity options provided by LPWA technologies and NB-IoT in particular will be very useful. Further training and education about computer technologies is a must if the current and next generation of farmers are to benefit from this technology. In general the capabilities of such systems for agriculture need to be explored and developed more in collaboration with primary farmers. The current electronics industry is developing technologies with industry and smart cities in mind and the possibilities for agriculture are not being discussed enough with primary users.

Six questions specific to non-users of Agri-IoT devices were asked of one non-using Agri-IoT farmer. The questions were designed to further explore the reasons for not using Agri-IoT devices. Particularly indicative and insight notes from each question are given.

1. Can you tell me your main reasons for not investing in Agri-IoT sensors?

   "We've a small farm here, in the early years of getting established, focused on just getting the critical things right first, needs time to look through the cost-benefit for systems like these"

2. Do you think there is sufficient information available on these products?

   "Would say no at the moment. Aware of them from the off-farm job. Doesn't see in main stream media. Need to disseminate and communicate to farmers. Not familiar topics with farmers at mart and around the area"

3. Is poor internet access stopping you using these types of products?

   "Signal on phone and broadband dongle here are Ok, but I'd have questions on how well different IoT technologies might perform. Farmer down the road has regular coverage blocked by a hill, so farmers can be lucky or not dependent on location"

4. Do you think you will purchase an Agri-IoT product in the future?
   "As long as I could see the cost-benefit was appropriate for the investment and it saved time yes, but I haven't been convinced of that yet"

5. Do you think Agri-IoT sensors is the right way for farming to go in Ireland?

   "As long as it helps farmers then yes but majority of farmers are not industrial scale operations and justifying the cost versus benefit will be key"
   "Development of devices to early detect animal health issues could be very useful"

6. What do you hope to see happen in this area in the future?

   "I'd like to see the technology developed and used to reduce expensive farm inputs, for example saving water and fertilizer use and reducing the environment impact. Healthy animals, improving work-life-balance and overall workload. Paperwork is constantly increasing for farmers and system that helps farmers automate and cope with that would be welcomed. Including more such systems in TAM would help adoption"

5 Conclusions and Future Work

5.1 Introduction

Combining the results of the survey, interview and literature review this chapter aims to illustrate the factors affecting the adoption of Agri-IoT in Ireland.
The literature review shows that while many studies have been conducted on general IoT in the agri-food supply chain and the sub-category of precision agriculture adoption by primary farmers, little research has been conducted on the factors affecting the adoption of Agri-IoT by primary Irish farmers. It also highlights that there is a complexity in predicting technology usage as there are a variety of farm structures and motivations for adopting such technology. Farmers may be looking to increase profitability, free up time to focus on other activities or increase production quality among others.

5.2 Answering the Research Question

5.2.1 Identifying the adoption factors

This studied aimed to identify the factors affecting the adoption of Agri-IoT technology in Ireland. Having reviewed the current body of knowledge and conducted farmer surveys and interviews the following conclusions can be drawn.

The primary drivers for adoption given by the survey were time savings and increased productivity. These were the top two reasons for experienced farmers currently using the devices and the expected belief of non-users. Saving time and increasing productivity both increase competitiveness highlighting this as a prime motivator for Irish farmers as was identified in the literature review. Non-users also listed saving money as a joint second motivator, possibly highlighting smaller profit margins available to non-user farmers shown to be primarily involved in less intensive cattle, sheep or mixed farm structures which often have tighter margins. Better operational visibility, reduction of waste and improving quality were mid-ranked determinants of adoption, while reducing environmental impact is currently not seen as a major motivator. Regulation and incentive programs such as TAMS II are important factors in encouraging this technology.

The primary barriers to adoption identified in the survey by both users and non-users alike were the purchase cost and difficulty to maintain Agri-IoT devices. These were also

identified by barriers in the literature review, given as cost and robustness. This highlights a common theme running throughout IoT and precision agriculture studies regardless of system or country. Greater cross-over innovation and economies of scale from industrial and smart city ecosystem development should help to drive down component costs and improve robustness for Agri-IoT systems. The national rollout of IoT specific LPWA networks such as NB-IoT should also help reduce the cost of connection per device.
The high number of non-users responding with a 'don't know' answer on both advantages and disadvantage question underlines a major barrier to adoption being communication to farmers on technology capabilities and benefits. Greater efforts will need to be made to up-skill farmers in information and communications technology (ICT) to adequately equip them to deal with these technologies on farms. It is also of note that non-users have a greater belief that Agri-IoT are expensive to maintain than is reported by actual users. Products vendors and agricultural advice staff could look to allay these concerns with potential adopters as it appears to be more belief than fact.
The lack of a return on investment was highlighted frequently in the interviews. Apart from the more established automated dairy and GPS guided fertiliser systems not enough studies have proven the cost/benefit ratio. More work needs to be done to understand the shortfalls and correct. It’s likely also that incentive schemes such a TAMS II will play a major role in initial adoption, allowing economies of scale and the normal market forces to take effect.

Looking at adoption across agricultural sectors, Agri-IoT use was seen to be strongest in the tillage and dairy sectors. These are more capital intensive farming operations, often with larger farms and higher margins. Also global Agri-IoT innovation has focused on these internationally prevalent farm types and there are more established use cases and confirmed cost/benefits ratios. Cattle and mixed farming structures had 42% and 31% Agri-IoT usage rates respectively predominantly in the calving sensor and GPS guidance areas. Only one sheep farmer reported using Agri-IoT this may be explained by the lower margins of that industry and a lack of appropriate use-cases currently for sheep farming.

Farm size is a strong indicator of Agri-IoT use with 67% of farmers on farms greater than 250 acres using Agri-IoT compared with only 27% of farmers on farms less than 40 acres. Spearman’s rho correlation also showed past familiarity with Agri-IoT devices was a strong indicator of Agri-IoT use. Social factors also play a part in adoption with 75% of users having interacted with peers about the topic. In contrast 62% of non-users had not heard people talking about the technology at all. Farming communities are close knit and valid comparisons can be drawn between successful technology applications on nearby neighbour's farms. With 78% of users stating that they would recommend their device to others, this work of mouth advertising coupled with an identified large social influence affect, can be seen as a strong driver for adoption.

Other factors such as full or part time farmer, farmer age or internet speed were not shown to be a determinant of Agri-IoT usage

5.2.2 Describing current Agri-IoT usage

An objective of the study was to ascertain Agri-IoT usage rates in Irish agriculture, the survey results showed 32 users or 40% of the total were actively using some form of Agri-IoT. This figure is likely to be higher than the national figure however given the bias effect of an online survey.
Another aim of this research was to explore the types of Agri-IoT systems currently being used by Irish farmers. The survey highlighted a broad array of devices in use. For tillage farmers, temperature sensors, GPS guidance and farm machinery security were the primary selections. Dairy farmers reported a wide variety including GPS guidance, tank monitors, animal health and grass management systems. Calving alert systems and GPS guidance were the most prevalent in mixed and cattle categories. Use of Agri-IoT was low for sheep farmers with only one sheep farming reporting wireless CCTV monitoring.

5.2.3 Recommendations on realising Agri-IoT benefits

This study highlights that ROI for Agri-IoT is a clear barrier to adoption. Incentive programs such as TAMS II and collaborative platforms such as DAFM's public agricultural IoT platform can go some way to encouraging adoption. However further mechanisms to mitigate this lack of confidence require further investigation.
As discussed in the literature review farmers appreciate in-field demonstrations as they promote the perception that the use of a technology is easy.
Inter-operability issues must be straightened out as the simplicity and compatibility of different devices used by farmers is of paramount importance to successful adoption
Agri-IoT devices must provide a benefit to the farmer but should be based on a low-cost and a low-performance technology.

5.2.4 New or Interesting Findings

Usage of calving monitors higher than expected in the surveyed population. An example of effective technology, suitably simplified for farmer operation and cost/benefit performance clearly communicated to end-users.
LPWA technology already in use by tillage farmers, the increased coverage and reduced connection cost of the Sigfox enabled VT Network providing suitable agricultural solutions.

5.3 Advancing Current Knowledge

Research has been conducted into the factors affecting the adoption of IoT in the agricultural supply chain and into how precision agriculture techniques are being adopted by large scale American and Chinese farms but no research has looked at the factors affecting the adoption of the broad range of Agri-IoT technologies by the primary Irish farmer. This research advances the current state of knowledge by highlighting the particular cost sensitivity of the industry here given the smaller average farm size and lower average operating margins. It also shows a gap in the communication of the abilities of the technology to farmers. As adoption is primarily based on cost/benefit analysis efforts to reduce the upfront costs through innovation, incentives and financing arrangements along with education and demonstration of the technologies capabilities will help to increase the adoption rates.

5.4 Research Limitations

Given the resource and time limitations of a part-time dissertation it was not possible to survey a broad enough population to statistically generalise the results. Although the attitudes and perceptions of 79 farmers spread across the country gives important insight to the topic and certainly highlights the major drivers and barriers to adoption it cannot be assumed that the findings can be assumed to be relevant for Irish farmers or farm types. While many themes will remain similar, given the specific area of focus of this study, the results are not likely to be generalizable to the broader EU or global environment.
The snowball sampling method also led to a clustering of survey participants in the 25 – 55 range precluding insights from the large and important segment of Irish farmers over 55. As Agri-IoT is really in its infancy however it can be said that the thoughts and perceptions of the up and coming farm generation will be the generation that will really need to deal with the topic

The distribution of the survey online also gives a bias towards more computer savvy farmers, possibly biasing the results towards Agri-IoT users as previous research from Pierpaoli, Carli et al. (2013) showed familiarity with computer technologies was a pre-determinant of new technology adoption. This bias in itself however points to a barrier factor and increasing computer literacy in Irish farmers is likely to increase Agri-IoT adoption.

5.5 Future Research

This study was aimed at all farm types but no responses were received from the intensive pig, poultry or horticulture sectors. While a much smaller segment of Irish farmers are involved in such areas, Agri-IoT is also likely to play a big role. It would be beneficial to study the particular forces at play for these areas.
A study of the factors at play for IoT adoption in agriculture related fields such the Forestry and Fishing sectors would be useful. These sectors have an important role in Ireland's rural economy and could benefit from the capabilities of such technology.
It was not looked at specifically by this paper but with 13% of farmers in Ireland being female, it would be interesting to study the gender difference in technology adoption.
This paper only had the opportunity to interview one non Agri-IoT user. It would be very interesting to explore the various reasons for not using the technology in more depth with this category of farmer.
A nationwide survey of Irish farmers utilising probability sampling methods would provide generalizable results that could be very beneficial to map out the requirements for this technology in the years ahead.
This study has looked at the factors affecting Irish agriculture as a whole but the differences between the different sub-sectors of Irish agriculture are apparent. Future work should look at the particular technological options and adoption factors at play in the various fields.

5.6 Summary

Technology is advancing at an ever increasing pace and major developments in technology will have a huge influence on the agricultural process. The last 30 years have seen genetically modified foods, automated milking, electronic tagging and crop spraying drones. Climate instability, growing populations and concerns over the environmental impact are demanding a major shift in agriculture. A focus on yields and cost is being replaced with sustainability, environmental concern and quality control. Agri-IoT technologies have the capability to bring the required scale and intensification to agriculture while maintaining the detailed care and precision control needed to ensure animal welfare and control inputs.

As the technology matures the smart devices become everyday farm hands, constantly vigilant and precise in their work, operating quietly in the background with minimal effort by farmers to maintain. As Mark Weiser said in his book 'The Computer for the 21st Century', the most profound technologies are those that disappear.

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7 Appendices

Appendix A - Participant Information, Consent Form and Questionnaire

Agri-IoT Farming Survey

Available @ https://scsstcd.qualtrics.com/jfe/form/SV_6g4OhfgnNflNNGd

SURVEY INFORMATION FOR PARTICIPANTS

Research Title: Factors affecting the adoption of IOT farming in Ireland

Researcher: John Divilly

Contact Details: Email: divillyj@tcd.ie

You are invited to participate in this research project which is being carried out by John Divilly as part of a dissertation for the Management of Information Systems taught masters in the School of Computer Science & Statistics, Trinity College Dublin.

Background
IT and agriculture are two of Ireland's biggest employment sectors and two areas that Ireland competes strongly in on a global scale. These strengths place Ireland in a favourable position to lead the rapidly expanding Agtech sector. One of the fastest growing technologies in this area is the agricultural Internet of Things (agri-IOT).
IOT sensors, also known as smart sensors, are devices that measure and automatically report on a given environment. They need to be low power and simple to maintain so that they can remain active in harsh conditions over a long period of time.

Aim of this research
This research aims to assess how agri-IOT technologies are being used on Irish farms and what factors will affect the adoption of products and capabilities offered by this new technology.

Current agri-IOT usage
IOT sensors are being used on farms today for:

1. GPS tracking/guidance
2. Silo or water/diesel/slurry tank levels and conditions
3. Soil/Air temperatures, moisture levels, Ph and nutrient levels
4. Farm perimeter monitoring, gates/enclousures secured, electric wire status
5. Livestock monitoring, cow calving sensors, animal health (temperature, movement)
6. Asset protection, machinery or farm building intrusion, motion detection sensors

Currently agri-IOT sensors use WiFi, bluetooth or 2G/3G cellular networks to send text messages or emails. New IOT wireless networks, dedicated to handling low power, long lasting, robust, smart sensors are beginning to be built in countries around the world. These networks will allow the connection of tens of thousands of sensors to the normal mobile network tower in your area. 2018 will see the major progression of these networks in Ireland.

Procedures of this survey
You are invited to participate in this survey as you are a full or part time farmer in Ireland. Your participation in this survey is voluntary and you have the right to withdraw or to omit individual responses without penalty.
You will be presented with an online Qualtrics survey of 20 questions. These will be a combination of yes/no, multi-choice and rating based questions and should take about 15 mins to complete.
Your responses will be confidential and **we do not collect identifying information such as name, email or IP address.**
If you have any questions or queries regarding this survey you are free to contact me directly using the contact details above.

Publication
Results, data and findings from this research will be published as John Divilly's final MSc thesis. Additionally, results, data and findings from this research may be published in one or more peer-reviewed journals, conference proceedings, and a variety of other research publications and conferences. Individual results may be aggregated anonymously and research reported on aggregate results.

Conflicts of Interest
Participants should be aware that the researcher works for Three Ireland which may develop such a nationwide IOT network in the future. The researcher is not working in this area currently.

Data Security
Your survey responses will be kept anonymous. The data will be stored on the researchers password protected and encrypted laptop. Access to the data will be confined to the researcher who will be responsible for the subsequent analysis. Data collection, analysis and retention will be undertaken in full compliance with the Data Protection Acts 1988 and 2003.

Third Parties
Please do not name third parties in any open text field of the questionnaire. Any such replies will be anonymised. Commercial suppliers of Agtech/IOT sensors or services are exempt as the adoption of such technology is the focus of this research.

Informed Consent Declaration

Consent:
- I am 18 years or older and am competent to provide consent.
- I have read, or had read to me, a document providing information about this research and this consent form.
- I have been provided the researchers contact details and know that I can contact him to have any questions answered to my satisfaction and to understand the description of the research being provided to me.
- I agree that my data is used for scientific purposes and I have no objection that my data is published in scientific publications in a way that does not reveal my identity.
- I understand that if I make illicit activities known, these will be reported to appropriate authorities
- I freely and voluntarily agree to be part of this research study, though without prejudice to my legal and ethical rights.
- I understand that I may refuse to answer any question and that I may withdraw at any time without penalty.
- I understand that my participation is fully anonymous and that no personal details about me will be recorded.

◯ I agree (1)

◯ I disagree (2)

Q1 Are you a full time or part time farmer?

◯ Full time (1)

◯ Part time (2)

◯ Not a farmer (3)

Q2 Can you indicate your age bracket?

◯ 18 - 25 (1)

◯ 25 - 40 (2)

◯ 40 - 55 (3)

◯ 55 - 65 (4)

◯ 65+ (5)

◯ Prefer not to say (6)

Q3 Can you give the county your farm is in? (e.g Sligo, Cork)

____

Q4 How would you categorise your farming type?

- ◯ Cattle (1)
- ◯ Sheep (2)
- ◯ Dairy (3)
- ◯ Tillage (4)
- ◯ Pigs (5)
- ◯ Mixed (6)
- ◯ Other (Please specifiy) (7) ____

Q5 Can you give an indication of your farm size?

- ◯ Less than 40 acres (1)
- ◯ Between 40 to 120 acres (2)
- ◯ Between 120 to 250 acres (3)
- ◯ Greater than 250 acres (4)

Q6 Are you happy with the speed of the internet available on your farm? (Internet accessed either via broadband to the house or via mobile)

- ◯ Very happy (1)
- ◯ Somewhat happy (2)
- ◯ Neither happy nor unhappy (28)
- ◯ Somewhat unhappy (29)
- ◯ Very unhappy (3)

Agri-IOT Information

Agri-IOT sensors, are devices that measure and automatically report on the farm environment or operation. They need to be low power and simple to maintain so that they can remain active in harsh conditions over a long period of time.

Agri-IOT sensors are being used on farms today for:

- GPS tracking/guidance
- Silo or water/diesel/slurry tank levels and conditions
- Soil/Air temperatures, moisture levels, Ph and nutrient levels
- Farm perimeter monitoring, gates/enclosures secured, electric wire status
- Livestock monitoring, cow calving sensors, animal health (temperature, movement)
- Asset protection, machinery or farm building intrusion, motion detection sensors

Q7 How familiar are you with the usage of agri-IOT sensors on Irish farms?

○ Extremely familiar (1)

○ Very familiar (2)

○ Somewhat familiar (3)

○ Not so familiar (4)

○ Not familiar at all (5)

Q8 In the past 3 months how often did you hear people talking about agri-IOT sensor usage on Irish farms?

○ Very Often (1)

○ Often (2)

○ A few times (3)

○ Once or twice (4)

○ I haven't heard people talking about it (5)

Q9 Do you use agri-IOT sensors on your farm currently?

- ○ Yes (1)
- ○ No (2)

Q10 Can you briefly describe the agri-IOT sensor/s that you currently use?

____

Q11 What do you see as the TOP THREE advantages of your agri-IOT sensor/s? If you see no advantage just select 'I see no advantages'.

- ▢ Saves money (1)
- ▢ Saves time (2)
- ▢ Reduces waste (3)
- ▢ Improves quality (4)
- ▢ Increases farm productivity (5)
- ▢ Reduces the environmental impact (6)
- ▢ Gives better visibility on farm operation (9)
- ▢ I see no advantages (7)
- ▢ Other (8) ____

Q12 What do you see as the TOP THREE disadvantages of your agri-IOT sensor/s? If you see no disadvantage just select 'I see no disadvantages'.

- ▢ Expensive to buy (1)
- ▢ High running costs (2)
- ▢ Difficult to maintain (3)
- ▢ Not needed on farm (7)
- ▢ Not as effective as hoped (4)
- ▢ Breaks down frequently (8)
- ▢ I see no disadvantages (5)
- ▢ Other (6) ____

Q13 How likely would you be to recommend your agri-IOT product to a friend or colleague?

○ Extremely likely (1)

○ Somewhat likely (2)

○ Neither likely nor unlikely (3)

○ Somewhat unlikely (4)

○ Extremely unlikely (5)

Q14 How likely would you be to purchase another agri-IOT sensor system in the future?

○ Extremely likely (1)

○ Somewhat likely (2)

○ Neither likely nor unlikely (3)

○ Somewhat unlikely (4)

○ Extremely unlikely (5)

Q10 Can you give the main reason you haven't bought an agri-IOT sensor?

○ Don't need one (1)

○ Don't know about them (2)

○ Too costly (3)

○ Too much trouble to setup (4)

○ I'm waiting for them to improve (5)

Q11 Can you select the TOP THREE advantages you would see in buying an agri-IOT sensor? If you see no advantage just select 'I see no advantages'

▢ Saves money (1)

- ☐ Saves time (2)
- ☐ Reduces waste (3)
- ☐ Improves quality (4)
- ☐ Increases farm productivity (5)
- ☐ Reduces the environmental impact (6)
- ☐ Gives better visibility on farm operation (9)
- ☐ I see no advantages (7)
- ☐ Don't know (10)
- ☐ Other (8) ____

Q12 Can you select the TOP THREE disadvantages you would see in buying an agri-IOT sensor? If you see no disadvantage just select 'I see no disadvantages'.

- ☐ Expensive to buy (1)
- ☐ High running costs (2)
- ☐ Difficult to maintain (3)
- ☐ Not needed on farm (4)
- ☐ Breaks down frequently (7)
- ☐ I see no disadvantages (5)
- ☐ Don't know (8)
- ☐ Other (6) ____

Q13 How likely would you be to purchase an agri-IOT sensor in the future?

- ○ Extremely likely (1)
- ○ Somewhat likely (2)
- ○ Neither likely nor unlikely (3)
- ○ Somewhat unlikely (4)
- ○ Extremely unlikely (5)

Q15 To what extent do you agree or disagree with the following statements on agri-IOT sensors?

	Strongly agree (1)	Somewhat agree (2)	Neither agree nor disagree (3)	Somewhat disagree (4)	Strongly disagree (5)
Agri-IOT sensors are too expensive to buy (1)	○	○	○	○	○
Agri-IOT sensors don't provide a return on investment (2)	○	○	○	○	○
I have no need for agri-IOT sensors on my farm (3)	○	○	○	○	○
Agri-IOT sensor systems are too complicated to setup/operate (4)	○	○	○	○	○
I have security concerns about agri-IOT systems (5)	○	○	○	○	○

Q16 Do you expect better agri-IOT sensors to be on sale in the 2 years?

- ◯ Definitely yes (1)
- ◯ Probably yes (2)
- ◯ Might or might not (3)
- ◯ Probably not (4)
- ◯ Definitely not (5)

Q17 In your opinion what farming area would benefit the most from agri-IOT sensors?

Please rank in order from 1 (Most benefit) to 5 (least benefit)

______ Dairy (1)
______ Crops (2)
______ Machinery Monitoring (3)
______ Livestock Management (4)
______ Farm security (5)

Q18 Do you feel you get enough information about agri-IOT applications?

- ◯ Definitely yes (11)
- ◯ Probably yes (12)
- ◯ Might or might not (13)
- ◯ Probably not (14)
- ◯ Definitely not (15)

Q19 Have you any further feedback to give on agri-IOT sensors?

____

Q20 OPTIONAL. If you would like to talk to the researcher further about this topic a small number of follow-up phone interviews will be held. These would consist of 5 questions and the interview is expected to take about 20 minutes. If you answer Yes a contact phone number will be requested otherwise select No and move to the end of the survey.

○ Yes (1)

○ No (2)

Please provide a name and contact phone number.

☐ Name (1) ____

☐ Phone (2) ____

Appendix B – Interview Information Sheet, Consent and Questions

TRINITY COLLEGE DUBLIN

School of Computer Science and Statistics

INFORMATION SHEET FOR INTERVIEW PARTICIPANTS

Research Title: Factors affecting the adoption of IOT farming in Ireland

Researcher: John Divilly

Contact Details: Email: divillyj@tcd.ie

You are invited to participate in this research project which is being carried out by John Divilly as part of a dissertation for the Management of Information Systems taught masters in the School of Computer Science & Statistics, Trinity College Dublin.

This research aims to assess how agri-IOT technologies are being used on Irish farms and what factors will affect the adoption of products and capabilities offered by this new technology.

Background

IT and agriculture are two of Ireland's biggest employment sectors and two areas that Ireland competes strongly in on a global scale. These strengths place Ireland in a favourable position to lead the rapidly expanding Agtech sector. One of the fastest growing technologies in this area is the agricultural Internet of Things (agri-IOT).

IOT sensors, also known as smart sensors, are devices that measure and automatically report on a given environment. They need to be low power and simple to maintain so that they can remain active in harsh conditions over a long period of time.

IOT sensors are being used on farms today for:

1. GPS tracking/guidance
2. Silo or water/diesel/slurry tank levels and conditions

3. Soil/Air temperatures, moisture levels, Ph and nutrient levels
4. Farm perimeter monitoring, gates/enclousures secured, electric wire status
5. Livestock monitoring, cow calving sensors, animal health (temperature, movement)
6. Asset protection, machinery or farm building intrusion, motion detection sensors

Currently agri-IOT sensors use WiFi, bluetooth or 2G/3G cellular networks to send text messages or emails. New IOT wireless networks, dedicated to handling low power, long lasting, robust, smart sensors are beginning to be built in countries around the world. These networks will allow the connection of tens of thousands of sensors to the normal mobile network tower in your area. 2018 will see the major progression of these networks in Ireland.

Procedures of this Interview

You are invited to participate in this semi-structured interview as you previously completed a survey on this topic and have indicated that you are willing to further discuss the topic with the researcher

Your participation in this interview is voluntary and you have the right to withdraw or to decline to answer any question at any time.

You will asked 6 questions about your thoughts on Agri-IOT sensors, the interview should take no longer than 30 minutes.

An audio-only recording of the interview will be electronically recorded on the researchers phone. The recording will be transferred to the researchers laptop for transcribing purposes and deleted from the researchers phone immediately after transfer. Participants will be informed of this prior to the start of the interview.

Participants will have the opportunity to review the recording after the interview and make any changes and/or corrections they deem necessary.

Publication

Results, data and findings from this research will be published as John Divilly's final MSc thesis. Additionally, results, data and findings from this research may be published in one or more peer-reviewed journals, conference proceedings, and a variety of other research publications and conferences. Individual results may be aggregated anonymously and research reported on aggregate results.

Conflicts of Interest

Participants should be aware that the researcher works for Three Ireland which may develop such a nationwide IOT network in the future. The researcher is not working in this area currently.

Data Security

The data will be stored on the researchers password protected and encrypted laptop. Access to the data will be confined to the researcher who will be responsible for the subsequent analysis. Data collection, analysis and retention will be undertaken in full compliance with the Data Protection Acts 1988 and 2003.

Third Parties

Please do not name third parties in any open text field of the questionnaire. Any such replies will be anonymised. Commercial suppliers of Agtech/IOT sensors or services are exempt as the adoption of such technology is the focus of this research.

Trinity College Dublin

Informed Consent Form

RESEARCHER: John Divilly

DECLARATION:

- I am 18 years or older and am competent to provide consent.
- I have read, or had read to me, a document providing information about this research and this consent form. I have had the opportunity to ask questions and all my questions have been answered to my satisfaction and understand the description of the research that is being provided to me.
- I agree that my data is used for scientific purposes and I have no objection that my data is published in scientific publications in a way that does not reveal my identity.
- I understand that if I make illicit activities known, these will be reported to appropriate authorities.
- I understand that I may decline to allow the interview audio to be recorded and that I may stop the audio recording at any time. Furthermore, I may at any time, even subsequent to my participation have such recordings destroyed (except in situations such as above).
- I understand that, subject to the constraints above, no recordings will be replayed in any public forum or made available to any audience other than the current researchers/research team.
- I freely and voluntarily agree to be part of this research study, though without prejudice to my legal and ethical rights.
- I understand that I may refuse to answer any question and that I may withdraw at any time without penalty.
- I understand that my participation is fully anonymous and that no personal details about me will be recorded.
- I have received a copy of this agreement.

PARTICIPANT'S NAME:

PARTICIPANT'S SIGNATURE:

Date:

Statement of investigator's responsibility: I have explained the nature and purpose of this research study, the procedures to be undertaken and any risks that may be involved. I have offered to answer any questions and fully answered such questions. I believe that the participant understands my explanation and has freely given informed consent.

RESEARCHER'S CONTACT DETAILS:

RESEARCHER'S SIGNATURE:

Date:

TRINITY COLLEGE DUBLIN

School of Computer Science and Statistics

INTERVIEW QUESTIONS

Research Title: Factors affecting the adoption of IOT farming in Ireland

Researcher: John Divilly

Contact Details: Email: divillyj@tcd.ie

Questions for users of agri-IOT sensors

1. Picking a sensor you use regularly, please tell me what it does and how long you have been using it?
2. What were the main reasons that lead you to invest in the technology?
3. Were your expectations meet?
4. Does it make farm work harder or easier? If so, in what ways?
5. Would you recommend the product to friends? Please explain your reasons?
6. What do you hope to see happen in this area in the future?

Questions for non-users of agri-IOT sesnsors

1. Can you tell me your main reasons for not investing in agri-IOT sensors?
2. Do you think there is sufficient information available on these products?
3. Is poor internet access stopping you using these types of products?
4. Do you think you will purchase an agri-IOT product in the future?
5. Do you think agri-IOT sensors is the right way for farming to go in Ireland?
6. What do you hope to see happen in this area in the future?

Appendix C – Interview Notes

Participant A

Questions for users of agri-IOT sensors

1. Picking a sensor you use regularly, please tell me what it does and how long you have been using it?

GPS guidance in tractor is used to map fields and apply fertilizer in exact quantities. Accurate guidance removes need for manually placing markers on fields for guidance and minimizes wasted fertilizer. Paid for in 18 months. Can set width, say 12 metre bulk width. Much more accurate. 7% gain. Cuts out trips back and over to refill. Has had it now 5 or 6 years. Using Trimble easy guide 250 with Small antenna. RTK. Needs 5 satellites to get a good lock but normally gets signal. One field with coverage issue. 800 EUR, brought in from England. Saves him having to pace out 12 metres for each row with bag markers. Went from an hour and a quarter to spread fertiliser to 40 mins.

2. What were the main reasons that lead you to invest in the technology?

Health issue, all the tractor work was taking a lot out of him. Saw reviews on the internet and price wasn't too bad so went for it

3. Were your expectations meet?

Helps spraying. Exceeded. Return on investment excellent. Needs sw updating. Needs a usb to update. Internet

4. Does it make farm work harder or easier? If so, in what ways?

GPS guidance removes the need for me to manual mark fields for fertiliser spreading while retaining accuracy, saving me time and money. On 50 ton of fertilizer can save quite a bit. Its all about getting the width right. So far hasn't had too many problems with it.

5. Would you recommend the product to friends? Please explain your reasons?

Absolutely. Pay back on fertilizer. 300 a ton. GPS guidance gives a good return on investment as savings on fertilizer can add up quickly. I would recommend that to anyone I talk to. Would most likely buy something in that line again if price was right.

6. What do you hope to see happen in this area in the future?

The addition of automatic tractor steering to GPS guidance will be even more beneficial

Participant B

Questions for non-users of agri-IOT sesnsors

1. Can you tell me your main reasons for not investing in agri-IOT sensors?

We've a small farm here, in the early years of getting established, focused on just getting the critical things right first, needs time to look through the cost-benefit for systems like these.

Make sure we don't run out of grass first! Farm priorities first before tackling the efficiencies.

2. Do you think there is sufficient information available on these products?

Would say no at the moment. Aware of them from the off-farm job. Doesn't see in main stream media. Need to disseminate and communicate to farmers. Not familiar topics with farmers at mart and around the area.

3. Is poor internet access stopping you using these types of products?

Signal on phone and broadband dongle here are Ok, but I'd have questions on how well different IoT technologies might perform. Farmer down the road has regular coverage blocked by a hill, so farmers can be lucky or not dependent on location

4. Do you think you will purchase an Agri-IoT product in the future?

Naturally inclined to but need to be realistic. As long as I could see the cost-benefit was appropriate for the investment and it saved time yes, but I haven't been convinced of that yet. Return on investment needs to be proven. We're not industrial scale farming. EID becoming compulsory. EID readers to be covered in TAMS.

5. Do you think Agri-IoT sensors is the right way for farming to go in Ireland?

Naively why not. As long as it helps farmers then yes but majority of farmers are not industrial scale operations and justifying the cost versus benefit will be key. Data security issues. Measuring grass growth. As long as cost benefit was appropriate.
Development of devices to early detect animal health issues could be very useful. Pedometer on a cow's leg at demo farm in Waterford. Cow walks 1000 steps for a while, then changes to only 800. Could be indication of on-set of lameness.

6. What do you hope to see happen in this area in the future?

I'd like to see the technology developed and used to reduce expensive farm inputs, for example saving water and fertilizer use and reducing the environment impact. Healthy animals, improving work-life-balance and overall workload. Paperwork is constantly increasing for farmers and system that helps farmers automate and cope with that would be welcomed. Including more such systems in TAM would help adoption. Farmer groups and different parts of the country need different support. EID -> Paperless systems.

Participant C

Questions for users of agri-IOT sensors

1. Picking a sensor you use regularly, please tell me what it does and how long you have been using it?

I've been using a Sigfox enabled remote temperature sensor to monitor a grain silo for years Also Wifi-plugs. Before using these would leave fans running on both hot and cold days. If temperature (from local weather station) goes above or below a certain temperature then an ifft system (connects devices together with logic) turns on or off the fans.
Uses an American company that produces a cheap wireless tag. Outdoor probe. Year or two power lasts. PIR power lasts 6 months or so.

2. What were the main reasons that lead you to invest in the technology?

Needed a way to check stored grain wasn't heating. Automatic sensor reduces the manual effort to check grain silo temperature, increases the measurement frequency from fairly infrequently to hourly. Previously had to check with an iron bar or temperature probe now uses a sigfox connected thermometer. More efficient usage of ventilation fans as system is connected to local weather station with defined temperature trigger

3. Were your expectations meet?

My expectations were exceeded, excellent return on investment. Some initial fluctuations in coverage but were sorted out and has worked well and very consistently since. Comes with a wire in a copper pipe.

4. Does it make farm work harder or easier? If so, in what ways?

Some initial issues with Sigfox coverage issues but now fixed. Overall yes it saves time and effort on the farm however some concern that connection fees are going to go up. Sales pitches are often for large scale systems and don't have individual end-users in mind

Example they've a tank sensor being used by Dunraven.Tank but you'd need to buy the full install. Saving hardware sprayer pump by detecting frost. Inexpensive & effective. VT networks user group. Good check against theft. Were able to keep grain cold this. 25C off dryer. A mid winter could still experience too warm a day for the grain.
Dairying milk truck won't pick up milk if tank is too warm.
Sigfox kept going during the snow.

5. Would you recommend the product to friends? Please explain your reasons?

I would recommend these devices but they can be hard to get used to, system needs to be very robust and easy to operate. Sigfox activated tracker and then posted

6. What do you hope to see happen in this area in the future?

Multiple sensors on a range of farm processes. Mesh network through various devices for fire detection. Once farmers start using these devices they won't go back, so likely to see large scale adoption in next few years. New NB-IOT networks to provide better options and pricing schemes. Benefit of such systems to elderly or vunerable people. System to monitor gait change to identify hip replacement need. Automatic fall trigger to send message. Health & safety, lone workers. Dog tracking
Checking the full lifecycle. Glanbia to require sensors in milk tanks, they don't want milk temp being too hot to add to collection lorry.

Participant D

Questions for users of agri-IOT sensors

1. Picking a sensor you use regularly, please tell me what it does and how long you have been using it?

Uses software to manage the farm, financial records etc via mysql database.
Records calf weight by taking measurements at feeder. Touch screen. Uses rasperbery PI microController. GPS and RTK base station connectivity from tractor.
Looking into other 900Mhz transmitters to form a mesh network

2. What were the main reasons that lead you to invest in the technology?

Originally a personal interest. DIY. Helps manage the farm. Was using Access for records. Python programming. Desktop manager. mysql link to raspberry microcomputer. Farmers pay a lot of money for these individual pieces. Could never make one themselves
Very expensive to justify the cost of for example a GPS module

3. Were your expectations meet?

Automatic calf feeder, weighs calves at the feeder. A lot of such technology only really available on the research farms. Commercial products are massively overpriced and will not provide any return on investment, everything I use I build myself.

4. Does it make farm work harder or easier? If so, in what ways?

Makes farm work easier. Helps to manage various tasks altogether. Reduces repeated and similar data entry and provides a more joined up view of the farm operation

5. Would you recommend the product to friends? Please explain your reasons?

Wouldn't recommend commercial products to ppl. Very hard to get return. Difficult to recoup thousands of euros spent on such systems with average farm margins.
I wouldn't recommend commercial off-the-shelf systems. Would be better to train farmers on how to build and operate such systems themselves.

6. What do you hope to see happen in this area in the future?

Network NB-IOT options. Government RTK, survey grade GPS. 2cm, correction signal. 500 pounds. Farmers to become more computer savvy and be able to tailor IoT systems to their specifc farm needs. A need for computer training.