An examination of technology as a food security solution
Boundary work in the co-production of science and politics

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An examination of technology as a food security solution: boundary work in the co-production of science and politics

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Abstract

Achieving food security for all is a well acknowledged challenge for the 21st century. This interdisciplinary thesis looks at the role of technologies in addressing these concerns. It draws on aspects of science and politics to ask where these fields come together, where they divide and what impact this has on food security.

The concept of food security encompasses the interaction of multiple dimensions including technical, political, economic, social and environmental factors. At present the academic fields of science and politics largely focus on their own terrain and there is very little that engages with the connections between the two. However, the very nature of the food security problem requires us to focus on how these fields interact. This research addresses this gap in existing knowledge by exploring how interaction between science and politics occurs in practice. A conceptual toolkit comprising of co-production and boundary work was developed to allow for commonalities and differences to be registered. This research explored forms of co-production between science, technology and politics in the past, and how this looks in the present.

Interviews were conducted with forty-seven participants from seven different groups of actors, and were analysed using content analysis. Three main situations in which co-production and boundary work was emphasised were identified: interaction in a broader food security setting, the research and development of technology, and technology adoption. This thesis explores these areas as core chapters to present a better understanding of how science and politics comes together, and how it divides in practice. It identifies patterns between them, but argues that there is a much greater emphasis on how boundaries are created in practice, as opposed to how they are crossed.

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Contents

Abbreviations

AFSI – L'Aquila Food Security Initiative

BCE – Before Common Era

CE – Common Era

CSO – Civil Society Organisation

DEFRA – Department of Environment, Food and Rural Affairs

EFSA – European Food Safety Authority

FAO – Food and Agricultural Organisation of the United Nations

GFSA – US Global Food Security Act of 2016

GM – Genetic Modification

GMO – Genetically Modified Organisms

GR – The Green Revolution

HYV – High Yielding Varieties

IP – Intellectual Property

IPR – Intellectual Property Rights

IR – International Relations

NGO – Non-governmental organisation

OECD – Organisation for Economic Co-operation and Development

REF – Research Excellence Framework

SDGs – Sustainable Development Goals

STS – Science and Technology Studies

UN – United Nations

WHO – World Health organisation

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Introduction

Food security is a prominent challenge for the 21st century. At present nearly 821 million people in the world are food insecure and this number is continually rising. This indicates that we are not on target to eradicate hunger by 2030 (FAO, 2018). This interdisciplinary thesis focuses on the role of technology as one potential solution to address food security concerns. It aims to understand how technology and food security politics relate. This thesis does not explore the extent to which technology will solve insecurity. Rather it explores how food security is constituted as both a technological and social and political practices. Further, it is not interested in the impact of particular technologies, but the inter-relations of technical knowledge, scientific and political communities, and social and political issues. . In particular it seeks to follow the co-production of technology and political issues through the connections and disconnections of differing scientific and political communities. That is, where do forms of science and politics come together? Where do they divide? And what impact does this have on food security practice?

This research follows the definition of food security developed at the 1996 Food and Agricultural Organisations (FAO) declaration on World Food Security and World Summit Plan for action:

> *"Food security is a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life"* (FAO, 1996)

The 2009 World Food Summit of Food Security further extended this definition with the addition of a 'four pillar model' (FAO, 2009). This model incorporates four independent yet interrelated components that must be fulfilled for food security to be realised: access (the ability for individuals or households to produce or purchase food that meets their needs), availability (that sufficient food or appropriate quality is available), utilisation (the efficient use of food to its fullest potential), and stabilisation (the stability of all other dimensions)[1]. The FAO definition and four pillar model is

[1] For further detail on each of these pillars see FAO (2009) and Gibson (2012)

particularly useful to this thesis in that it is not only one of the most commonly used, but it also emphasises the broad multidisciplinary nature of food security by highlighting a wide range of dimensions that are related to a fuller understanding.

Rather than focus on food security through the lens of one discipline, this thesis draws on the fields of the social and political sciences and biological sciences. It does so based on the understanding that in-depth disciplinary research can prove problematic as it is often not holistic. Given the multidimensional nature of food security, the need for interdisciplinary research is not only well accepted and recommended, but is an increasingly regular approach in researching this topic (Ingram, 2011; Foresight, 2011). However, while it is acknowledged that different dimensions and disciplines are part of food security, there is insufficient exploration of how they interact. Specifically, food security practice increasingly emphasises the need for political and technological dimensions to work together but as of yet how these areas connect and affect each other in practice has received limited academic attention. This research aims to begin to fill this gap by exploring the interaction of science and politics in practice. Focusing on technology as a food security solution allows for a fuller understanding of how this occurs.

An abundance of food security challenges exist and are well documented in the literature. Shortage of land and water, climate change, natural disasters, population growth and urbanisation provide just some examples (Godfray et al., 2010a; Sonnino et al., 2013; Grote, 2014). While the scope of this thesis does not require specific focus on particular challenges, they provide a useful indication on the need for technology. Based on such challenges it is recognised that there is a need for maximising the efficiency of existing technologies, as well as the development of new ones (Beddington, 2010). The recognition of the importance, and need, for technology is not a recent claim. For example, Article 11 of the 1976 International Covenant on Social, Economic and Cultural Rights not only recognised the right for all people to be free from hunger, but the need for science and technology to achieve this. Article 11.2(a) recommended the following: “To improve methods of production, conservation and distribution of food by making full use of technical and scientific knowledge…” (UN General Assembly, 1976). Further, poor or inadequate technologies, and low productivities as a result, have also been identified as drivers of food insecurity (Godfray et al., 2010a; Grote, 2014).

While the use of technology presents a potential solution, the food security problem is not solely technical. It is also social, economic and political (Ingram, 2011). In practice, technology often integrates with these factors. This is apparent through debates on ownership and disparities between developed and developing countries (Serageldin, 1999; Runge et al., 2003), labour concerns in countries where underemployment is a chronic issue (Nally, 2016), and public perception for example (Frewer et al., 2011)

Chapter one of this thesis expands on this by providing an overview of the key food security literature on technology. It considers how the academic fields of biological science and the social and political sciences have approached these issues and explores how they interact with each other (i.e. interdisciplinary approaches to research). This chapter will show that these disciplines have a limited understanding of one another. Debates on food security and technology as a possible solution are not only engaged to differing extents, but they are done so as two different academic fields. When these fields do engage, there is a nuanced understanding of how the other operates and what this entails. Interdisciplinary research is not only lacking, but these disciplinary areas see 'science' (technological advancements) and 'politics' (social and political concerns) as separate, but actually the very nature of food security requires that they interact. Why there are distinct spheres between technological advancements and social and political issues in food security is an area that has received limited academic attention.

To address this gap and explore how forms of science and politics interact within a food security context, this thesis asks the following research questions:

- What forms of knowledge are being prioritised?
- How is this organised and translated in particular practices?
    - What ways are forms of science and politics entwined? How are these interactions negotiated?
    - How are practices represented and undertaken at different levels?
- What impact does this have on food security?

To answer these questions it is important to establish a set of conceptual tools that will help understand the interactions between forms of science and politics in practice. Chapter two engages with the wider literature on this, and illustrates the benefits of utilising a co-production perspective and exploring boundary work within it. Co-production avoids one of the issues that science and politics has fallen into; it is seen as inherently and permanently separate. While co-production views science and politics knowledge forms as separate, it also recognises that they interact and form each other in various ways – they are simultaneously produced (Jasanoff, 2004). This approach therefore allows for a much more nuanced view on these interactions and their significance. Boundary work creates platforms that meet the needs of multiple and often epistemically different groups, and therefore identifying forms of boundary work allows for an exploration of how co-production occurs in practice. This chapter not only lays out the concepts of co-production and how they will be used within this research, but it also details the research methodology designed to help understand how boundaries are created and crossed in practice. This data is obtained through the content analysis of key informant semi-structured interviews.

Before co-production and boundary work is explored in practice it is important to understand how this came to be. Chapter three explores the history of co-production in food security. It will argue that not only is there interaction between technology and society (as forms of science and politics), but this has a long history. They have always been entangled. This is a particularly important piece of work in that by showing that these forms of science and politics have always been entangled in a food security context, it validates the use of co-production as a conceptual tool to explore this further. By tracing key stages in agricultural history this chapter will show that not only have forms of interaction always been observed, but that these are distinct. While they have always been co-produced, the modes in which this happens shifts throughout time. This therefore raises the question of how co-production looks in current food security practices.

Chapter four is the first of three empirical research chapters to explore the interaction of forms of science and politics (scientific communities and policy making practices, institutions and structures) within food security practice. It specifically focuses on barriers to interaction between key actors in food security practice, and identifies forms of boundary work within this. Three barriers to interaction are discussed: ownership, perception, and issues pertaining to stakeholders not knowing who to talk to. This chapter demonstrates how these barriers individually constitute as forms of boundary work, and how they interlink. Through the exploration of these boundaries, it also highlights some important national differences that are constituted through different institutional and regulatory arrangements and principles. It also shows how political controversies (like genetic modification) and uncertainties (such as Brexit) amplify this. This chapter looks at the bigger picture of boundary work and food security. However, it is important within this research to explore how this picture changes, if at all, when specific stages of technology are considered.

This leads into chapter five which specifically focuses on technology research and development (R&D). This chapter demonstrates how boundaries are created between science and politics communities (those that develop/create technology and those that govern it) within the R&D process by discussing key challenges that emerged in interview discussions. This includes operational differences, different understandings in the conceptualisation of scientific practice and how it should be conducted, and finally perceived politicisation and regulatory challenges. While operational differences speak to organisational and structural challenges, the remaining two ways in which boundaries are created specifically speak to how scientific practice is politicised. This chapter will show how this draws on notions of scientific credibility, and the role of regulations, standards and risk assessment within decision making. This chapter will also argue that risk setting bodies have the potential to help cross boundaries between these forms of science and politics. As such, it will argue that risk contributes to both intensifying and reducing divides between communities that develop technology and communities that govern its use in an R&D context.

The final chapter moves on to look at how boundaries are created and crossed within the adoption of technology. By exploring key adoption barriers that were identified by interview participants, this chapter will show that boundaries are created by a lack of sufficient knowledge exchange. This is reinforced by the way in which boundaries are crossed. This chapter will discuss two examples that emerged empirically (extension services and trainer the trainer models) to demonstrate how a deliberate convergence between differing science and politics communities can be observed. More specifically, this chapter looks at the interaction between those that develop technology and those that use it. By exploring the ways in which boundaries are created and crossed, this chapter will argue that rather than the diffusion of technology and knowledge being distinct from its adoption, these are more representative of combined trajectories. That is, technology diffusion and adoption does not just happen, it is made to happen by the ways in which knowledge is transferred and translated.

This thesis will conclude by drawing out patterns between each of these situations. It will show that risk related challenges present a commonality among different practices, that ‘science’ and ‘politics’ is interpreted differently in different practices, boundary work is shaped by operational and national differences and there is a greater emphasis on how boundaries are created as opposed to how they are crossed.

Chapter one: Literature review

This chapter reviews the existing literature on how technology acts as a potential food security solution, and how it is influenced and challenged by various political dimensions. It specifically focuses on literature that is situated within the fields of Biological Science, and Politics and International Relations (IR). There are two reasons for this. Firstly it aligns with the interdisciplinary nature of this research. As a project that is situated between both academic fields it is important to understand how these different disciplines speak to food security, how they approach technology as a food security solution and how they engage with each other with respect to the their approach on the intersection between technology and various political, social and economic issues. Secondly, by conducting a review in this manner it allows for both similarities and distinctions to be drawn out between them, highlighting the gaps in the literature that thesis will begin to fill.

The literature discussed in this review was obtained in a systematic manner. Literature searches were conducted on numerous electronic databases including Web of Science (ISI), PubMed, Scopus and JSTOR. Databases used were selected to best cater to the interdisciplinary requirement in addressing the aims of this review. Google scholar was used to compare results obtained and access publications otherwise available. Grey literature (including government documents, reports and the internet) was also used.

Key terms (“food security”, “politics”, “science” and “tech*”) were selected from the project aim, and key words were derived from the formal and informal examination of food security literature. These included, but were not limited to, nano*, genetic modification, GM, synthetic biology, synbio, biotechnology, public perception, intellectual property and markets. Combinations of these key words were used to identify relevant documents. The references and / or citations of these documents were also consulted to identify any other potentially relevant research. All studies and/or documents were only considered if they were in English, peer reviewed or from reputable government sources, and examined the role of technology for food security to some extent. Studies were technology was only briefly touched upon, or absent entirely from the article, were excluded.

To help position the contribution that this research will make, it is beneficial to first provide an introduction to how food security is currently situated, the challenges it faces and why technology has been identified and used as a solution to achieve this. The current narrative is largely shaped in response to the global food price crisis of 2007-08.

1.1. The 2007-08 food price crisis

The acknowledgement of food as human right can initially be traced back to the 1948 United Nations (UN) declaration of Human Rights, which was agreed upon in response to World War Two (United Nations, 1948). However only in the last decade has food security received a significant increase in attention, which correlates with the global food price crisis of 2007-08[2]. The food price crisis was a result of increased agricultural commodity prices and highlighted serious concerns regarding global food security. The prices of grain doubled, rice prices tripled and the prices of vegetable oils, sugars, and meats were all recorded at a record high (Dupont & Thirlwell, 2009). The World Bank estimated that approximately 105 million people were pushed into poverty as a result of rising food prices, with up to thirty three countries at risk of social upheaval (Davis & Belkin, 2008).

The food price crisis stemmed from a number of cumulative trends and causes. These included a rise in income growth, which saw a shift in consumption patterns, an increase in agricultural based energy, whereby the cultivation of crops were diverted for use in the development of biofuels, and a widening gap between supply and demand[3] (Evans, 2008; von Braun & Torero, 2009; Dupont & Thirlwell, 2009). Additionally, policy responses and subsequent market over reactions contributed to exacerbating the crisis. For example a number of countries banned exports on agricultural commodities thus strengthening domestic food security but also restricting the global market (von Braun & Torero, 2009).

The food price crisis brought a number of fundamental failures in regional, national and global food security governance to the forefront of attention. An examination of

[2] This statement refers only to the correlation between increased interest in food security and the global food price crisis. It does not mean to make any claims on the core drivers of food insecurity. These are mentioned in section 1.2 in this chapter.
[3] Cultivation is the process in which soil is prepared and crops are planted, tended to and harvested (Harris & Fuller, 2014).

the causal effects led to the realisation that existing policies were detrimental to food security. It also highlighted inconsistencies in global food security governance, failure of governance at national levels as a result of technocratic derived policies, and inadequate investment in developing countries (de Schutter, 2012). As such the 2007/08 food price crisis not only brought food security to the forefront of international development, but it also instigated international action. This resulted in the creation of expert panels, comprehensive frameworks and global funding initiatives.

The High level taskforce for Global Food and Nutrition Security, established by the UN secretary-general in 2008, provides one such example. It brought together the heads of UN agencies, the World Bank, World Trade Organisation, the International Monetary Fund and the Organisation for Economic Co-Operation and Development (OECD) to develop a comprehensive strategy to respond to this crisis. While this was designed as a response to the immediate needs of the most vulnerable populations, it also contributed to long term resilience by addressing all aspects of the FAO four pillar model of food security: access, availability, utilisation and stabilisation (UN-HLTF, 2011).

Food security was also a high priority at the 2009 G8 summit in L’Aquila Italy where leaders recognised the urgent challenges that it faced. Consequently they launched the L’Aquila Food Security Initiative to address under investment which, coupled with the food price crisis, was identified as a core contributor to food insecurity through increases in hunger and poverty in developing countries (AFSI, 2012). The G8 collectively pledged $22 billion over a three year period toward this goal. In the same year, the World Food Summit on Food Security brought together 193 countries to establish a strategic and urgent response to increased hunger, poverty and food insecurity. The agreed result was the Five Rome Principles for Sustainable Global Food Security. This called for strategic co-ordination at regional, national and global levels, direct action to tackle hunger for the most vulnerable, along with long term plans of action to address the root causes. It also placed an increased emphasis on multi-lateral systems as well as a pledge to invest in country own plans, and agriculture and food security at an international level (World Food Summit, 2009).

These are just three examples of strategic responses to the food price crisis by the international community that marked a change in the approach to global food security governance[4]. However, increased attention on food security is not only confined to practical examples surrounding global governance. An increase in academic attention is also apparent. This can be seen in **figure 1.1** which shows the increase in publications on “food security”. Starting from 1974 (the first food security related publication on Web of Science (ISI) database) a gradual incline can been observed, however this is most prominent post 2008-09. **Figure 1.2** shows the increase in publications for the fields of biological sciences and various social sciences between 2009 and 2019. Based on Web of Science alone, more research has been conducted in the field of biological sciences. However this figure does show that the publication output for both fields has considerably increased in the last decade, post the food price crisis. Disciplines included in the category of social sciences include International Relations, Political Sciences, Law, History, Philosophy, Anthropology, Development Studies and Agricultural Economic Politics.

It should be noted that the aim of these figures are to illustratively show the broad correlation between increased publication output on food security and post food price crisis. For that reason, one search term (“food security”) was used in this instance only. Furthermore, while the literature presented in this review was obtained from a variety of sources and electronic databases, data for these figures were from Web of Science (ISI) only. This is not an attempt to prioritise one database over the other. Rather, Web of Science (ISI) was selected as it is a platform that allowed search terms to be refined according to selected years and disciplines.

[4] See de Schutter (2012) and Page (2013) for an in depth list of actions undertaken by the international community in response to the food price crisis.

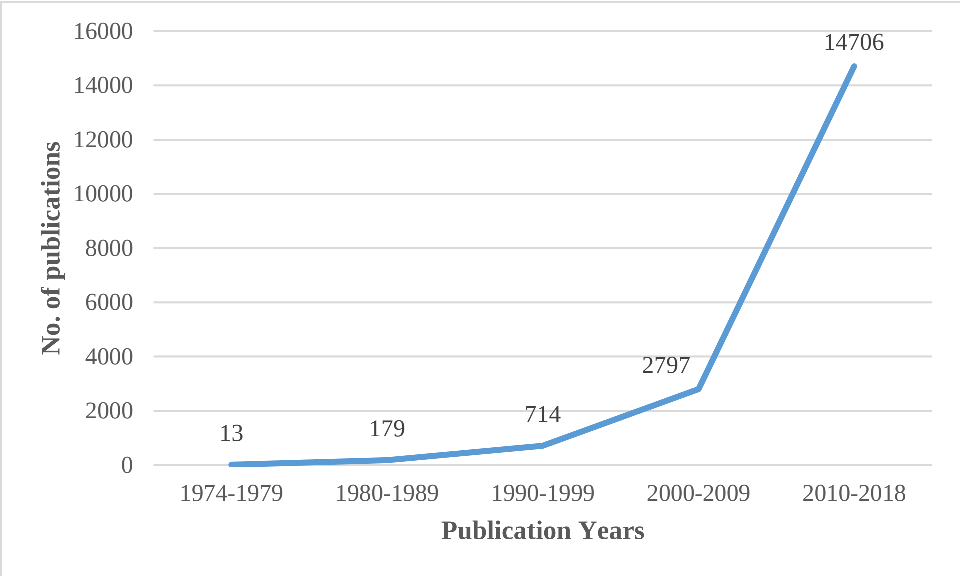


Figure 1.1 The increase of publications on the topic "food security" from 1974 to 2018. (Figures were obtained from Web of Science (ISI) database and give an accurate representation as of 06/12/18).

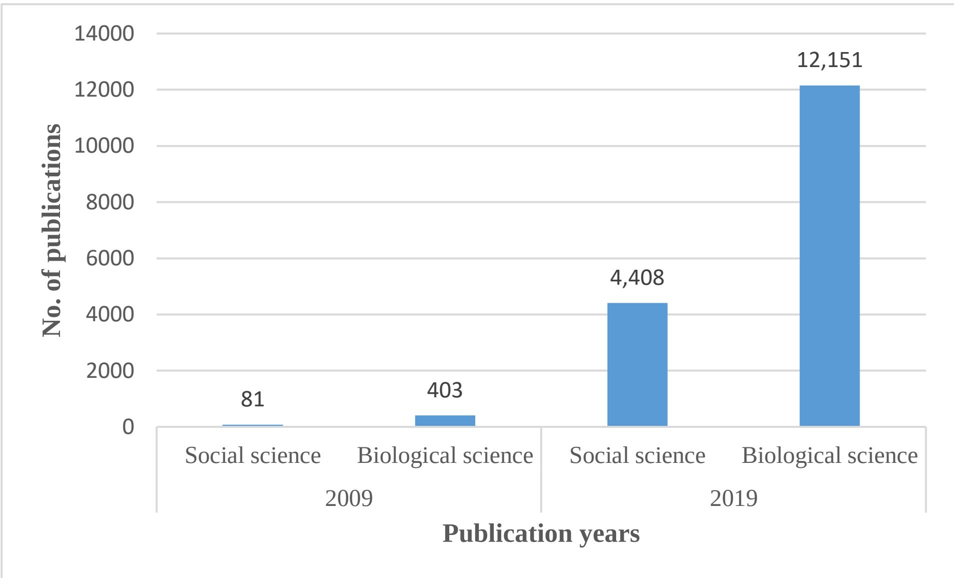


Figure 1.2 The increase of publications in the social science and biological sciences on the topic "food security". (Figures were obtained from Web of Science (ISI) database and give an accurate representation as of 01/06/19)

1.2 Drivers of food insecurity

The concept of security always involves some form of insecurity be it risk, vulnerability or a threat (Bourne, 2014). Food insecurity is a reality for billions of people worldwide. Evidence has shown that the number of hungry is growing, having reached 821 million (or one in nine people) in 2017 (FAO, 2018). This suggests that we are not on target to eradicate hunger by 2030, as set out in the Sustainable Development Goals[5]

The unanimous achievement of all dimensions within the FAO definition and four pillar model of food security presents a significant challenge. It has been recognised that the global food system regularly experiences an unprecedented amount of interrelated pressures. **Figure 1.3** presents an overview of some of the core drivers of food insecurity that have been identified in the literature. These are often categorised as supply versus demand based drivers, with market related constraints also receiving attention.

[5] Goal 2 of the SDGs (‘zero hunger’) aims to end hunger, achieve food security, improved nutrition and promote sustainable agriculture (UN, 2015).

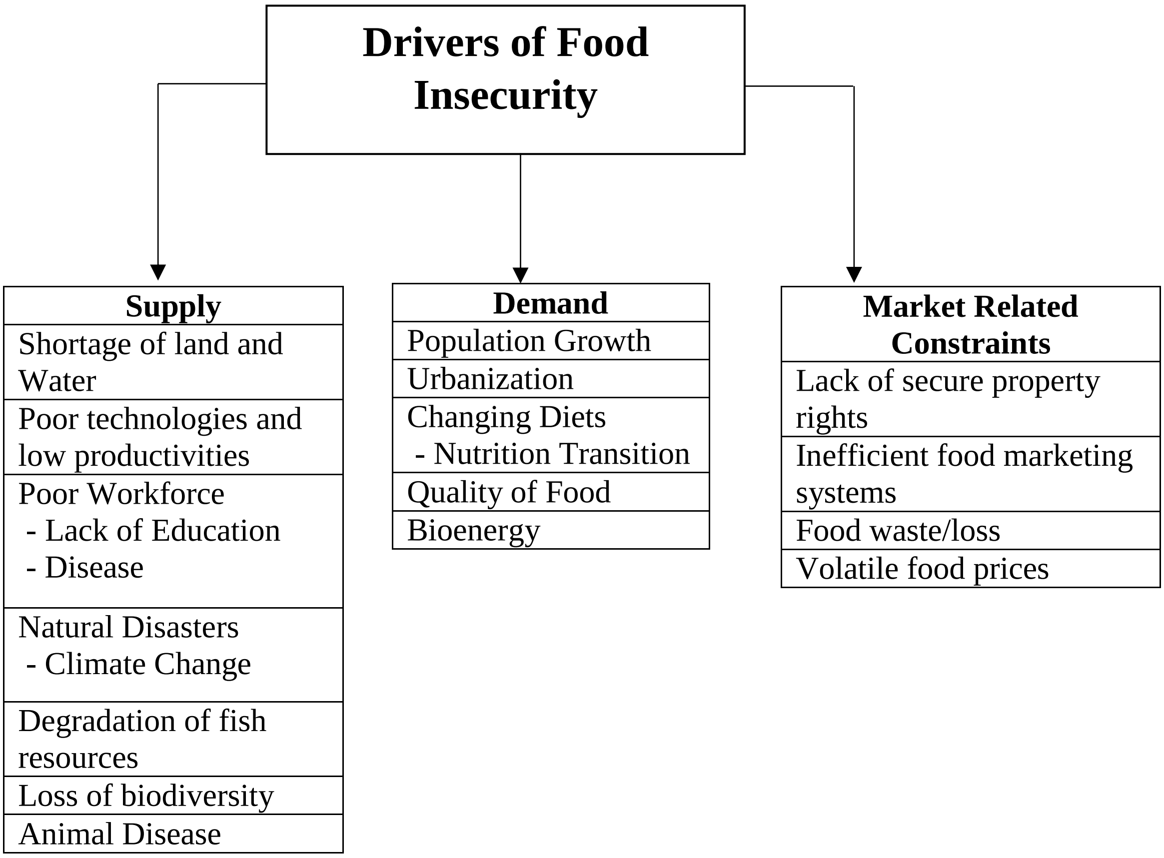


Figure 1.3: Drivers of food insecurity

(Adapted from Godfray et al., 2010a; Sonnino et al., 2013 Grote 2014)

Pressures related to demand coincide with an increase in population growth and urbanisation as a result of increasing wealth (Godfray et al., 2010a). Population growth is expected to reach 9.1 billion by 2050 and it is estimated that 70% of the world's population will be urban by 2050. This figure was 49% in 2009 (FAO, 2009). Furthermore, the global demand for food and feed is expected to grow up to 70%. As such there is an evident need for an increase in food production in order to feed a larger, more urbanised, richer population. This is also a requirement as crops are also increasingly being used for alternative sources (FAO, 2009). Biofuels have added to competitive pressures, and further increase the amount of food that will be required to feed a continually increasing population (Godfray et al., 2010a). On the supply side of the food system, pressures relate to access and availability. This includes an increase in competition for land, energy and water, as well as environmental concerns like climate change which have been identified as having significant impacts on the food system (Rosenzweig et al., 2001; Grote, 2014).

1.2.1 Technology as a food security solution

As mentioned in the introduction of this thesis, the role of technologies in addressing food security displays promise. Advances have not only proved beneficial for the agricultural environment (Runge et al., 2003), but have also been identified as a necessity for food security (Godfray et al., 2010). It is not unusual for studies that focus on drivers of food insecurity to posit the need for technology as a solution. For example, this has been the case in the discussion of challenges posed by declining investments in agricultural research, irrigation and rural infrastructure (Godfray et al., 2010b) and challenges caused by continuing population and consumption growth (Godfray et al., 2010a). Technology has also been argued to be a necessary requirement to address challenges to food security caused by climate change and HIV, among other diseases (Rosegrant & Cline, 2003).

Calls for technology to address food security have also been prominent in food security practice. Goal two of the SDGs ('zero hunger') speaks to food security. It not only aims to end hunger and ensure access to food for all by 2030, but recognises the need to double agricultural productivity through increased investment in agricultural research and technology development. This is emphasised in SDG 2A which calls for:

> "*Increased investment, including through enhanced cooperation, in rural infrastructure, agricultural research and extension services, technology development and plant and livestock gene banks in order to enhance agricultural productive capacity in developing counties, in particular least developed countries"* (UN, 2015).

The need for technology to achieve food security was also emphasised in the strategic responses to the food price crisis by the international community. The UN High Level Task Force developed a comprehensive framework for action to reduce hunger and malnutrition. This was to help achieve the immediate food and nutrition security needs of the most vulnerable populations and a number of outcomes and actions were identified. Within this an emphasis was placed on the importance of ensuring food productivity by smallholder farmers and the increase of food availability. Necessary actions included the need for technical advice, increased investment in agricultural research, and the need for technologies to increase productivity. Importance was also placed on technologies that address climate change and soil health (UN-HLTF, 2011).

As previously mentioned, actors at the L'Aquila G8 summit considerably increased financial resources to achieve food security. It was acknowledged that continued technological innovation is essential to address drivers of food insecurity. As such it was agreed through the L'Aquila Food Security Initiative that one priority should be the increased investment and access to technology at all levels as well as the improved dissemination of new technologies (AFSI, 2012). The importance of technology has also been recognised through the Five Rome Principles for Sustainable Global Food Security. It acknowledges that increasing productivity is the main means to meet increasing demand. Therefore it not only highlights the importance, but aims to enable smallholder access to technologies, offer technical support, mobilise resources to ensure increased productivity and adoption of technologies, and to promote agricultural technology research and access to its results (World Food Summit, 2009).

1.3 Technology as a food security solution: a scientific perspective

The need for technology is well emphasised in both scholarship and food security practice. As such this is the subject of considerable research within the field of biological sciences. Studies have looked at the benefits of technology and their potential food security applications. This thesis does not focus on specific technologies. Rather it aims to assess the interaction between technical and political practice. However to review how the field of biological sciences approach research on technology in a food security context, it is useful to draw on examples from specific technologies. There are three technologies that have received (and are beginning to receive) increased academic attention with regards to their potential in alleviating food security challenges: biotechnology, nanotechnology, and synthetic biology. This section provides a brief overview on some of the literature that has researched these types of technologies and their benefits to food security.

Biotechnology has been identified as a defining technology of the 21st century (Lang & Heasman, 2004). The existing literature provides an array of potential biotechnology applications that contribute to food security. Numerous studies have demonstrated the agronomic, economic and farm welfare benefits of GM crops. This is a result of increased yields, increased farmer profits and increased productivity as a result of cost savings in production and the reduced use of chemical pesticides (Pray et al., 2002; Qaim & Zilberman, 2003; Huang et al., 2004; Qaim & Traxler, 2005; Klumper & Qaim, 2014). It is claimed that genetic engineering of crops has also allowed for the development of insect resistant transgenic plants by using genes that include secondary plant metabolites. Such genes have been inserted into a wide variety of crops (Sharma et al., 2002). Genetic engineering has also been shown to contribute to the nutritional enhancement of crops. This includes the addition of missing nutrients as well as the increase in nutrients already present (Farre et al., 2011). It has also been argued that scientific advances have proven beneficial in providing substantial increases in crop yield growth. Beddington (2010) presented evidence that showed an increase of 2.8% in cereal yields between 1961 and 2004 in East Asia. This, they note, was the result of the application of technological advances.

The application of molecular breeding and genomics is another form of biotechnology that has received academic attention. The application of genome sequences have been shown to have potential in identifying suitable genes related to stress tolerances which, it is argued, can subsequently be employed in crop improvement and increased productivity (Varshney et al., 2011). Further, it has been argued that the identification of genes and markers may also lead to increased crop variety, quality, and tolerance to disease (Edwards & Batley, 2010). To date genomic sequences have been identified in a number of crops including rice and maize (Shnable et al., 2009).

Biotechnology is perhaps the most recognised technology as a result of visceral debates surrounding genetic engineering and its application in food matrices[6]. So far its application in solving food insecurity has been discussed in this section, however research into the applications of nanotechnology and synthetic biology for food security is also increasingly rising[7]. Some of the potential food security applications of these two technologies are presented in table 1.1, which shows how they speak to a range of food security requirements.

All of the studies mentioned in this text of this section (on biotechnology), and in table 1.1 (on nanotechnology and synthetic biology), make reference to food security. For some it is the sole focus of their papers, for others it is mentioned in passing. That is, they include a

[6] These debates are discussed in greater detail in Chapter three of this thesis.
[7] Nanotechnology is the manipulation and control of matter at dimensions of nanoscale. This ranges from approximately 1 – 100 nanometres (EFSA, 2009). Synthetic biology is the merging of biology and engineering (Schmidt et al., 2009).

sentence or two noting that the implementation of their discoveries may prove beneficial in achieving different dimensions of food security and addressing related challenges. Regardless, this shows a clear acknowledgement from the field of biological sciences on the importance of technology for food security purposes.

Table 1.1: Examples of the potential food security applications of nanotechnology and synthetic biology

	Factors of Food Security		
Technologies	Productivity	Sustainability	Safety
Nanotechnology	- Nanoencapsulation for enhanced target delivery of genetic material / nutrients resulting in increased efficiency of functional foods and crops (Weiss et al., 2006) - Nano based smart delivery systems can increase the efficiency of pesticides at lower dosage rates (Mousavi & Razaei, 2011) - Nano bioengineering can be used to enhance the bioavailability of water insoluble vitamins and minerals (Prasanna, 2007) - DNA sequencing in nanofabricated gel free systems can enhance the progress in molecular-assisted breeding for crop improvement (Prasanna, 2007)	- Use of Quantum Dots for plant and animal health diagnostics (Valizadeh et al., 2012) - Nanoshell implants in livestock can be used for early disease detection (Patil et al., 2009) - Nanoparticles have been proved beneficial for the remediation of contaminated soils (Tungittiplakorn et al., 2004; Karn et al., 2009) - Disease outbreaks hinder the sustainability of aquaculture and fisheries. Nanoparticle vaccine carriers may contribute to high levels of protection to fish and shell fish against bacterial and viral diseases (Rather et al., 2011)	- Food pathogen and mycotoxin detection / monitoring via nanosensors and nanobased smart delivery systems (Dingman, 2008; Valdes et al., 2009; Mousavi & Rezaei, 2011). - Nanoparticles in food packaging and processing can detect, inhibit and monitor pathogen growth (Duncan, 2011) - Nano barcodes and 'smart labels' as ID tags to ensure food safety, authenticity and traceability (Chaudhry & Castle, 2011) - Nanotechnology has been used for the purification and desalinisation of water by breaking down organic pollutants and toxic metals and eliminating pathogens (Chaudhry & Castle, 2011; Sastry et al., 2011) - Nanomaterials can be used as alternatives to more time consuming and costly

<table>
<tr><td></td><td>- The application of metal nanoparticles at varying concentrations have been shown to have a positive impact on seed germination (Shah & Belozerova, 2009; Sastry et al., 2011).</td><td></td><td>chromatography techniques to detect pesticide residue limits. This may help farmers re-establish dosage rates and frequencies (Khot et al., 2012)</td></tr>
<tr><td rowspan="2">Synthetic biology</td><td>- Redesigning of photosynthesis to improve crop yields (Raines, 2010; De Paoli et al., 2014)

- Used in biofuel production (Savage et al., 2008). This decreases the use of animal feed for this purpose, which affects food security by increasing food processing and altering patterns of food production (Tokgoz et al., 2009)</td><td>- The use of synthetic site specific nucleases to aid engineered plant genomes can contribute to the designing of plants tolerant to abiotic and biotic stresses. This results in the decreased use of pesticide and fertiliser use (Kathiria & Fudes, 2014)</td><td>No literature available.</td></tr>
<tr><td colspan="2">- The application of synthetic meat (using cell culture techniques) may answer concerns about food availability. Researchers have currently developed a synthetic burger (Jha, 2013) and synthetic chicken meat (Scott-Thomas, 2015).

- Engineered synthetic stress response systems and associated signalling networks in plants may allow for the development of defence mechanisms (not yet evolved in plants) against variable climate conditions and invasive plants and diseases (Fesenko & Edwards, 2014).</td><td></td></tr>
</table>

1.3.1 Challenges to the implementation of technology

There is no shortage of literature within the field of biological science that focuses on a variety of technological innovations as food security solutions. However, studies that consider these technologies from a science perspective and also engage with social and political issues are more limited. Further, those that do engage in this area, tend to consider 'politics' through a narrow lens. Premanandh (2011) highlights the important contributions that modern technologies play in ensuring food security and sustainability. This research details the factors that affect food security, and note that political will is a necessity to ensure technologies are utilised to their maximum potential. While this study touches upon politics from a science perspective, 'political will' is solely confined to policy regulations which, it is argued, need to be relaxed.

Political issues are often framed as challenges to the benefits and opportunities of technology. This has been argued in the case of nutritional enhanced crops, where political expediency has been argued to have negative consequences on the opportunities that technologies provide (Farre et al., 2011). In this case the term 'politics' is used broadly however it is apparent that the understanding of what constitutes as political issues are actually somewhat restricted. Farre et al reduce politics to the effects of manipulation, sensationalism and propaganda by activists, the media, the public and politicians. This was also the case in a previous study by the same lead author. This paper argued that major challenges to the adoption of technological innovations are political, rather than technical. However, the claim that 'politics' minimised the potential of technology was also based on a narrow perspective of the term. It was restricted to legislation and perception of advocate groups, the public and the media (Farre et al., 2009).

Similarly, when also focusing on nutritionally enhanced crops, Hefferon (2015) discusses how political factors present challenges to the uptake of technology but these political factors are also restricted to perception issues and propaganda related to this. Yuan et al., (2011) also reference irrational political handling as a significant barrier to the uptake of technological innovations. They note that scientific progress is hindered by the actions of politicians which are shaped by popular support and sensationalism created by NGOs and other such advocate groups. These studies not only raise some of the perceived challenges to the implementation of technology, but indicate that while some science based academics do highlight issues of a ‘political’ nature, these forms of engagement are superficial. There is a seemingly narrow understanding behind what constitutes as a political concern.

While these studies highlight a lack of understanding, they also draw attention to the challenges posed by perception. Public perception has received considerable attention as a challenge restricting the implementation of technologies that have potential to help address food security concerns. Genetic modification (GM) is a prominent example of a technology that has been the subject of publicised controversies surrounding its risk and benefits within the food system (Sharma et al., 2002; Azadi & Ho, 2010; Chen & Lin, 2013). It has been substantially argued that GM crops are safe for both the environment and human consumption (Dale et al., 2002; Brookes & Barfoot, 2010; Qaim, 2009; Snell et al., 2012; Brookes & Barfoot, 2015), with the World Health Organisation declaring that GM foods on the market are not likely to cause any more damage to human health than their counterparts (WHO, 2005). Further, a meta-analysis on the adoption of GM crops found that this not only increased crop yields by 22% and farmer profits by 68%, but it also reduced the reliance on chemical pesticides by 37% (Klumper & Qaim, 2014). Such claims are often viewed as indirect remarks. They do not show a full picture. It is important to highlight that in practice GM crops are only considered safe when stringent safety tests have been performed, and compliance is met (Cockburn, 2002; European Commission, 2010; König et al., 2004).

It has been argued, however, that research into the benefits and potential implementation of GM technologies are misleading due to methodological flaws (Glover, 2010). In addition, Domingo & Bordonaba (2011) argue that assessments of the safety of GM for human consumption are conducted by biotechnology corporations responsible for the commercialisation of the strain or crop in question. Criticisms surrounding GM have resulted in research refuting these concerns, but also attempts to understand how this shapes perception.

For example, research has been conducted to understand the process of how citizens formulate attitudes and perceptions on food applications of nanotechnology, genetic modification and irradiation techniques. It finds that beliefs, values, relevance to their own personal lives (among other factors), contribute to shaping perspectives (Greehy et al., 2013). It has also been argued that negative societal responses surrounding GM include ethical concerns, perceived ‘unnaturalness’, a lack of policy implementation surrounding traceability, and inequalities between developed and developing countries (Frewer et al., 2011).

1.4 Technology as a food security solution: a political perspective

As shown in **figure 1.2,** the last decade has seen an increase in publications in the social sciences. Figures from Web of Science (ISI) database indicate that the number of publications within the field of International Relations (IR) increased from seven in 2009 to two hundred and forty six in the first five months of 2019 alone. While this increase is promising, attention in this field is still relatively modest. As such, it is first useful to situate food security in the field of politics, particularly within International Relations and Security studies.

Achieving security involves the alleviation of threats and vulnerabilities (McDonald, 2010; Bourne, 2014). Security has long been the focus of academic research with traditional threats such as the military capability of states and nuclear proliferation, for example, still receiving attention today. However the global security landscape has led to new challenges and many contemporary security concerns like terrorism, drug trafficking, infectious diseases, and so forth, which operate in different ways to traditional security challenges. While these challenges transcend the borders of states, they generally are not linked to the behaviour and policies of individual states (Matthew & Shambaugh, 1998; McDonald, 2010). These new modes of security have instigated a shift in its conceptualisation whereby it has been broadened to include issues of health, urbanisation, environmental degradation and also, more increasingly, food. These are threats and vulnerabilities that can be felt in the daily lives of people and are often encompassed within the notion of human security. The concept of human security was addressed in the United Nations Development Programmes 1994 report on human development. The achievement of human security protects people from both freedom from want and freedom for fear and food security was identified in this report as one of seven overlapping dimensions that pose a threat to this (UNDP, 1994; McDonald, 2010). The UNDP report talks about the importance of entitlement within food security. People are entitled to food by growing it for themselves or buying it. This concept of entitlement is strongly emphasised by Dreze & Sen (1989) in their book ‘hunger and public action’. They argue that failure to establish entitlement by ensuring availability and access to food will result in hunger which has been recognised as a pervasive vulnerability in human security (UNDP, 1994).

The cumulative effect of the food price crisis, climate change, population growth and energy scarcity has driven political interest in food security (Death, 2011). Research has focused on hunger, environmental changes, and the strategies of powerful interests (McDonald, 2010; Death, 2011). Shepherd (2012) considers the conflict between food security scholarship on food insecurity and hunger, and the actions of states to maximise their control over food supplies and resources for production. This study argues that food security favours certain actors whereby those with more power can use this to compete for advantage in a resource strained world. Food safety has also received attention in the field of Security Studies. Food as a vessel for bioterrorism is one example. The intentional contamination of food and water is reportedly one of the easiest ways to distribute biological agents for the purpose of harm. This is particularly effective due to the globalised nature of the food system, allowing for the rapid delivery of intentionally contaminated goods to large amounts of people. While these types of attacks have been used to discredit a political or economic competitor, it has also been argued that they prove detrimental to food security. The impact is not only felt at a state level, but at an individual level. It affects livelihoods, incomes, availability and access to food resources (Khan et al., 2001; Chyba, 2002; Wein & Lu, 2005). Addressing these types of threats to the food system and global health is an integral part in maximising human security (McDonald, 2010).

All of these studies present an insight into some of the existing food security research within this field. However, these particular pieces of research do not consider technology as a solution. This has actually been the subject of research in itself whereby attention has been given to the use of science and technology and how it responds to various social, political and economic variables. For example it has been argued that science and technology do not fit well into International Relations research and practice. Weiss (2005) argues that this relates to the variety of processes involved within this. Rather than allowing for a determination of a single causation, science and technology responds to a variety of social, political, economic, and cultural influences. Nevertheless, Weiss goes on to argue that science and technology not only influence international affairs, but international affairs also directly and indirectly shape science and technology (Weiss, 2005; 2015).

Weiss uses genetically modified crops (among other examples) to help illustrate this claim. He notes that the development and evolution of genetically modified crops were shaped by international affairs as their future was influenced by European restrictions on import. This in turn had economic implications for the American agricultural sector. Further, the action taken by the EU was encouraged by strong reactions from the public as well as environmental, religious and philosophical advocate groups. On the other hand, GM crops affected International Relations as they contributed to the creation of new issues. They gained a place on the international agenda, led to the development of new strands within international organisations, and significantly highlighted international issues of intellectual property (IP) (Weiss, 2005).

Research on science and technology in the field of International Relation is increasingly prominent (see for example Fritsch, 2011; Mayer et al., 2014; Davidshofer et al., 2016). However, there is little that considers this through the lens of food security. Further, the literature that does engage with technology and food security tends to more often identify challenges, and make arguments, that emphasise the problems associated with this approach to achieving food security. The following sections look at this literature.

1.5 Criticisms of technology

While there is a wide body of literature, particularly within the field of biological science, on the potential of various technologies to provide solutions that can contribute to ensuring food security, there are also challenges which impede this. Olivier De Schutter, the previous UN special rapporteur (2008-2014) reports that the application of scientific technologies may not necessarily, or adequately promote the basic human right to food whereby "[the] spread of certain technologies may not be best suited to certain categories of users" (De Schutter, 2011: 309). Such critique is not an anomaly, with numerous social, economic and political concerns facing the use of scientific technologies in addressing food security. These concerns have included those of an ethical nature (Bennet et al., 2013), apprehension surrounding environmental and health effects (McDonald, 2010) and subsequent negative societal perceptions (Frewer et al., 2011). Challenges to technology have received attention within both fields. Section 1.3.1 of this chapter reviews the literature on this from a science perspective. This section will review the literature on this through the lens of political and social science.

There is no shortage of research on technology within the field of biological science. These studies all refer to food security in various extents. For some it is the central theme of their paper, and for others there are a few sentences on how their discoveries will be beneficial for food security. Nevertheless there is one main take home message that is clear: technology is an important factor for food security. As such through this type of research developing technologies, increasing yields, maximising efficiency and promoting production is seen as a goal of food security. However, this is a deeply contested view among the political and social science literature.

In a critical analysis, Nally (2016) set out to expose the power dynamics of what he defined as 'hungercrats' in changes to the policy landscape correlating with the new global consensus of food security that emerged after the food price crisis. He argued that this new vision was deeply problematic (food security controlled the poor under the pretence of doing them good) and in supporting this claim, he presented a number of mythologies about global insecurity that let lent legitimacy to dominance. Nally presented four myths in total, however one is particularly pertinent to this review – 'technology is a solution to global hunger' (p. 5).

In supporting this claim, Nally gave five reservations on the use of technology as a solution for food security. Firstly, Nally argued that technology has the potential to deflect attention from more urgent social reforms in such a way that contributes to 'de-development' and the creation of new patterns of dependency. Secondly, he drew attention to labour concerns. In countries where under- and unemployment are chronic issues, the importation of labour saving technologies will be a further hindrance. Thirdly, there is commercial and corporate bias. Corporate control of technological processes, Nally argued, means that R&D is directed to commercially successful products as opposed to those that are nutritionally or culturally valuable. Fourthly, technology has been used to recalibrate how their users think and conduct themselves. Nally argued that the new vision of food security envisioned technology as cultural tool capable of "modernising the minds and habits of the poor" (2016:10). Finally, the complex issue of ownership is rarely discussed. In sum, it was noted that whilst technology can be pro-poor, it is rarely given the opportunity when R&D is controlled by powerful businesses.

Nally presents valid arguments that are well articulated and supported by practical examples, but they are also too absolute. While it can be agreed that the international community's views and visions for the use of technology, on the back of the food price crisis, can be problematic to food security, Nally writes in a definitive sense. He predominately focuses on criticising the actions of the 'elite' with regards to technology without acknowledging potential benefits, or ways that the examples he presented, can be used for good and contribute positively towards the use of technologies in achieving food security. Nor does he suggest a more viable approach. Nevertheless, the views of Nally are well supported in the literature and a variety of criticisms exist.

Research has been conducted that considers how biotechnology shapes power relations between different actors within global agriculture, arguing that technology has been used as a way to exert power, accumulate wealth and control food production globally (Barbosa Jr & Pfrimer, 2018). From a UK perspective, Tomlinson (2013) argued that there has been an over emphasis on the production aspect of ensuring food security. This particular research criticises the use of statistics that claim a significant increase in food production is required. It is argued that this not only contributes to already existing problems in the global food system, but can be used as a tool by dominant institutions to aid their ideologies on particular approaches to food security.

1.5.1 Market concerns and political economy

The food price crisis has been credited with contributing to bringing the political economy of agriculture back to the forefront of international trade and development agendas (Swinnen, 2010). At a practical level food price fluctuations in the global market resulted in trade deficits in many countries. This contributed to increased poverty, particularly in developing nations (Harrigan, 2012). From an academic perspective it has been argued that agricultural intensification is detrimental to existing political economy in Northern Ghana, offering smallholder farmers limited to no support. The same study also finds that hybrid seeds are politicised even at a household level (Nyantakyi-Frimpong & Kerr, 2015).

Nally (2010) argues that neoliberal regimes present multinational corporations, agricultural biotechnologies and global markets as preconditions for the alleviation of world hunger. This particular piece of work is critical of the over emphasis on the availability dimension of food security, noting that there is no correlation between the regulation of food scarcity and ending hunger. It has also been argued that the political economy of GM can negatively affect gender relations. Exploring the influence of GM on smallholder farmers in Vietnam, Bonnin & Turner (2014) found that hybrid crops only set to increase vulnerabilities in smallholders and households by contributing to tensions of gender ideologies, and uncertainties associated with access to seeds and cash flow.

1.5.2 Intellectual property

Intellectual property (IP) has been identified as one of five significant policy decisions in developing countries on the use of genetically modified crops (Paarlberg, 2001). It is noted that from a private sector perspective IP provides an incentive for investment. Without it there is little commercial drive due to the potential of competitors being able to copy new technological developments. It has also been argued that IP can be used for humanitarian purposes and the lack of protection provided by patents can create challenges for the export of crops and other food sources (Farre et al., 2009).

The use of IP however has also received criticism in the literature. It has been argued that the introduction of patent laws for biotechnology industries to protect their IP contributes to market failures in developing countries. This hinders their ability to access and avail of the benefits of GM technologies (Byerlee & Fischer, 2002; Chi-Ham et al., 2012). While policy options and IP incentives in agricultural biotechnology for developing countries have been put forward, market related concerns still exist. It has been argued that the strengthening of IP can alter the balance in relationships between those that retain technology and those that need to use them. This presents economic consequences to farmers (Trommetter, 2008; De Schutter, 2011).

Conducting a case study in the developing regions of the South Pacific, Forsyth & Farran (2013) found that the introduction of intellectual property right (IPR) strategies may correspond with the priorities of international bodies and trading partners. This often ignores the needs of local communities. It has been noted that difficulties relating to IPR frameworks lie with the translation of novel research to developing countries.

It poses an ethical dilemma that reinforces a 'poorer' versus 'richer' country narrative (Serageldin, 1999; Runge et al., 2003). Further, it has been argued that strengthening IPR may present tension when ensuring the human right to enjoy the benefits of scientific progress (De Schutter, 2011).

1.5.3 Public perception

While public perception has been mentioned previously, this is on the understanding that it is seen as a barrier to the progress of technology from a scientific perspective. Public perception has also received attention from a social science perspective. Public perception of genetically modified crops has been used as an example to illustrate how international affairs influences the development of science and technology. The work of Weiss argues that the reactions of religious and philosophical groups in Europe led to import restrictions of GM crops which had economic implications at a global level (Weiss, 2005; 2015). It has been noted that consumer uncertainty about the meaning of food security, and problems facing the food system, render the public perception of food security technologies problematic. This is on the basis that the dichotomy between science and food security is not one that exists or is fully understood by the lay public (Kneafsey et al., 2013).

Public perception in developed continents, such as Europe, have been argued to have detrimental effects in decisions made by governments in developing countries. In exploring the impact of genetically modified crops in Africa, Paarlberg (2008) argued that governments and urban political elites, with limited knowledge of the challenges facing smallholder farmers, have contributed to the rejection of GM crops and the adoption of precautionary approaches similar to that adopted in Europe. Paarlberg notes that this is not only out of deference to the European approach, but that it is not a good fit to the need of developing countries.

Further, it has been argued that the emphasis on public perception in developed countries has seen a decrease in R&D investments. This has subsequently had a knock on effect in developing continents, such as Africa, as international assistance in these areas are also withdrawn (Paarlberg, 2008). This has also been identified through research on the use of GM in the United Kingdom and Australia. Dibden et al (2013) argue that debates occurring in developing countries actually stem from unharmonious views regarding visions on the future of farming in developed countries.

1.6 Conflicting food security narratives

The divide between technical aspects of food security and the social, political and economic aspects are further intensified by conflicting food security narratives. This is an area which has received attention in the social sciences. These narratives partly link with demand versus supply based drivers of food insecurity that were introduced in section 1.2 of this chapter. It has been argued that food security tends to focus more on the supply side of the food system as it appears to emphasise food production (Pinstrup-Andersen, 2009; Sonnino et al., 2013). Despite this, it has also been claimed that demand is likely to outweigh this as a priority in the future (Kannan et al., 2000; Chand, 2008).

Two narratives, which present two very different solutions to how food security is resolved, have been conceptualised in academic research: productivist versus demand led approaches. The productivist approach has long been an overarching perspective of food security. Feeding the growing population is central to this narrative and therefore it tends to be supported by powerful actors such as the World Bank Group, the World Trade Organisation, and the FAO (Sonnino et al., 2013). The productionist paradigm has seen a shift from local, farmer led, small scale production to the mass production of food. Its primary goal is to increase output (Lang & Heasman, 2004). Conversely, demand led approaches view food insecurity as a lack of access to food (Sonnino et al., 2013). Advocates of the demand led narrative argue it is vital that focus is put towards enhancing the resilience of both local and regional systems (Clapp, 2014; Jarosz, 2014).

A key difference between these narratives are the views on the use of technological resources. The productivist approach enforces the need for innovation in science and technology to increase food production and crop resilience. Supply based drivers of food insecurity often situate around addressing the ‘yield gap’. This is defined as the difference between realised productivity and the best that can be achieved using available technologies. This however is also the focus of critique, particularly as it relates to the over emphasis on the use of technology. Despite being described as a powerful framing device, it has been argued that yield gaps are often too loosely constructed by policy advocates to support existing narratives or policy options (Sumberg, 2012). Further, proponents of the demand led approach criticise the prioritisation of technological responses over local technologies and knowledge systems. The food price crisis highlighted a concerning imbalance between demand and supply drivers of food insecurity which have largely been ignored (Cribb, 2011). There is an inelasticity in the food system, with food supply responding slower than demand (Evans, 2008). As such it has been argued that approaching these drivers of food insecurity as a collective may render the productionist approach less likely to resolve vulnerabilities associated with food insecurity at an international level (Sage, 2013).

These narratives are important to mention as they not only highlight the variety of approaches to food security, but place further emphasis on the diverse views on the use of technology. It particularly reinforces the critical views of technology and food production as a solution.

1.7 Food security should go beyond the technical

Another area that has received attention in the social sciences is the argument that technical dimensions of food security are commonly and unjustifiably the sole focus of research. This is often at the neglect of other dimensions such as political, economic and environmental factors. It is noted that debates and existing narratives on food security are inherently technical and it is notions of technological change that occupy the most space on policy debates. Subsequently there is a growing body of literature that reinforces the importance that social science plays within this.

It has been observed that the importance of social science has been recognised within other disciplines of science and the assessments of policies within this. However this has not been adopted within an agri-food context (Rivera-Ferre, 2012). Rivera-Ferre argues that different discourses and understandings result in different framings of research and, subsequently, completely different solutions for hunger. As such there is a need for a paradigm shift whereby the need for more interdisciplinary research is not only encouraged, but an emphasis is placed on the critical role that social sciences play in this process. Focusing on rice intensification systems in India, Taylor & Bhasme (2018) argue that current debates are too technical in scope and as such advocate using a political ecology framework to explore the process of adoption and access to intensification processes. This work indicates a shift in perspective, but it does not tell us anything about how technology and 'politics' come together in this context.

A similar argument has been made by Thompson & Scoones (2009) who argue that policy space within the agri-food sector is dominated by technical dimensions. They note that despite technological innovation, significant challenges to food security continue to persist. It is argued that this is a result of the existing emphasis on the technical solutions which fails to provide sustainable outcomes on its own. Thompson & Scoones discuss a variety of challenges, the contributions that technology has made (both positive and negative), and potential alternatives to overcome challenges to ultimately argue for and outline an interdisciplinary research agenda. Berners-Lee et al., 2018 also present a practical example of the importance of considering factors beyond the technical when it comes to ensuring all of the populations nutritional needs are met by 2050. By conducting a quantitative analysis of global and regional food supply systems, they argue that while there is enough food to feed the growing population by 2050, this depends significantly on socio-economic conditions. If the actions of society remain as they are at present, an increase in food production of over 100% while be required. While this highlights the need for these factors to work closely together, this study could benefit from the authors explicitly stating this.

1.8 Science-politics interface

Thus far this review has focused on the differences in approach between the fields of biological science and the social and political sciences when considering technology. However, it is important to acknowledge that some research does exist at the interface of these fields, particularly through the identification of underlying problems in practice. This is often approached through the lens of science for policy decision making. For example it has been argued that scientists lack the language to communicate with policy makers and vice versa (Gregich, 2003), and that the overuse of scientific research based evidence in political decision making can remove the scope from value based political debate (Weingart, 1999).

By focusing on the research-policy nexus for food security and global environmental change, Holmes et al., 2010 argue that using science based evidence in policy decision making is actually controversial due to a lack of shared understanding on the term ‘science’. Rivera-Ferre (2012) also considers the role science plays in policy making. It is argued that providing evidence based science to decision makers creates a form of political authority for scientists that specifically considers the challenges posed by different fields (social and natural sciences) conducting research on food security. This study further argues that this results in either a simplistic analysis or one that is too complex. The critical role of social science within this frame of research is emphasised and the importance of a paradigm shift to not only encourage more inter-disciplinary research, but research that is coherent and subsequently relevant, is highlighted.

While this review has highlighted a considerable difference between how these fields approach technology and food security, this observation is somewhat contradictory to the numerous calls from scholars for interdisciplinary research. There is an increasing emphasis in the literature on the importance of interdisciplinary research within food security (see for example Godfray et al, 2010a; Ingram, 2011; Foresight, 2011; Rivera-Ferre, 2012; Benton 2016).

Research has been conducted into the opportunities and challenges of interdisciplinary research in the study of agrifood. Hinrichs (2008) argues that attempts to achieve interdisciplinarity can both increase and reduce divisions between different groups both in practice and in an academic context. This however is a relatively short piece of work that makes these conclusions based on only one UK example. Interdisciplinary research has also been highlighted as imperative to improve food production while also ensuring conservation of the environment (Acevedo et al., 2018). For example this study argues that bringing together food production and environmental conservation requires a full spectrum of natural and social sciences to conduct research that integrates science, policy and action. This has also been recognised beyond a research context. The coming together of stakeholders within natural and social sciences have been argued to be a requirement to address numerous food security challenges through the maximisation of production by the means of scientific progress (Karunasgar & Karunasgar, 2016).

All of these studies acknowledge the need for inter-disciplinary research, and the important contributions that the social sciences can make in collaboration with fields in natural science. However, this is often where these arguments and conclusions end. That is, they fail to engage key conceptual questions further. Interdisciplinary research is necessary, but in what ways do forms of science and politics come together? What ways do they divide? And how does this impact food security? This presents a significant gap in existing knowledge.

1.9 Critical analysis and conclusion

It is apparent from the existing literature that diverging views exist. This is evident through conflicting debates on productionist versus demand narratives, but also through the research conducted within different fields. While there is a considerable amount of literature on existing and novel technological solutions to achieving food security within the field of biological sciences, this is not the case from a social and political science perspective. Food security research in this field is a relatively new development with the focus often on hunger and malnutrition, environmental changes, debates on land acquisitions for agricultural development, and food safety and disease (McDonald, 2010; Death, 2011). Therefore an assessment of how technology is perceived is not as easy to engage. This review has shown that examples exist whereby social scientist examine the intersection between technologies and various social, political and economic perspectives / variables (Jasanoff, 2004; Weiss, 2005). However, there is also an abundance of examples that indicate that when the field of politics does engage with technology in a food security context, this literature, for the most part, either criticises the use of technology and the emphasis on technical dimensions within food security, or argues along the trajectory that too much technology is not beneficial. It does not diminish the need for technology, but recognises that other approaches should also be considered. This is particularly apparent through the work of Nally who is openly critical of the role of technology as a solution to address hunger (see section 1.6). In a document wrote for the UN, Nally later went out to argue that technology is necessary, but should only be considered as one piece of a much bigger puzzle (Vira & Nally, 2013). Similarly, there is little in the field of biological sciences that engage issues of a political nature, and when they do, a nuanced understanding of what constitutes as ‘politics’ is apparent. That is, politics is often defined and restricted to policy or the politicisation of science as a result of perception issues.

Literature does exists that considers technology from the perspective of both disciplines, however there is little that actually engages both technology and social, political and economic factors. Food security is inherently multi-disciplinary and the importance of this in achieving food security is emphasised. While there are an increasing array of studies that highlight the importance of interdisciplinary research there is little that identifies where and how these fields interact. There is a clear gap to understanding how these fields come together, how they divide, and what impact this has on food security. It is this gap that this thesis will begin to contribute to.

Chapter two: Conceptual toolkit and methodology

2.1 Introduction

Based on a review of the literature this research aims to understand where forms of science and politics comes together, where forms of science and politics divides, and the impact that this has on food security. The following research questions will be considered:

- What forms of knowledge are being prioritised and created?
- How is this organised and translated in particular practices?
    - What ways are forms of science, and politics entwined? How are these interactions negotiated?
    - How are practices represented and undertaken at different levels?
- What impact does this have on food security?

In order to address the aim of this research, an approach is needed that does not situate forms of science and politics as inherently separate and allows types of interaction between 'science' and 'politics' to be registered. As such this chapter introduces the conceptual tools that will be used throughout this thesis to undertake this. It presents a case for using a co-production perspective, and exploring forms of boundary work within this as core tools to identify where science and politics communities connect and disconnect in food security practice.

This chapter begins by looking at how academic understanding on the interaction between science and politics as different knowledge forms and practices has evolved. It considers how different communities analyse these different forms of knowledge. Following this, co-production is introduced. What it is, how it can be used, and the relevance of using this within the scope of this research. This section considers science and politics as different knowledge forms and identifies ways in which interaction between them can be registered. Boundary work is then introduced as tool that allows for the identification of how boundaries are made and how they are crossed through the use of boundary objects, and boundary organisations. The next section explains how this conceptual toolkit will be used within this thesis. The final section of this chapter lays out the research methodology used within this thesis, explaining the key groups that this research engages, and the methods undertaken to collect and analyse the data.

2.1.1 The evolved understanding on the relationship between science and politics

In a post-World War Two report to President Franklin D. Roosevelt on scientific research and development, Vannevar Bush advocated for the importance of basic research – the creation of knowledge for its own sake (Godin, 2006) – arguing that this approach was the "pacemaker of technological progress" (Bush, 1945). This paved the way for positivist views of science that occupied thinking and practice in the 1950's and 1960's.

In practice, a good training in scientific fields was seen as a trait that put a person in an authoritative stead both within their own field and beyond. For many social scholars of science and technology the aim was to reinforce the success of science rather than to question its basis (Collins & Evans, 2002). This approach was the basis of one of the first theoretical models used to understand the relationship between science and politics when considering technology - the linear model of innovation - which treated science and politics as separate entities (Godin, 2006; Pielke, 2007). It stipulated that agreement on science and scientific knowledge must be reached as a prerequisite for political consensus, and only then should policy action occur (Pielke, 2007).

This approach however has been subject to many criticisms (Guston, 1999; Godin, 2006; Sarewitz, 2016). The top-down manner in which many decisions about science seemed to occur have been viewed as politically naïve (Lawlor, 2003), unrealistic (Branscomb, 1988), and too 'utopian'; science always results in more than one political outcome (Pielke, 2004). Further, in practice there is a general consensus that such deterministic models advocating for the strict separation of science and politics renders decision making irrelevant (Jasanoff, 1990).

As such a re-examination of this form of relationship led to the utility of what Funtowicz & Ravetz defined as 'post-normal science' in the early 1970's; "…a new, enriched awareness of the functions and methods of science is being developed". (Funtowicz & Ravetz, 1993:740)[8]. It emphasised the importance of the environment

[8] This view builds upon the earlier work of Kuhn (1962), Latour & Woolgar (1979), Collins, (1985)

and social relations, acknowledging that knowledge is always situated and therefore is particular to specific communities (Fenwick, 2012). This represents an evolved understanding of how science is used for decision making[9] whereby separations of science and politics knowledge forms are rejected based on the understanding that change cannot occur through any one dimension acting by itself. There is a necessity to draw on factors that go beyond autonomous science (Collins & Evans, 2002; Jasanoff, 2005; Sovacool &Hess, 2017).

2.1.2 Science and politics in International Relations

While subject to debate, this evolved understand in academic thinking is also apparent within the field of International Relations. It has been previously been argued that most IR scholars deny technological change has an impact on global affairs (Lidskog & Sundqvist, 2015). Key schools of thought within this literature externalise technology in ways that technology as a scientific process is seen as neutral and can be separated from politics (Mayer et al., 2014; Lidskog & Sundqvist, 2015). The construct of epistemic communities support this approach.

> *"An epistemic community is a network of professionals with recognized expertise and competence in a particular domain and an authoritative claim to policy-relevant knowledge within that domain or issue-area"* (Haas, 1992:3)

By bringing together groups of professionals with similar beliefs and values, this framework presents a way to explore the role of knowledge based experts in international policy making, with Haas (1992) arguing that control over knowledge and information is an important source of power. To be influential, it is argued that scientific knowledge should be separated from the policy process: the more autonomous the science, the greater its potential influence (Haas & Stevens, 2011). Epistemic communities have been subject to debate. On one hand it has been argued

[9] In practice, Millstone (2007) defines each stage of the shift in how science is used for decision making as models of technocracy (decisions should only be based on 'sound science'), 'decisionism' (where scientists identify goals and policy makers decide the means through which these goals are reached) and co-evolutionary (reciprocal links between science and politics). This shift has also been defined as waves in the sociology of science studies i.e. wave one resembles positivist science. Wave two stipulates that science is a social construction (Collins & Evans, 2002: 239).

that this serves a positivist agenda in which authority and claims of situating their own advice as truth has been exaggerated (Toke, 1999).However such arguments have been critiqued by proponents of the epistemic community framework who note that not only are such claims overstated, but they are based on a misunderstanding of the work of Haas (Dunlop, 2000).

Nevertheless research within IR has begun to explore the roles that science and technology play on International Relations, and vice versa, with scholars beginning to argue that science cannot be separated from politics (Mayer et al., 2015; Weiss, 2015). Moreover, emphasis has been placed on the need for IR to draw from different fields that do not treat these dimensions as distinct (Bueger & gadinger, 2007; Bueger, 2012; Lidskog & Sundqvist, 2015). The field of Science and Technology studies is a prominent example. Having initially introduced the concept of co-production, this is tool that is increasingly being utilised in the field of IR[10]. Science and political practices are seen as intertwined whereby the relationship between them presents a co-production and separation creates a false dichotomy (Jasanoff, 1990). The research conducted for this thesis uses a co-production perspective and the remainder of this chapter details why.

2.2 Co-production

Co-production can be explained as "the simultaneous production of knowledge and social order" (Jasanoff, 1996:393) whereby "scientific knowledge…is not a transcendent mirror of reality. It both embeds and is embedded…in all the building blocks of what we term as the social" (Jasanoff, 2004: 3). This form of interaction, as it relates to technology and society, is concisely summarised by Guston & Sarewitz who note that "science and technological innovation continually remakes society. Society reciprocally accommodates, manages and redirects innovation" (2002:93).

This thesis uses a co-production perspective to explain how different knowledge forms (types of science and politics) interact when using technology as a solution for food security. The concept of co-production is of particular relevance in that it provides an alternative to deterministic viewpoints. Neither science nor politics are separate

[10] The edited volume on the global politics of science and technology by Mayer et al., 2014 presents some ways that co-production has been used within IR. However none of these chapters focus on co-production within food security or food related technologies.

entities and therefore they cannot be reduced to such (Lidskog, 2014). It steps away from rhetoric's that argue scientific knowledge shapes social reality or material interests, and vice versa, and acknowledges different knowledge forms that are understood to be simultaneously produced (Jasanoff, 2004; Lidskog, 2014). This allows for the recognition and exploration of interconnectedness and differences by providing a methodological approach to thinking about the myriad of ways in which science and technology unfolds within society (Jasanoff, 2005). Emphasis is placed on its role as an idiom as opposed to being utilised as a theory; "[it is]…a way of interpreting and accounting for complex phenomena so as to avoid the strategic deletions and omissions of most other approaches in the social science" (Jasanoff, 2004:3).

A co-production perspective has been used in many studies across many disciplines[11]. More specifically, scholars focusing on food security have utilised this approach to understand interaction between knowledge forms. Co-production has been used to understand how scientific advice is used in food safety policy making. This allows for questions to be asked about the ways through which evidence is selected and interpreted, what types of evidence, questions and agendas are perceived as relevant and what types are avoided and ignored (Millstone, 2007). In the development of sustainable agricultural practices, co-production has been used to explore how knowledge is used by multi-stakeholders (researchers and technology end users) involved in its creation (Akpo et al., 2015). It has also been used in an explanatory form to understand effects on food production that correlate with the relationship between land use change and livelihoods in South Africa and Ghana. This particular approach explores the co-production between knowledge/understanding of meaning with knowledge/understanding of the material (McCusker & Carr, 2006).

Whilst these studies are similar in that they all recognise that different forms of knowledge, systems, or societies are dependent upon each other to function, they each use a co-production perspective in different ways i.e. how it is understood, how it is analysed and with whom and what co-production is between. There is no common

[11] Examples of some fields that have explored co-production include politics, education, engineering, geography, management, organisational studies and so forth.

definition or 'univocal position' in how this is used[12] (Jasanoff, 2004; Gustafsson, 2014). To help explain the variation in how co-production is used, Jasanoff describes different perspectives as either *constitutive* or *interactional*. Studies utilising a constitutive co-production perspective analyse *'what it is'* whereas interactional studies analyse *'how we know about it'* (Jasanoff, 2004: 19).

Constitutive uses of co-production concern itself with metaphysical dimensions in the philosophy of science. It is not suffice to ask questions about what constitutes as nature or society without first asking questions about what it means to be natural or social (Jasanoff, 2004). It focuses on the emergence of new facts, objects, institutions, technologies, systems of thought, and so forth, to understand ways in which stability is created and maintained (Jasanoff, 2004; Gustafsson, 2014). An interactional approach, by contrast, concerns itself with knowledge conflicts between the natural and social worlds that have occurred in practice. Whilst this takes a more epistemological approach in which pragmatically, people already 'know' what is nature or science and what is society, it understands that conflicts still exist at boundaries: "nonetheless boundary conflicts about where these domains begin and end continually arise and call for resolution" (Jasanoff, 2004:19). As such, it explores how ideas are organised or reorganised under certain circumstances by elucidating how practical scientific and social interaction within socio-technical systems are accommodated at the boundary.

Co-production suggests that attempts to separate forms of science from social and political act only as representations that hide further, and more fundamental, processes of co-production (Lidskog, 2014). It is noted that behind the separation, co-production between differing types of knowledge, actors or activities can always be found and therefore boundaries between forms of science and social/political issues are subject to negotiation. The bridging of these worlds, and the stabilisation of boundaries, often occur through the support of boundary work.

[12] This is also reflected in Sheila Jasanoff's edited volume on the States of Knowledge and co-production which presents a range of essays that understand and use co-production in differing ways (Jasanoff, 2004).

2.3 Boundary Work

The term boundary work was first introduced by sociologist Thomas Gieryn in the early 1980's as a tool to explore and explain the demarcation from science and non-science, offering a sociological explanation of the cultural authority of science (Gieryn, 1983; Gieryn, 1999). Initially defined as "an effective ideological style for protecting professional autonomy…the goal is immunity from blame from undesirable consequences of non-scientists" (Gieryn, 1983: 789). Gieryn identified three ways in which boundary work could be used as a resource for scientists:

- When the goal is to expand authority or expertise into a field dominated by another profession. Boundary work allows for the comparison of different professions in ways that flatter those who are applying it.
- "When the goal is monopolisation of professional authority and resources, boundary work excludes rivals from within by defining them as outsiders with labels such as 'pseudo', 'deviant' or 'amateur'". (p.792).
- When the goal is the protection autonomy, boundary work allows the blame for consequences of work to put on scapegoats from outside that professional activity, as opposed to the responsible members[13].

Boundary work in this context is driven by a social interest and utilised as a strategy which scientists can use to enhance their authority. This reflects what Gieryn later refers to as an essentialist approach in which essentialists identify qualities that set science apart from other fields (Gieryn, 1995). However, the drawing of sharp lines between science and politics in this manner effectively restricts the input from non-scientists thus preventing challenges towards, or differing interpretations of, various claims that have been labelled as 'science' (Jasanoff, 1990). Furthermore, the assumption that all scientists are unified can create a practical problem. Scientists may belong to a variety of groups, for example having differing political opinions or religions, and so forth, that shape the kind of claims that they make about science. As

[13] These uses were presented in this manner when the term boundary work was initially introduced by Thomas Gieryn in 1983. They have since been more concisely described in Gieryn's later work as three genres; expansion, expulsion and protection of autonomy (Gieryn, 1999).

such, boundary work utilised as a tool to separate science from social and political issues can be a source of ambiguity (Gieryn, 1983).

Conversely, it has been noted that the most successful examples of boundary work politically have been those that allow room for the negotiation of the location and meaning of boundaries. More increasingly, boundary work is used as a means to create platforms that meet the needs of multiple and often epistemically different groups (Jasanoff, 1990; Guston, 1999). Boundaries are viewed more as a means of communication as opposed to a means of division. In this case demarcation is viewed as something not to be encouraged, but rather to be bridged. It is a requirement for science to remain credible (Lidskog, 2014).

There are two dominant, and inter-related, reasons behind the applicability of identifying forms of boundary work as tool to minimise separation between science and politics within this thesis. Firstly, boundary work acts as an appropriate framework to explore and understand interactions between science and non-science actors by creating knowledge solutions that meet the needs of multiple groups (Clark et al., 2016). It bridges knowledge differences between those that produce technical knowledge and those that use it. Secondly boundaries not only manage associated tensions with the transfer of knowledge, but appear to be fundamental in linking knowledge and action (Cash et al., 2003; Nel et al., 2015).

Exploring what happens at this boundary space allows for the understanding of how differing forms of knowledge are prioritised, created, organised, and translated. However by tracing the ways in which boundary work is used, it is apparent that it has different dimensions: boundary making and boundary crossing. Boundary making is when boundary work is used as a tool for autonomy, thus contributing to the separation between science and social /political issues, whereas boundary crossing aims to bring them together. This thesis engages with both. That is, it not only aims to understand how forms of science and politics comes together, but also how they divide.

Although not essential, factors of boundary work are shown to be involved in co-production as they facilitate relationships between different types of science and social / political communities (Guston, 2001). In practice, boundary work functions to create a space in which science and social / political issues can negotiate and in doing so, it aids the establishment of legitimacy for both knowledge domains (Gustafsson, 2014).

It addresses boundaries by providing a bridge for science and social / political issues, which subsequently requires a concerted effort by both worlds (Mollinga, 2010). It is this effort that this work is interested in.

The identification of two boundary concepts allows us to think about, and explore, how aspects of technology and food security politics interact. These include boundary objects and standardized packages, which are created and managed by boundary work to establish a shared understanding between differing forms of knowledge and action (Nel et al., 2015), and boundary organisations, which commonly mediate boundary work (Guston, 2001; Nel et al., 2015).

2.3.1 Boundary objects

Defined as an entity that is "both plastic enough to adapt to local needs and constraints of several parties employing them, yet robust enough to maintain a common identity across sites" (Star & Griesemer, 1989:393), boundary objects were first noticed by Star & Griesemer (1989) in the study of Berkeley's museum of vertebrate zoology. They found that whilst specimens of dead birds had different meanings between amateurs (such as avid bird watchers) and professionals (such as ecologists) they both used the same bird albeit in different ways. This constitutes a boundary object. It encompasses a model that helps balance meaning and presents a useful concept to suggest a way to improve communication and manage tension among divergent viewpoints (Bowker & Star, 2000). Boundary objects sit between two social worlds and act as a point of reference to find common viewpoints. They are an object that can be used by individuals on both sides for their own purpose, without losing their particular identity (Guston, 2001). They allow actors to interact with each other despite having differing perspectives of the object (Lidskog, 2014) and as such they are weakly structured in common use but become strongly structured in individual site use (Bowker & Star, 2000).

Boundary objects are not restricted to exclusive lists. Rather, they can take a range of forms based on action and co-operation between actors (Star, 2010). They can be knowledge, systems, technologies, maps, definitions, metaphors, representations, abstractions and so forth. They are entities that speak to a number of communities and practices, helping them to work across barriers without homogenising knowledge by acting as a means of translation (Bowker & Star, 2000; Carr & Wilkinson, 2005; Fox, 2011). Modes of translation are of particular interest to this research in that they forge links and transmit understanding. The notion of translation, as it engages with science, always includes change, interpretation and modification of meaning. The analysis of this presents insight into various forms of entanglement between actors from varying science and social / political communities within the field of food security. Boundary objects however are not just a helpful tool for effective communication between differing communities of knowledge, but they also “encapsulate the broader social meaning of a concept, theory, technology or practice, and the underlying relations that surround its development and adoption” (Fox, 2011:82).

Boundary objects have been further developed with the concept of standardised packages (Fujimura, 1992). Whilst similar to boundary objects in that they sit between two social worlds, facilitating interaction and co-operation between them, they are much more robust, structured and less ambiguous. Standardised packages have been described as ‘performative’ in that they can change practices on both sides of the boundary (Guston, 2001; Lidskog, 2014: 674). They employ standardised methods which can further restrict or define boundary objects (Fujimura, 1992; Lidskog, 2014). Whilst this does not define actions, it can impact the identity or practice of actors that develop or use them; it narrows the range of actions, thus allowing for the stabilisation of facts. As such this presents a useful concept for analysing collective action that aims to produce stable facts. Further, both standardised packages and boundary objects are helpful tools for analysing how action across differing groups of actors and knowledge are managed to achieve agreement (Fujimura, 1992).

The stability or fixed nature of boundaries are often necessary in order to persuade actors to interact (Gieryn, 1999). Whilst boundary objects and standardised packages provide stability through the agreement of actors on both sides of the boundary, it is noted that general changes in culture and specific practices need to be taken into account. On this basis, boundary objects and standardised packages may not be sufficient on their own (Guston, 2001). Boundary organisations attempt to solve these problems.

2.3.2 Boundary Organisations

The ‘science/politics’ boundary is contingent in nature. It is dependent on the environment and occurs differently in particular circumstances. Boundary organisations, often acting as a tool through which these worlds are bridged, are useful in exploring these differences. Introduced by David Guston as a concept that 'internalizes' such contingencies (1999:90), boundary organisations negotiate and create a space that enables the creation and use of boundary objects to facilitate and encourage communication between differing actors (Guston, 1999; Cash, 2001). In order to offer a space where negotiation, communication and collaboration can occur between different knowledge forms, boundary organisations have to separate science and social/political issues (i.e. draw boundaries between them). In doing so, they give both science and non-science actors the opportunity to create the boundary between them in ways that are favourable to their own interests and perspectives (Lidskog, 2014). They lie between science and social/political issues and may refer to social arrangements, networks and institutions (Miller, 2001; White et al., 2010).

In summary, boundary organisations minimise the divide between differing knowledge forms by addressing a three point criteria first highlighted by Guston (1999; 2001) in his initial framework. First, as stated above, they help to negotiate between science and social/political issues, encompassing participating actors from both sides of the boundary and often professionals who serve a mediating role. Secondly, they exist in two different social worlds but with direct lines of accountability to both sides of the boundary. This helps provide stability: "the boundary organisation draws its stability not from isolating itself from external political authority but precisely by being accountable and responsive to opposing, external authorities" (Guston, 2001: 402). Thirdly, they provide the opportunity and space for the creation and use of boundary objects or standardised packages. Whilst boundary objects and standardised packages are more portable, material representations, boundary organisations are much more stable institutional forms (White et al., 2010).

This three point criteria indicates that the concept of boundary organisations can correspond with aspects of co-production. Boundary organisations not only facilitate collaboration between science and non-science actors by acting as agents of both, but they simultaneously produce scientific and social knowledge through the generation of boundary objects and standardised packages (Guston 1999; 2001).

2.5 Boundary work in the co-production of science and politics

The previous sections introduced two forms of boundary work. In practice the use of these boundary concepts have a number of benefits. They enhance the effectiveness of engagement (Cash, 2001), promote and encourage greater diversity between actors (Carr & Wilkinson, 2005), and contribute to the stabilisation of boundaries between science and politics (Guston, 1999). Additionally – and of particular relevance to this research – they help to register forms of co-production. Co-production is positioned as more than an alternative relationship between different science and social/political communities / actors. Rather, it is positioned as a mechanism that influences the shape of relationships between them.

The concept of co-production attempts to understand the complexities of interactions and it is this perspective that allows us to – as described by Gustafsson – "see how boundary objects and boundary organisations consciously or unconsciously incorporate differences that boundary work separates" (2014:112). Boundary work is not only useful in analysing how interactions are managed, how knowledge is organised, and how it is translated across social worlds to facilitate action, but has also been identified as a tool to support and manage associated tensions with the co-production of knowledge (Nel et al., 2015).

The research for this thesis is approached through the lens of co-production as it allows us to register the relationships between science and social/political issues. However to explore how this occurs in practice, different dimensions of boundary work will be identified. That is how boundary work is used to create and draw divides between different food security communities and how it is used to bridge these communities by identifying forms of boundary objects and organisations.

2.6 Methodology

In order to address the research questions of this thesis through a co-production perspective, qualitative research was designed to allow for the identification of forms of boundary work that are currently in practice. In particular, it was used to explore how boundaries are created, how they are crossed, and thus allow for an understanding of how science and politics connect and disconnect within the context of food security.

To achieve this key informant, semi-structured interviews were conducted with a variety of food security actors.

2.6.1 Stakeholder demographics

This research involved engaging with key groups of food security actors that contribute to discussions and practices relating to food security in various ways. Stakeholder groups engaged included government bodies[14], industry, industry trade associations, research institutes, international organisations, funding bodies, non-governmental organisations (NGO's) and civil society organisations (CSO), funding bodies, farmer union's and regulators.

Government bodies that addressed food security in both the UK and the US were engaged with. This was to allow for any potential comparisons, and identify national influences on how boundaries were created and crossed. These two developed countries were selected because of their involvement in food security issues at a global level. They are both OECD countries, members of the UN Security Council, and the G8/G20. As such, they have a voice in contributing to advancing consensus on global concerns including food security A key example of this is the commitments made at the 2009 L'Aquila G8 summit mentioned in chapter one of this thesis. Furthermore, it is not uncommon to compare the US and EU on an agricultural and food landscape, particularly through the consideration of GM crops[15]. In addition, both countries put forth a solid policy response to the food price crisis which instigated global action, they both are English speaking countries, and have a high quality and availability of government documents. Although there are other strong examples that could make useful comparisons – such as the remaining G8 countries – language barriers were prominent. What's more, accessibility was also considered when identifying groups to talk to. Both the UK and US were among the most accessible with pre-existing contacts available through the supervisory team of this project. This was particularly beneficial to the recruitment process.

[14] This research did not directly engage with politicians, but rather government bodies that inform policy solutions.
[15] This is an area that is discussed in greater detail in both chapters three and four of this thesis. Chapter four particularly emphasises the difference in approach to utilising various forms of technology. Understanding if these differences shapes boundary work differently is of interest.

Industry bodies engaged with were large multinational organisations that specifically conduct research on, and develop, forms of agricultural technologies as food security solutions. Although identified as possible targets for engagement, small to medium enterprises (SME's) were often too context specific; they focused on specific technologies in specific areas. To counteract this, discussions were had with trade associations (both international and national) to help ascertain a broader industry perspective on issues relating to food security and technology.

It is not suffice to answer the research questions of this thesis by engaging only three groups of actors within food security. Food security is increasingly global and actions to achieve it often involve a variety of groups with diverging roles. As such, the remaining stakeholder groups were engaged with in order to get an overall picture of how boundary work occurs in practice. Decisions on which groups to talk to were shaped by assessing the key players in global food security through their representation on global platforms, and also core reports. Further decisions on which specific organisations to talk to within each stakeholder group were made based on expertise and those that are well acknowledged at national and global levels. For example, those that contribute significantly to national and international food security policy formation and implementation, or have specifically published / contributed to the development of core reports. By doing this, it was felt that these groups would be representative of the core professional communities in food security and thus qualified to give a general picture of the views of each group.

As mentioned above, government bodies engaged with were those that had a substantial voice in UK and US food security, contributing to key documents and policy decisions, and only large multinational organisations in industry were engaged with. Further, the roles of interviewees from both research institutes and international organisations were primarily research roles, interviewee's from farmer's unions operated in a policy capacity and interviewee's from trade associations were industry watch dogs. Some participants were from the same organisations, albeit from different departments. Where multiple people were spoken to, these were much larger organisations where a significant diversity in roles exist.

A summary of stakeholder demographics can be observed in figure 2.1. This shows the number of interviewee's engaged with each group of actors. Stakeholder under representation was addressed through specific targeting on the basis of their expertise and role (i.e. key informants). As this is an exploratory piece of work, key informants (opposed to much larger sample size) were used for a depth of understanding as opposed to breadth that might arise through the work of surveys. This is not a statistical piece of work and therefore sample size was not the greatest concern. Rather, this work aimed to talk to the right people, it did not set out to establish a public opinion.

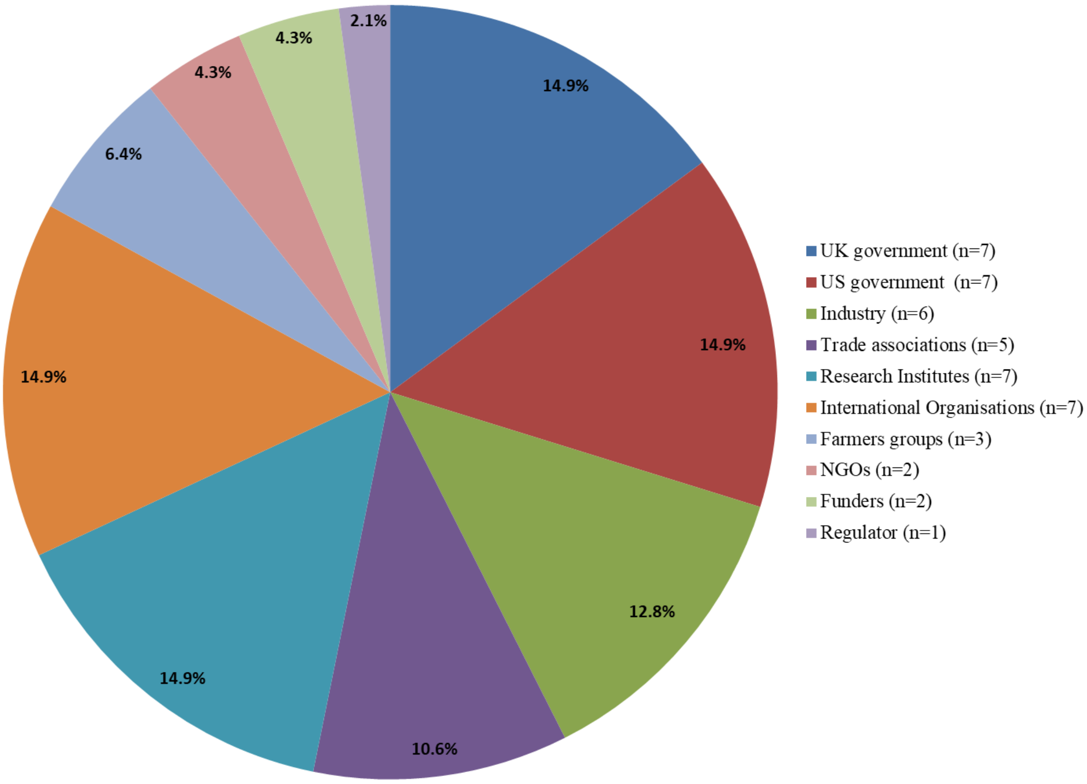


Figure 2.1 Number of research participants belonging to each group of actors

2.6.2 Data collection

Following the development of research questions and establishing the key actors to engage, data was collected using key informant semi-structured interviews and through core reports and documents on food security. These provided further insights into concepts, platforms or issues raised in interview discussions. Semi-structured interviews were used as they allowed the researcher and participant to discuss issues in a greater depth than much more structured approaches, such as surveys. A semi-structured approach allows for participants to expand on their views, perceptions and opinions on certain topics, and enables them to raise additional issues that may be of interest to the research (Bryman, 2016).

Focus groups were initially considered as the primary form of data collection in this research as they illuminate perspectives in different groups of actors (Rabiee, 2004). However this was not only faced with logistical concerns (such as getting groups of elite actors in the one place), but also the potential for some sociological risks. As this research focused on technology, responses may have the potential to cause negative perceptions or attitudes towards stakeholders, which has previously been observed with other agricultural and food technologies (i.e. genetic modification). Similar challenges also restricted the use of same stakeholder focus groups. Significant issues were present surrounding logistics (date, time and location), and sensitivity would still be a concern. This is particularly pertinent with industry bodies who would be wary about divulging information to potential competitors. As such, this may have restricted participants in a focus group setting from being open and transparent. The use of interviews mitigated this risk as they occurred on a one – on – one basis and subsequently could offer anonymity to the participant. It also allows for a richer and more open source of data as it does not inhibit discussions as much as focus groups – stakeholders are not trying to impress each other, or avoid showing vulnerabilities, in this setting.

Interview questions were developed in a way that allowed for a greater insight into the ways in which different types of science and politics communities interact in practice (appendix A) and ethical approval of the research design was obtained from both the school of Biological Science, and school of Politics, International Studies and Philosophy (since merged into the school of History, Anthropology, Philosophy and Politics). To test the validity of these questions, a pilot interview was conducted in early October, 2016. This was to ensure that the interview schedule developed would result in interesting and substantial data (Silverman, 2013).

Potential participants were identified and recruited in a number of ways. This occurred through attending appropriate conferences and events, by identifying experts that contributed to relevant reports within the field of food security, and through existing contacts in the Institute of Global Food Security at Queen’s University Belfast. Beyond this, a snowball sampling technique was employed: experts deemed information rich were identified and introduced by existing participants (Marshall & Rossman, 2011).

In the case of conferences and events, contact was made in person, however initial contact with the majority of participants was primarily via email. This email introduced the researcher, the purpose and importance of the research being carried out and why the recipient's expertise and role was identified as relevant to the nature of the research project. A participant information sheet was then sent to those who replied and registered interest (appendix B) and a time, date, and form of communication for an interview was determined. Some responses were received that declined an interview but signposted relevant reports and documents, as well as possible experts that would be useful to engage with. Follow up emails were also sent after a two week period if no response had been received. A further, and final email was sent one week after this. In some cases an additional request was sent (i.e. if a participant initially responded to register interest in the study, but did not respond to an email arranging interview details). In total, 127 emails were sent, and a final number of 47 interviews were conducted. These took place between October 2016 and April 2017 over telephone (n=37), skype (n=8) and in a face-to-face setting (n=2). For the most part, data collection was considered complete when data saturation for each stakeholder group had been met i.e. nothing new was emerging from the data. An additional factor was when it was not possible to arrange interviews, for a variety of reasons. This was counteracted by considering key reports and documents from these organisations.

Prior to each interview session verbal consent was obtained. This was to ensure that all information pertaining to the project was understood, that participants understood they were free to withdraw at any time, that they gave their permission for interviews to be recorded, and to determine the level of anonymity that they required (appendix C). All participants indicated that they wanted to be identifiable by stakeholder group only. Interviews were recorded from this point forward.

Interviews were recorded digitally on the researcher's iPad using a ZOOMiQ5. This is a professional stereo microphone with a lightning connection to IOS operating system devices. The iQ5 device was placed into the lightening port of the iPad and interviews were recorded directly through this onto the ZOOM Handy Recorder app. This allowed for a high quality recording that minimised all background noise. The researchers iPad was password protected, with no one else having access to this code. Interview recordings were also backed up onto a computer directly from the ZOOM Handy recorder app via email, and were stored in a password protected file. The purpose of password protection was to comply with confidentiality and anonymity requirements laid out by all participants.

All interviews followed the same interview schedule and the length of time varied greatly, with interviews lasting between 30 minutes and just under two hours. Although the average time was one hour. Interviews were concluded by gaining permission for follow up, if necessary.

2.6.3 Data analysis

Content analysis was used to analyse the primary data collected through semi-structured interviews. Analysing interviews in this way was beneficial as it allowed for the identification of overall perspectives from different actors and as such is useful for identifying complex interactions (Marshall & Rossman, 2011; Bryman, 2016). Content analysis allows for this through the construct of codes and themes that represent commonalities and patterns in the data, therefore highlighting similarities and differences. This was a particularly important factor in addressing the aim of this research. Additionally, content analysis was also useful in that it can identify unanticipated insights and summarise key points in large bodies of data (Hsieh & Shannon, 2005). Further, in comparison to a thematic analysis approach, content analysis also allows for the quantification of data (Vaismoradi, 2013). While this was not applied to the analysis of interview transcripts, it proved useful when considering core reports and documents.

Deductive content analysis was undertaken. A deductive or 'top down up' approach is used when the researcher is driven by a particular interest in the area or wishes to test existing theories in different contexts. While this tends to provide a less rich description of the data overall, it generates an in depth insight into particular areas. As such, this corresponds to why the data is being coded (Elo & Kyngas, 2008). In this case data was coded and themed for specific research questions that emerged from a review of the literature. It set out to establish patterns in the data that indicate how boundaries are created and crossed between different types of science and politics communities in practice and the broader impact that this has on food security.

In the initial stage of data analysis, interviews were transcribed verbatim thus bringing the researcher closer to the data through familiarisation (Bryman, 2016). An additional benefit of using the iQ5 microphone device was its ability to aid the transcription process of interviews. The ZOOM Handy recorder app consists of a tracking screen that allows the user to know exactly where in the recording they are, and easily create time stamps. Additionally it incorporates hot keys to fast forward and rewind audio files in 10 second increments along with the function to use a sliding motion to get to exact stages in interviews in an efficient manner.

All transcripts were printed and read multiple times to allow for data immersion. Following this, initial codes were then generated by highlighting words and sentences that captured key thoughts, processes, and areas of interest. Codes were written in the margins of the transcript documents. As there were 47 interviews, coding was a time consuming process. However, this in some respects was beneficial. It meant that there was a substantial amount of time between the initial coding of a transcript and returning to it for a second time. By leaving a transcript for a period of time before recoding, a comparison could be made to ensure similar codes had been identified. This allowed for intra-reliability of the analysis process. Once this was satisfactory, all transcripts were reread until no new codes emerged.

After lists of codes were identified within the dataset, they were sorted into different themes. To do this, codes (with a brief description) were written onto separate pieces of paper and organised into piles corresponding with commonalities – codes were grouped and initial themes emerged based on codes that were reflective of more than one key thought, concept, or process. These themes were labelled accordingly to the similarities between codes. Following this all codes and themes were reviewed. The purpose of this was to ensure that all themes were applicable to the coded data and the complete data set.

The final stages of the analysis process involved developing clear definition and names for each theme. By utilising a deductive approach, this analysis indicated three core themes, and the ways boundaries are crossed and are overcome were identified as subthemes within this. These core themes consisted of boundary work in a broad sense, boundary work within the R&D (research and development) process, and boundary work within technology adoption. These are the focus of chapters 4-6. Chapter 3 first looks at forms of co-production in the past.

Chapter three: History of co-production and food security

3.1 Introduction

The earlier chapters of this thesis have emphasised the multi-dimensional nature of food security. Without addressing all of these dimensions and ensuring access, availability, utilisation and stabilisation, it has been recognised that food security cannot be achieved (FAO, 2009; Gibson, 2012). There is a need for the multiple aspects of food security incorporated within the FAO definition and four pillar models to interact. Particularly, there is an emphasis on the need for the technical and political dimensions to entwine. Chapter one of this thesis noted that food insecurity is driven by production limits and distribution issues of food and thereby entails a particular relationship between social and economic organisations with technology agricultural practice. This however is not representative of the existing literature whereby scientific, social and political science accounts of technology and food security are somewhat separate. There is a lack of clarity on how these fields interact.

This chapter aims to investigate the relationship between various forms of science and politics. It specifically considers the use of technological advancements and its mode of interaction with broad political, social and economic issues. It argues that not only do these variables interact within a food security context, but it has its own history of doing so. While food security can be traced back to the UN Declaration of Human Rights in 1948, it has a much longer historical trajectory through which food security has always brought science and politics together. That is, rather than simple deterministic relationships between scientific advancements (i.e. forms of technology) and social forces (in which science and technology drive social change, or vice versa) there is an apparent co-production between the two. Furthermore this chapter argues that while co-production between technology and society has always existed throughout key periods in history, the character of this relationship differs as time has progressed. This analysis therefore reveals the multiple ways technology and social change have been co-produced with agriculture.

While there are several histories of food security in the literature[16] these are relatively short contemporary histories that fail to engage issues of scientific advancements. As such, the analysis conducted for this chapter not only aims to assess how complex relationships between technology, food security and wider social political developments occur, but it also contributes to filling a gap in understanding.

The remainder of this chapter is framed as follows. Section two uses secondary data sources to explore both technological and social developments within five key time periods in the history of agriculture (Neolithic, Antiquity, Middle Ages, 1st Modern Agricultural Revolution, 2nd Modern Agricultural Revolution) and how these variables interlink within each. Section three presents a discussion of the core findings within this research. It considers how food security can be traced back to the emergence of agriculture, the nature of the relationship between technology and society, and how this changes according to different environments throughout history. Finally, conclusions are presented in section four.

3.2. Key periods within the development of agriculture

Mazoyer & Roudart (1995) demonstrate how the history of agriculture can be conceptualised into five key phases that centre not only on particular technological revolutions, but changing agricultural systems. This chapter uses these five periods - Neolithic, Antiquity, the Middle Ages, First Modern Agricultural Revolution and Second Modern Agricultural Revolution - to help frame technological and social change throughout time. It is important to note that while this chapter will acknowledge food security becoming global in nature, the understanding of entanglement that is developed within this analysis is one based on a predominately European history (although there are a few exceptions). It may well be that other

[16] For example existing research has conducted a genealogy of the contemporary understandings of food security (Alcock, 2009), a genealogy to understand the influence of food and agriculture (among other variable have contributed to discourse surrounding agricultural biofuels (Kuchler & Linner, 2012) and analysing the history and political economy of food system designs in India and Bangladesh to improve food security (Banerjee et al., 2014).

regions had different forms of entanglement but there isn't the scope or material to engage this within this chapter. Additionally, this chapter does not focus on the food price crisis that occurred in the later time periods. The food price crisis speaks to how the food security landscape is currently, whereas this chapter is interested in how it came to be.

The greatest depth of secondary data can be found in the discussion of the latest transition, the Second Modern Agricultural Revolution (section 3.2.5) not only because information on this era is more readily available than that further back in history, but as will be shown, the relationship between technology and society develops significantly. The four key era's prior to this time however are explored to demonstrate that recent changes associated with technology, social and political forms have a much longer historical trajectory.

Figure 3.1 shows the technologies/modes of production that will be referred to in each of these eras. These modes of production demonstrate how the conceptualisation of what is constituted as a technology has changed throughout time and thus presents a representation of what is classed as a 'technology' within this chapter. This figure not only presents five examples of differing types of production in the form of handheld tools, the plough, motor-mechanisation, chemical, and biological technologies, but also draws attention to the longer and more gradual trajectories of the use of fertilisers and irrigation throughout history. Additionally, fertilisers and irrigation techniques differ in that they don't fit into any of these pre-defined modes of production, however they are important to acknowledge as they are often employed alongside these different methods to further enhance their role in increasing production.

This figure aims to indicate that these modes of production were more prominent in some eras as opposed to others. This does not mean however that they did not exist throughout other times. Further, it is important to clarify that whilst other technologies may have existed throughout each era, these key modes of production represent examples of the most prominent and significant technologies: it is neither feasible nor necessary in answering the key questions this chapter asks to formulate a fully comprehensive list of technologies both used and developed within each timeframe. Finally, the dates of these eras are approximates only based on the timeframe that each historical period reportedly occurred and therefore are not always in succession. Their relevance to agriculture is based on the work of Mazoyer & Roudart (1995) who note that these are key periods within the development of agriculture, and perhaps other time periods between are not as significant. This indeed is a questionable claim, but not the goal of this research. Rather, these time periods are used to frame this chapter to allow for a much clearer demonstration as to how technology and security has progressed throughout history.

	Neolithic (Approx. 10,000BCE – 1000 BCE)	**Antiquity** (Approx. 200 BCE – 476 CE)	**Middle Ages** (Approx. 500 – 1500)	**1st Modern Agricultural Revolution** (Approx. 1750-1914)	**2nd Modern Agricultural Revolution** (Approx. 1918-present)
Handheld tools*	Wood and Stone tools (Martin & Sauerborn, 2013)				
Plough*	First handheld plough (Fussell, 1966; Lal et al., 2007)		Animal drawn plough (Fussell, 1966; Tauger, 2011)		
Motor-mechanisation*				Tractorisation (Rasmussen, 1962)	
Chemical*				Green Revolution (Dupont & Thirlwell, 2009)	
Biological*	Selective breeding, Plant and animal husbandry (Martin & Sauerborn, 2013)			Selective breeding Green Revolution, Genetic modification (Martin & Sauerborn, 2013)	
Fertilisers		Natural fertilisers (Mate, 1985; Cumo, 2016)		Chemical fertilisers/pesticides (Martin & Sauerborn, 2013)	
Irrigation		Aids plant cultivation/agricultural intensification (Mazoyer & Roudart, 1995; Dupont & Thirlwell, 2009)			

BCE – Before Common Era; CE – Common Era

* - modes of production

Figure 3.1 Gantt chart showing the technology (with examples) that was most utilised in each historical era in agriculture. Handheld tools through to biological represent different modes of production of which fertilisers and irrigation play a contributing role too.

3.2.1. Neolithic Era

There is a common consensus among historians that the Neolithic era instigated the development of agriculture whereby some Neolithic societies had begun to sow seeds and keep animals in captivity to make use of their by-products as early as 10,000 BCE (Mazoyer & Roudart, 1995). Examples of the development of technologies within this time frame are limited. However it is known that cultivation and fallowing[17] during this era largely began through the use of wood objects and stoned tools (Martin & Sauerborn, 2013). In an era that spanned centuries these handheld tools underwent significant transitions throughout. For example, the early use of a digging stick, which was developed over several continents simultaneously, eventually evolved into a spade and then an ard – a form of handheld plough.

However, one of the more significant technological advancements that contributes to an understanding of food security within this era was the apparent use of biological modes of production. As indicated in **figure 3.1** the Neolithic era saw the use of selective breeding and plant and animal husbandry. This is known as domestication which is best defined as a biological process that involved "the conscious and unconscious change in plants and animals as a result of selection to make them more useful for humans than the original wild form" (Martin & Sauerborn, 2013:14). Domestication strongly correlates with a significant cultural development in the shift from hunter-gathering societies to sedentary farming communities. As such, social and cultural development is characterised by the adoption of particular agricultural systems (Brown et al., 2009). This presents an example of the interaction between technology and society within this era.

The voluntary shift from hunter-gathering societies to farming sedentary based life styles has perplexed some historians. For example, archaeological evidence in the form of bones and teeth has suggested that the health and nutrition of the first farmers was far worse than hunters and gatherers (Andres-Guzman, 2007; Seabright, 2008). It has been argued that the transition to agriculture resulted in reduced vitamin intake as a result of less variety in the diet and decreased meat consumption. The exploitation of children who often worked from the age of five or six was identified as an issue, as

[17] A period of time were land is left unseeded after ploughing to increase fertility of crops (Martin & Sauerborn, 2013).

was the need for increased 'back breaking' labour, and a Malthusian explanation where any initial surplus of food was offset by population growth (Shard, 1974; Robson, 2010; Rowthorn & Seabright, 2010). This shift has also been associated with a 30 % decrease in life expectancy between Mesolithic (which dates back to approximately 17,000 BCE) and Neolithic times (Galor & Moav, 2007).

By contrast, it has also been argued that from an economic perspective there is nothing perplex or unusual about this transition. Not only do the facts of the Neolithic revolution make perfect sense, but they were also inevitable (Andres-Guzman, 2007). Furthermore, evidence has shown that in the long run this transition from hunter-gathering to farming societies resulted in large surpluses, removing food supply constraints previously faced by hunter-gatherers and allowing up to a quarter of the labour force to be released into other activities (Tauger, 2011).

This to some extent links to the 'broad spectrum revolution' which provides an additional explanation for this transition. Archaeologists have determined that Neolithic sites have shown fewer remains from larger animals and more remains from smaller animals such as birds and fish. Neolithic sites also indicated an increase in the remains of wild plants and grains later in this era which contributed to domestication. Archaeologists have interpreted this as an indication of difficulty in obtaining necessary food supplies which not only corresponds with over hunting, but also the extinction of large mammals after the ice age (Tauger, 2011). This presented subsistence difficulties that lead to the transition to sedentary farming lifestyles to overcome this. Innovative approaches included storing gathered food, watering plants, removing undesirable ones and most importantly, domestication. Therefore early agriculture was to a great extent an attempt to improve food security.

Further supporting this claim was the reported need for increased defence among farming communities (Seabright, 2008; Rowthorn & Seabright, 2010). In the field of Security Studies the concept of securitisation denotes the way issues change from being 'normal' social and political issues to being treated as 'security issues' understood in terms of threat and response (Buzan et al., 1998). While this is often understood as a shift in political discourse, in this chapter it is better understood as how food and security become conjoined through particular developments. When we consider the securitisation of food the process of domestication as a method of food production presented more threats to food supply than hunter-gatherer approaches. The storage of foods could be faced with issues of theft or environmental factors ranging from weather related concerns to natural disasters. Seabright (2008) argues that agriculture was initially only slightly more productive than its predecessor's hunter – gatherer lifestyle, and this was offset even further by the need for farmers to invest in defence as a result of their sedentary nature. That is, they had more to lose as they stored food between harvests. The adoption of more productive approaches to enhance the physical security of food and crops (as opposed to dedicating all resources to food production in this case) indicated a prioritisation of access for food supplies – a core pillar of food security today - whereby their food sources were protected so that production was not over utilised (Rowthorn & Seabright, 2010).

Therefore security as the protection of particular territories or resource began with food through which food and security were entangled as such that the invention of agriculture invented security. Furthermore, not only have food, security and technology been entangled as far back as the Neolithic era but food security, physical security, agriculture and social, economic and political forms have co-evolved since the birth of agriculture.

3.2.2. Antiquity

A small number of technological innovations that contributed to the improvement of agriculture were apparent within Antiquity (200BCE to 476 CE). As displayed in **figure 3.1** these included further innovation of the handheld plough. This involved the development of iron tools which contributed significantly to improving cultivation. Additionally a shift to animal drawn ploughs were observed within this time period. Traction from oxen drawn ploughs proved to be a less time and labour consuming alternative to previously used wooden and stone tools within the Neolithic era (Lal, 2009; Tauger, 2011). The use of natural products for fertilisers were introduced during this time period by the Romans who used animal manure and crop rotation to improve cultivation. Where manure was in shortage, the residue of plants were used to make compost (Cumo, 2016). Finally, irrigation systems were initially established by the Egyptians who relied on flood water from the river Nile for plant cultivation.

This era however also saw an emphasis on social structure that was considerably different from Neolithic times and a shift in the co-production of technical and social dimensions is therefore apparent. Evidence suggests that the development of new forms of technology in this era contributed to developments in social structures. In turn these social changes shaped patterns of the distribution and access of technology. This can be seen in the following examples.

In a European context all of these societies were almost entirely agrarian, recognised themselves as agrarian and idealised the small farmer and agriculture. However this era also saw the seizure of small peasant farmer owned lands by wealthy landlords, leading to poverty on the basis of expanding empires (Tauger, 2011). Status reflected control over land and access to technology development. Antiquity also saw the rise of plant science and empiricism through the work of Theophrastus (a student of Aristotle) who was the first to study soil and its properties. While technological development was somewhat evolutionary until later dates there is evidence to suggest that such empirical knowledge contributed to the development of agriculture and food production. For example, the observed benefit to the cultivation of plants from iron tools was then applied to the wooden plough which was subsequently fitted with an iron cutter to help prepare the land for sowing and weeding (Lal, 2009). Empirically derived knowledge was applied to improve existing tools for increased food production. However innovation, knowledge and the development of agricultural techniques were often inaccessible for poorer peasants controlled by rapacious landlords resulting in debt and land loss (Tauger, 2011).

This was also observed beyond a European perspective. The development of irrigation systems within Egypt allowed for further strengthening of power hierarchies. Peasants often controlled agricultural systems based on irrigation for which they were granted plots of land. However they were also subject to heavy labour on these estates with all products developed being used to support the needs of the pharaoh (Mazoyer & Roudart, 1995). Access and distribution of technologies were controlled by social structures that gained power from the development of the technology itself. This form of co-production also transcends to the Middle Ages.

3.2.3. The Middle Ages

Technological development in the Middle Ages (5th to 15th centuries) seemingly occurred at an evolutionary pace. Leading on from Antiquity, the plough was further developed whereby a shift from Oxen (which were slower and weaker) to horse drawn implements were observed in the late Middle Ages of Northwest Europe (Poulsen, 1997). This era also involved early stages of agricultural mechanisation. One example was the use of mills which ground grains into food sources (Comet, 1977). A final development to mention corresponds with the use of fertilisers. While they were first introduced in the period of Antiquity, it was this era that they evolved and had a full effect. Soil was fertilised through the addition of manure and marl (a calcium carbonate), an approach which that proved beneficial within this time period (Mate, 1985).

The Middle Ages in Britain and Europe saw the introduction of a feudal system that determined social class and standing. Local lords expanded the territory subject to them and intensified control over the individuals living there. This was emphasised through enclosures which occurred when a small number of land plots were bought together to create one farm that was no longer available for communal use (Ashton, 1977). Technology encouraged a social class structure formed through the division of labour. The mill provides a relevant example of this in this time period. Lords were able to take advantage of their economic and political power to establish a monopoly in the building and operation of mills by enforcing taxes that had to be paid for its use (Tauger, 2011).

Marxist scholars have argued that technological inputs were no more than a variable being advanced or constrained by forces dominant in class relations (Comet, 1997). From this perspective there is emphasis on how society shaped technology. This could also be attributed to notions of food insecurity, like that observed in Antiquity. Feudalism and other social structures effected patterns of distribution, access and the availability of particular technologies that were developed. This was also observed through the development of fertilisers. Despite praises surrounding their benefits in Middle Ages soil, access was only available in limited quantities for farm workers and labourers as a result of dominance within the class system (Comet, 1997).

Subsequently, continuing on from the period of Antiquity, the interaction of technology and society emphasised co-production. Both periods indicate how the development of technology contributed to furthering the shifts in society. It emphasised class and authority within it. Society reciprocated by using technologies in ways that exerted the authority of lords and landowners, thus shaping the ways that technology and innovation was used.

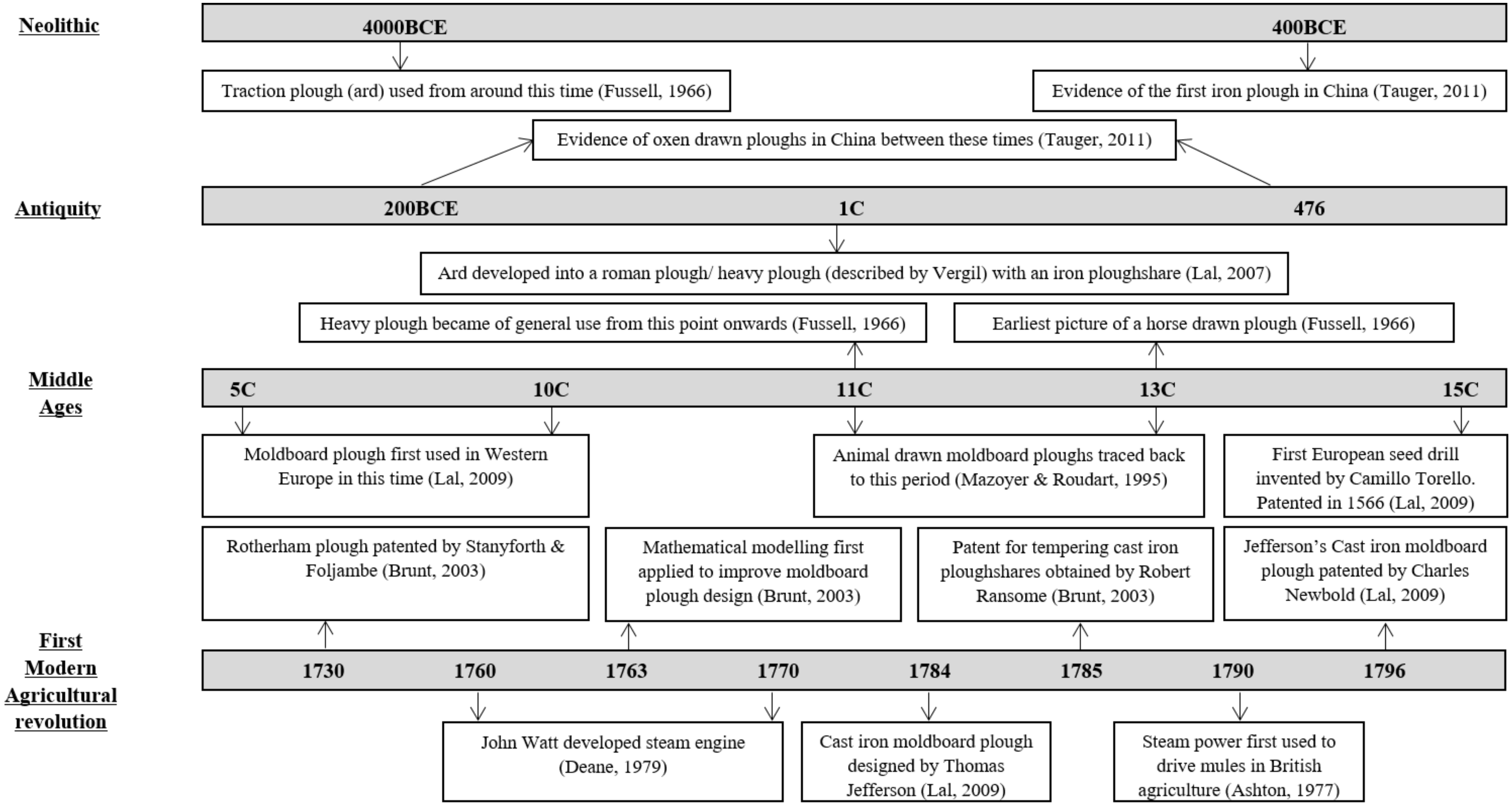
3.2.4 First Modern Agricultural Revolution

According to Mazoyer & Roudart (1995), the First Modern Agricultural Revolution largely occurred from approximately 1750 to 1914. This was an era that seen a shift to more revolutionary trajectories of technological change. As shown in **figure 3.1**, all modes of production, with the exception of handheld tools, were utilised in this period. Biological developments were apparent through purposeful selective breeding in the 1700's (Martin & Sauerborn, 2013). Additionally, Charles Darwin published work on plant breeding and cross fertilisation in 1859[18] and the finding of genetics was largely attributed to Gregor Mendel's 1866 publication "experiments on plant hybridisation". It should be noted that the importance of the work from Darwin and Mendel was not recognised until much later in the First Modern Agricultural Revolution, with Mendel's publications only rediscovered in 1900 (Kingsbury, 2009). Nevertheless it does indicate an increased interest in the First Modern Agricultural Revolution on the use of biological methods to improve agricultural production. Developments in the chemical mode of production was also observed within this era. The first application of chemical based fertilisers being observed in 1840 where powdery mildew was controlled using sulphur based components (Martin & Sauerborn, 2013) and motor-mechanisation was also introduced towards the end of this era. The first gasoline based tractor was developed in the US in 1882 (Rasmussen, 1962).

A final example is the plough, which embodied revolutionary technological change. This can be observed in **figure 3.2** which presents a timeline of the plough ranging from the Neolithic Era to the First Modern Agricultural Revolution. It indicates examples of key stages within its development, based on available and accessible data, to provide an insight into how revolutionary or 'radical change' (Rasmussen, 1962) occurred within this era. It demonstrates that innovation of the plough accelerated within this time frame[19].

[18] Darwin's work "The origin of species by means of natural selection or the preservation of favoured races in the struggle for life" is often accredited as the corner stone of evolutionary biology

[19] Innovation in this context is understood as described by Sunding & Zilberman who note that "innovations – new ways to perform tasks, new products and new procedures – are the elements of technological and institutional change" (2001:207).


Neolithic
4000BCE
400BCE
Traction plough (ard) used from around this time (Fussell, 1966)
Evidence of the first iron plough in China (Tauger, 2011)
Evidence of oxen drawn ploughs in China between these times (Tauger, 2011)
Antiquity
200BCE
1C
476
Ard developed into a roman plough/ heavy plough (described by Vergil) with an iron ploughshare (Lal, 2007)
Heavy plough became of general use from this point onwards (Fussell, 1966)
Earliest picture of a horse drawn plough (Fussell, 1966)
Middle Ages
5C
10C
11C
13C
15C
Moldboard plough first used in Western Europe in this time (Lal, 2009)
Animal drawn moldboard ploughs traced back to this period (Mazoyer & Roudart, 1995)
First European seed drill invented by Camillo Torello. Patented in 1566 (Lal, 2009)
Rotherham plough patented by Stanyforth & Foljambe (Brunt, 2003)
Mathematical modelling first applied to improve moldboard plough design (Brunt, 2003)
Patent for tempering cast iron ploughshares obtained by Robert Ransome (Brunt, 2003)
Jefferson's Cast iron moldboard plough patented by Charles Newbold (Lal, 2009)
First Modern Agricultural revolution
1730
1760
1763
1770
1784
1785
1790
1796
John Watt developed steam engine (Deane, 1979)
Cast iron moldboard plough designed by Thomas Jefferson (Lal, 2009)
Steam power first used to drive mules in British agriculture (Ashton, 1977)

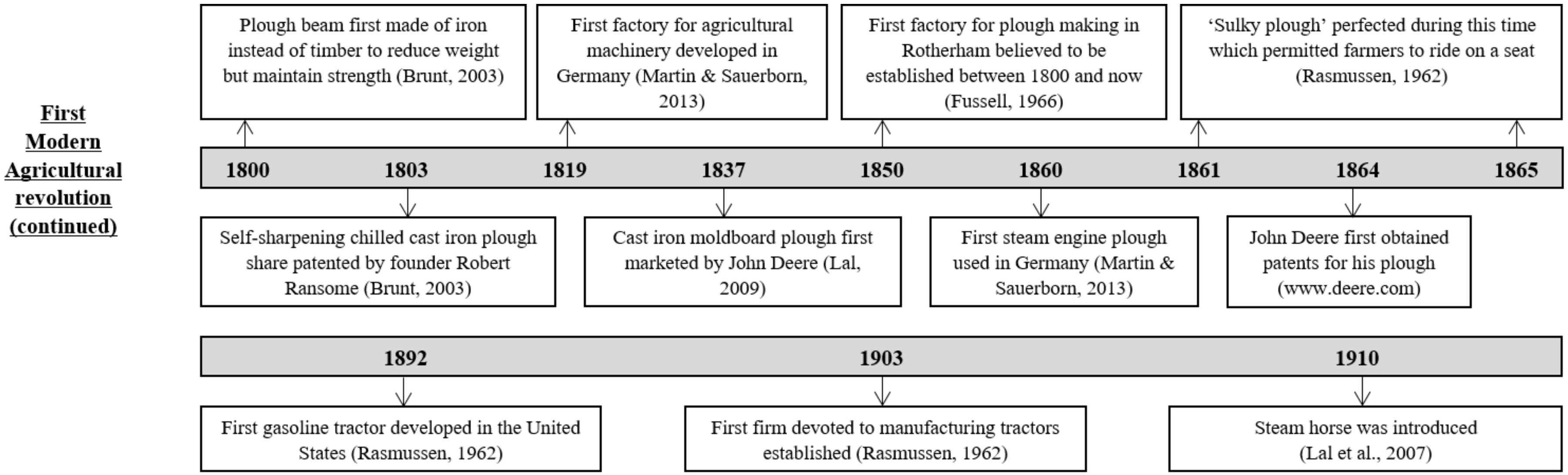


Figure 3.2 Parallel timelines showing the evolution of the plough from Neolithic times to the First Modern Agricultural Revolution

The increased innovation of the plough in this era also draws back to a claim previously made within this chapter. While technology may have been invented and utilised in previous times, it relies on specific factors associated with different forms of social and economic organisations to excel. Processes such as enclosure were further emphasised within this time period, whereby it was noted that wealthy land owners controlled over 70-75% of all cultivated land in Britain (Beckett, 1990). However in contrast to that observed with the Middle Ages and Antiquity, this era also saw changes in the organisation of labour.

The introduction of the Corn Laws in 1815 aimed to provide protection to British land owners and farmers by preventing cheaper foreign imports of cereals and grains[20] (McLean & Bustani, 1999). It was framed as a 'protectionist legislation' to initially protect the profits of landowners and their tenants by fixing prices (Beckett, 1990; Flood, 2010:221). This had the effect of keeping domestic prices high and therefore while this was originated as a source of protection, it also contributed to insecurity for poorer populations who were unable to access sufficient food. The Irish Potato famine was an example of significant insecurity throughout this time period. An increase in population and an over-reliance from the most vulnerable on this particular crop led to widespread starvation (O'Grada, 1993). The potato famine was one of many factors that led to the elimination of the Corn Laws. Additional factors that encouraged this coincided with British farmers beginning to produce higher yields with better crop rotations (Beckett, 1990). This also contributed to social changes in the forms of industrialisation and urbanisation.

The industrial revolution presented a significant shift in social structure compared to the previous two era's which were based on a politics determined by class. Urbanisation was one of the biggest transitions to occur during the industrial revolution as a growing number of people moved to urban areas in search for employment (Ashton, 1977). A transition from agricultural societies to human skills and industrial urban societies occurred. This shift partly coincided with the constraints posed by the Corn Laws whereby more people moved to urban areas in search of work and cheaper prices (Flood, 2010). However, the industrial revolution not only saw an increase in urbanisation, but also population growth. As seen in **figure 3.3** a significant increase

[20] For an in depth discussion of the Corn Laws, the politics behind it, and their implication on food security see Beckett (1990), McLean & Bustani (1999), and Flood (2010).

in population occurred in the First Modern Agricultural Revolution compared to the previous eras. This has been attributed to increased innovation and modification of technologies.

Figure 3.2 illustrates significant innovation of the plough within this era, and evidence suggests that this correlates with increased population growth. Increased innovation occurred when population growth rose significantly and therefore it has been noted that innovation in technologies was due to the demands and pressures of larger and denser populations to increase food production. At the height of the industrial revolution, population growth increased at a rate of 1% per annum (Ashton, 1977). While this is relatively slow in comparison to the rates in some developing countries today, it was above anything previously experienced in this time. Population growth created a need for increased innovation and therefore the security of populations drove agriculture and technology development.

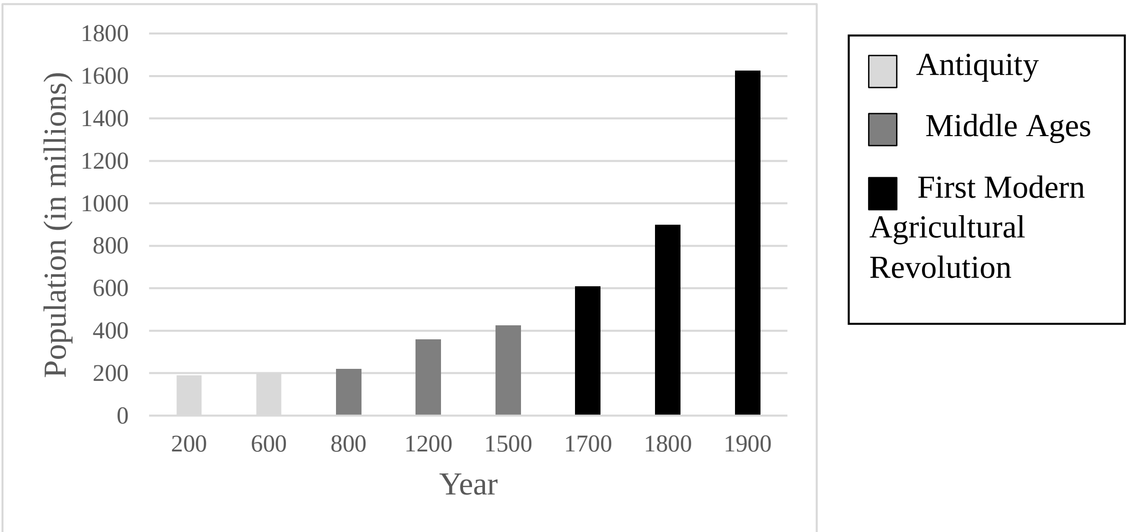


Figure 3.3 Global population growth from Antiquity to the end of the First Modern Agricultural Revolution (Adapted from Kremer, 1993)

Beyond this it has been argued that population density influences the types of technology adopted. Ester Boserup, for example, presented evidence that showed areas with low population experiencing a higher rate of productivity through fallowing approaches, as opposed to the plough. Further it was argued that the plough was an invention that was induced by a decreasing ratio of available land to population (Boserup, 1965; Pryor, 1985). This particular example of the plough indicates a correlation between technological and social changes. Technological development and innovation addressed the demands of social change such as urbanisation and population growth and social and economic arrangements within this time period generated a need for revolutionary technological development. Changes in technology and society were simultaneously produced.

Although the shift to industrialisation was prominent within this era, agriculture still flourished. A final point of note is that this technology development and innovation at a revolutionary pace within this time frame also highlighted the establishment of new forms of access not observed in the previous eras. This not only included the introduction of early patents (as shown in **figure 3.2**), but also the creation and emphasis on new forms of knowledge dissemination.

In 1773 a voluntary society known as the board of agriculture was set up with some support from the government to promote improved farming methods. Many progressive landlords forced their tenants into innovation by writing into their contracts the duty of taking the board of agriculture's advice (Deane, 1979). Additionally, the general desire for agricultural improvement led the publication of the first farmer magazine in Britain 1766, followed by the establishment of the 'Farmer's Journal' in 1806. Further, by 1866 the Board of Agriculture began to collect and publish data on agricultural outputs. This was one of the first recognitions of the use of statistics (Beckett, 1990). This presents a shift in that it promoted a way through which access to technological knowledge was available in ways not previously observed. It introduced new forms of access. This does not mean that technology was accessible for all, but it helps to indicate a shift in co-production in this era. Technology and legislative restrictions instigated social action which in part contributed to innovation and the creation of new forms of access not previously observed.

3.2.5 Second Modern Agricultural Revolution

This era saw the introduction of a politicisation of technology still largely present today. This section therefore focuses on three examples of social and technological development on the basis of their prominence within this time period. It touches upon the impact of war on food security, and the global response that it received, this is then followed by focusing on two examples of technological development: the green revolution (GR) and genetic modification (GM). As will be seen, these examples are useful as they not only have the most available data, but allow for a clear identification of how science and politics have interacted.

By Mazoyer & Roudart's estimations the First Modern Agricultural Revolution came to an end in 1914 with the Second Modern Agricultural Revolution not beginning until approximately 1918. This timeline neglects the events that occurred within the First World War. However within the history of food security it is imperative to engage with both World War One and Two. Food was increasingly used as a tool of warfare within this period. For example on the eve of World War One, leaders in Britain were planning on how to defeat each other in the coming war by disrupting each other's access to foreign food supplies. Britain, who had become increasingly reliant on food imports after the elimination of the Corn Laws, had to force farmers to grow food crops, as they imposed severe blockages on imports and exports which were reinforced by the British Navy. As a result of these restrictions, Germany and Austria lost many citizens to starvation towards the end of the war (Offer, 1989). Similarly, World War Two also involved significant blockages to food supply that affected agriculture and trade on a global scale and took many years to recover from following the ceasefire. For example, rationing which was introduced as a result of limited access to food supplies, continued in the UK until 1954 – eight years after the war had ended. **Table 3.1** presents some examples that demonstrate the extent of hunger and famine in Europe throughout and after World War Two.

Table 3.1 Incidents of famine/hunger that occurred in Europe during and after World War Two (Source: Kesternich et al., 2014)

Country	**Year(s)**	**Evidence of famine/hunger**
Greece	1941-1942	Between 100,000 and 200,000 deaths associated with food blockages occurred during this autumn/winter
Poland	1941	The average calorie intake was 931 for the polish population during 1941. This was significantly worse for Jews. Food rations were limited to 186 calories per day in the Warsaw Ghetto[1]
Netherlands	1944-1945	Approximately 20,000 deaths were attributed to famine caused by food blockages and a harsh winter.
Germany	1945-1948	After World War Two food supply to Germany from previously occupied countries ceased. Death rates rose by 4x for adults and 10x for children during this period.

[1] To put this data into context, the recommended amount of calories per day to maintain a healthy and balanced diet currently ranges from approximately 2000 kcal for women and 2500 kcal for men. This varies depending on age and level of physical activity.

The security of food had a prominent influence throughout this period. Following these wars, food and its security was increasingly emphasised at a global level. It resulted in the development of international inter-governmental organisations such as the FAO, for example. The history of this international organisation began before World War One with the International Institute of Agriculture. The International Institute of Agriculture was one of the first organisations to be developed in 1905 with the goal to better the plight of farmers. It was successful in ensuring this until it was interrupted by the World Wars. Following World War Two the FAO absorbed its assets. The FAO was established on the 16th October 1945 and aimed to provide education and technical assistance for agricultural development throughout the world. It also aimed to address persistent challenges associated with hunger (Phillips, 1981; McDonald, 2010; FAO, n.d. (a)). In this regard the politics of war and hunger contributed to the development of a global food security and an emphasis on the use of technology to ensure it. For example, the preamble of the FAO constitution in 1945 emphasised the importance of food production and distribution to achieve food security, recommending national and international action on "scientific, technological, social and economic research relating to nutrition, food and agriculture" (Article 1.2(a). FAO, 2017). Additionally, as mentioned in chapter one of this thesis, food was identified as a human right in the 1948 UN Declaration of Human Rights – another global acknowledgement. As such, this not only resulted in a shift of technological responses to hunger and other food security concerns, but it also introduced new forms of politicisation that were not as prominent in the past. Technology and social political factors therefore were not only simultaneously produced, but this was shaped by a politics of war.

While this era saw further developments in irrigation techniques and the acceleration of motor-mechanisation, there was also a considerable shift in the understanding of science. It has been noted that it was not until the seventeenth century that science became recognisably like it is today. While the term 'scientist' did not emerge until the mid-1800s, it was only in this Second Modern Agricultural Revolution that it began to involve much larger numbers, and not just the wealthy elite credited with its development (Bauer, 1994). Technological innovation has continued to accelerate and the introduction of laboratory based approaches have seen the capability of science progress significantly through this time period. The remainder of this section will illustrate this through the exploration of the Green Revolution (GR) and Genetic Modification (GM). It particularly looks at the benefits and concerns of the GR and GM as technological solutions. In doing this, it allows for the acknowledgement of not only how technologies have been emphasised as important contributors to achieving food security, but also how they are subject to social and political factors.

3.2.5.1 The Green Revolution

The GR has been described as a massive expansion in agricultural land, linked to technological advances in farm machinery, higher yielding grain varieties, the use of fertilisers and the spread of irrigation (Dupont & Thirlwell, 2009). This revolution was one that arose out of a combination of chemical and biological scientific changes. Reported dates vary however the GR was a phenomenon that began in the mid-sixties through to the 1980's. Nobel Laureate Norman Borlaug was largely credited with the construction of this revolution through the development of high yielding varieties

(HYV) of wheat and rice. This was a result of his work in the International Maize and Wheat Improvement centre in Mexico (launched in 1966) and the International Rice Research Institute in the Philippines which was launched in 1960 (Pingali, 2012). Interestingly technological change in the GR originated in developing countries proving beneficial for their economy. For example the development of new wheat varieties in Mexico put the country in the position to be leading exporters by the 1960's. Therefore the GR played a significant contribution to food security not only through the amelioration of hunger, but by improving production and trade in developing countries and stabilising economic concerns - some examples exist whereby prices paid to farmers increased (Evenson & Gollin, 2003).

The combination of HYV crops and seeds alongside agricultural intensification[21] allowed for a number of positive and beneficial impacts on food production. Within this time frame food production not only exceeded population growth by 20%, causing average food prices to fall by up to 60%, but also saw the production of grain quintuple (Dupont & Thirlwell, 2009). Global crop production rose by 162% (Burney et al., 2009) with yields in developing countries rising by 208% for wheat, 109% for rice and 157% for maize between 1960 and 2000 (Pingali, 2012). The GR saw India, who was on the verge of famine in 1967, produce enough wheat and rice to feed everyone without relying on American imports by 1972 (Cumo, 2016). In addition, the length of production also decreased. This is apparent in rice. While traditional rice takes between 150-180 days to mature, the introduction of new HYV such as IR8 initially only took 130 days (Davis, 2003). Finally, success was even greater in the later GR[22] with HYV in Africa accounting for approximately 80% of gains in total input.

While there was significant evidence of the benefits obtained through the GR, it was also subject to critiques which highlighted interactions between technical and political dimensions. For example it has been argued that this American led revolution was politically motivated. The application of science to agriculture and farming was a way for the United States to gain previously unaligned allies from nations in the developing

[21] A combination of irrigation, fertilisers, pesticides and motor-mechanisation, for example.
[22] The later GR refers to a period in which prices paid to farmers, and growth in food production, had decreased in most areas except Sub Sahara Africa who finally experienced increased yields in the 1990's (Evenson & Gollin, 2003). Despite the initial development of the GR occurring in developing countries, and attempts to integrate HYV into Sub Sahara Africa during the initial GR, poor results were yielded due to a lack of adaption to climatic conditions (Pray, 1981).

world by contributing to their food production. While the need for progression in science was acknowledged, it was political gain and the want for increased national security through strengthening America that reportedly shaped this technological development (Cumo, 2016). Furthermore, scholars have argued that the socio-economic structures within the GR resulted in the benefits mainly being distributed to larger farmers which mirrors access challenges observed in earlier periods of history (Pray, 1981). However this belief that wealthy farmers benefited more so than poorer farmers was challenged by the Consultative Group on International Agricultural Research who presented findings that indicated the wages of landless labours increased by 125% at the height of the GR (between 1972 and 1983) and the income of smallholder farmers rose by up to 90% (Cumo, 2016).

Environmental Challenges

A prominent concern of the GR is the effect intensification had on the environment. While the GR contributed to the improvement of self-sufficient food production, it also resulted in environmental degradation. The increase of specialisation in intensification (i.e. the use of specific pesticides and fertilisers) lead to biological consequences including decreased biodiversity (Matson et al., 1997). Therefore while intensification was successful from a humanitarian perspective, it was not environmentally successful. Greenpeace note that the GR failed for this reason; crop production came with chemical pollution, contaminated soil and water, and destruction of agricultural landscapes (Naidoo, 2013). Singh (2000) presented the environmental consequences of the GR in the Haryana state in India. Here an evident relationship between decreasing organic matter levels in soil, and the increased use of intensive chemical inputs, could be observed with such chemical degradation of the soil limiting crop productivity. Further, mechanisation and the excessive use of pesticides contributed to a loss in plant, crop, and animal diversity. Chemical run off has been shown to affect lands beyond cultivation. For example, up to 60% of cultivation areas in Haryana (India) faced soil degradation even after the GR, indicating this revolution not only had environmental consequences at the time, but a long term effect on agricultural development for other technologies. Approximately 1.6 billion hectares of land worldwide is currently being cultivated (FAO n.d. (b)). However globally, it is estimated that severe environmental and land degradation results in five to twelve million hectares of agricultural land loss annually (Dupont & Thirlwell, 2009)

Whilst pesticides and fertilisers were intentionally dispersed into the environment to improve productivity and control pests, they also have been reported to cause adverse side effects on non-targeted species. Residues can contaminate soil and water but also remain in crops and subsequently enter the food chain to be ingested by humans. Ammonia provides a relevant example. This chemical was first produced in 1910 through the Haber-Bosch process which allowed for the development of industrially produced nitrogen as a fertiliser to meet the needs of agriculture and ensure crop yield security. Nitrogen as a fertiliser was largely responsible for an increase in production obtained from the same surface of land, however its increased use also resulted in water contamination. Nitrate decreased the quality for human consumption and caused serious eutrophication issues around the world (Schroder et al., 2004; Carvalho, 2006). These concerns have led to scientists seeking alternatives to chemical based methods through breeding crops that fixed nitrogen in the soil and thus minimised the need for fertilisation (Cumo, 2016). Despite these efforts social perception, particularly of critics objecting on an environmental basis, remained unchanged with it being argued that there have always been more ecologically sustainable alternatives (Naidoo, 2013). The use of agricultural intensive technologies within the GR were subjected to environmental politics, and the influence of campaign groups in shaping technological development. Such objections have seen the use of new methods being altered: the development of genetically modified seeds that reduce the need for pesticide and fertiliser and subsequently reduce environmental effects to a level lower than that during the GR, for example, are now framed as a key benefit for that technology.

3.2.5.2 Genetic Modification

The 1980's saw the introduction of modern biotechnologies which encompass a broad range of technologies in food and agriculture for the genetic improvement of plant varieties and animal populations (Ruane & Sonnino, 2011). Perhaps the most prominent example of biotechnology is genetic modification and its resulting product, genetically modified organisms (GMO's) which were commercialised in the mid 1990's (Brookes & Barfoot, 2015). GM differs from the development of HYV's seen in the GR in that it does not rely on the fertilisation or cross breeding of two plants with desirable traits. Instead it utilises selective breeding within crops by inserting one or more genes into a plant to create specific advantages (Azadi & Ho, 2009). As emphasised in chapter one of this thesis, GM enables the development of new crop varieties with beneficial characteristics for farming, including resistance to insects, disease and herbicides. New generations of GM crops varieties have also looked at seeds tolerant to abiotic stresses such as drought, salinity and extreme temperatures (Liang et al., 2014) and the nutritional enhancement of crops through the addition of vitamins and minerals (Perez-Massot et al., 2013).

Other benefits of GM incorporate agronomic, economic and farm welfare aspects whereby numerous studies have demonstrated increased yields, increased farmer profits, and productivity as a result of cost savings in production and the reduced use of chemical pesticides (Pray et al., 2002; Qaim & Zilberman, 2003; Huang et al., 2004; Qaim & Traxler, 2005). It has been argued that GM crops are not only safe for the environment, but also human consumption with associated health benefits being observed by a number of scholars (Dale et al., 2000; Qaim, 2009; Brookes & Barfoot, 2010; Snell et al., 2012; Brookes & Barfoot, 2015). For example the reduced exposure to chemical fertilisers and pesticides from that observed in the GR as a result of the application of GM has been associated with improved health and decreased death among farmers (Qaim, 2009). However despite the World Health Organisation (WHO) declaring that commercialised GM crops are not likely to cause any more damage to human health than their non GM counterparts, scepticism is still rife among critics (WHO, 2005; Dupont & Thirlwell, 2009).

Although GM has proved beneficial, the manner of distribution reinforced other aspects of food insecurity, particularly as it related to access. For example it has been argued that IPR and associated patents enables and drives large private sector investments in agri-biotech research, which can result in a monopolisation of knowledge and restriction of seeds for specific regions. GM has seen the introduction of more strenuous ethical and moral concerns than previous technologies. The prominent role of large corporations in the development and commercialisation of GM crops has been argued to question who makes the decisions and who benefits from them. There is, to many extents, a boundary between the producer and user of technologies, created by the monopolisation of agriculture. Around 80% of commercialised GM crops to date have been developed by the private sector with Monsanto – the leading developer – contributing to nearly 50% of this figure (Bennet et al., 2013).

Issues on ownership and intellectual property are subject to debate. Supporters of IP and patenting have argued that if the private sector invests large sums of money into research it must recoup what it has put in, with legal protections of IPR's being an important incentive for private sector involvement in the development of biotechnologies (Serageldin, 1999; Cullet, 2004). On the other hand it has been argued that applications of research and development from the private sector largely exclude the poor. This in some ways presents a different form of class politics identified and previously mentioned in the eras of Antiquity and the Middle Ages, but now it is on the basis of global divisions being more important. It is argued that privatisation of GM is unfair towards poorer farmers where access to knowledge is more difficult than it is to farmers in the developed world (Cullet, 2004; Azadi & Ho, 2009; Beddington, 2010). Therefore, while IPRs are designed to promote technological development, they do not consider socio-economic concerns including food security.

Concerns on access, monopolisation, and IP are particularly voiced by campaign groups who advocate for the rights of the poor farmer in alignment with debates on food sovereignty. The concept of food sovereignty – where peasant rights are the priority – objects to the use of GMOs. One of the most recognisable campaign groups within this is the international peasant movement La Via Campesina who have long urged for a ban of the production and trade of GM seeds, crops, and other food products (Jarosz, 2014). This presents an example whereby campaign groups contribute to the politicisation of technological solutions. In this case, it is argued that the use of GM and biotechnology promotes a corporate globalisation which favours a handful of transnational corporations and their agendas. Biotechnologies, it is argued, are expensive, patented and controlled by a few which undermines the attempts of poorer countries to increase social and economic welfare, and contributes to the obstruction of access (La Via Campesina, 2001; 2010).

While this introduces a politics shaped by access to GM, there is also an apparent politics of scientific evidence and funding whereby corporate based research is accused of bias that impedes the robustness and quality of data (Langley & Parkinson, 2009). In 2015 a freedom for information request was put forward by the non-profit organisation group 'right to know' which provides an example of these concerns. This request allowed for access to the emails of a number of science academics and showed that unrestricted grants and industry funded trips to promote biotechnology and corporate interests were received from the food industry. In this instance corporate backing was described as "dirty money, dirty science" by the non-profit organisation Food Tank who stated that "the biotech industry's web of attempts to buy credibility, by laundering its messages through supposedly independent academic scientists, is unravelling…" (Food Tank, 2015). An article in the New York Times "Food industry enlisted academics in G.M.O lobbying war, emails show" gave an in depth account of the role of academics in enhancing corporate agenda's by summarising these emails. However, while they established that academics were recruited as lobbyists, there was no evidence that their research had been compromised (Lipton, 2015). Regardless of this, opinions had already been formed. This presents an example of the influence of campaign groups, however examples also exist whereby pressure has been exerted in such a way that it has contributed to reshaping public policy.

In response to fears from the public, the EU established a legal framework for GMOs, which is continually being redrawn[23]. For example, this framework saw the introduction of Directive 2015/412 which came into force in April 2015. This amended Directive 2001/18/EC on the deliberate release of GMOs into the environment by allowing member states of the EU to make their own decisions as to whether GMO crops are grown. Prior to this directive, while authorisation was required to grow GMO crops, once it was obtained that specific GMO was automatically authorised in all member states despite no wide EU agreements on whether cultivation should take place. This directive was therefore the product of ongoing disputes and tensions prompting the development of an opt out clause into main legislation.[24]

Northern Ireland became the second member state to ban the growth of GMO crops. While a lack of assurances that cross contamination between GM and non GM crops would not occur was a concern, the environment minister at the time put this ban down to notions of prestige in which it he stated to the media that "we are perceived internationally to have a clean green image. I am concerned the growing of GM crops…could potentially damage that image" (Macauley, 2015). This decision was to a great extent informed by the greater public perception.

[23] Some of these public perception concerns, and the debates surrounding them have been introduced in chapter one.

[24] For additional examples on how pressure from the public and campaign groups shaped public policy at a European level see Levidow et al., 2005 or Holmes et al., 2010.

3.2.5.3 The interaction between technology and society

There are a number of important points that have been raised in this section on the Second Modern Agricultural Revolution. Firstly, a politics of war contributed to increased global attention on food security through the development of international bodies who called for technological progress to address hunger, social and economic related concerns. This indicates an apparent co-production between technology and society in this time period: technology development contributed to the needs of an increasingly global society, and the need for technology was emphasised by a shift to a global approach to address food security challenges.

Secondly, the exploration of the benefits and challenges of two prominent forms of technological development allowed for an insight into the influence of political factors. One main example emphasised within this work was actions of various campaign groups. Therefore, while the benefits of technologies can be widely recognised, they have also been faced with apprehension. For example, the ample benefits of the early GR indicated the major role that science can play in achieving food security, however environmental politics had a role to play in driving technological change. The introduction of biotechnologies such as GM were framed as beneficial in that they addressed these concerns however this particular technology has long faced opposition by the public and campaign groups. This has introduced significant debates on the importance of science and technology versus the environment, the economy, and social factors such as the rights of smallholder farmers and so forth.

Thirdly, this has only provided examples of debates associated with the use of technologies. Nevertheless, these types of debates are prominent within this period. That is, there is little evidence of similar occurrences throughout the previous eras, at least to the same extent. While this chapter has presented evidence that suggests the development of technology (biological or not) throughout history has had important effects of society (and vice versa), it has been noted elsewhere in the literature that only in recent decades have the actions and roles of scientists, as they are currently defined and understood, had an important effect on wider society that it has come under public scrutiny (Bauer, 1994). This difference observed between these eras perhaps links to the influence of science on the emerging global politics of food.

Finally, such public scrutiny has also highlighted access concerns. This era has seen an emphasis on IPRs and while this illustrates a shift in the approach to access, the arguments against IPRs tend to mirror the concerns observed in the earlier eras of agriculture: a monopolisation of agricultural technology and the application of IPRs restrict access to poor smallholder farmers.

3.3 Analysis and discussion

The exploration of core examples of technological and social / political change throughout five key historical periods within agricultural history allowed for a number of findings to emerge. Firstly, while the term food security is relatively new the concept can actually be traced back to the emergence of agriculture. Secondly technology has always been politicised, this is a finding that ties into the most dominant argument within this work – throughout each of these eras there are apparent signs of co-production. The final observation from this analysis is that these forms of co-production look different in different periods of time. This section discusses these findings further.

3.3.1 Food security can be traced back to the emergence of agriculture

As previously mentioned the term food security can be traced back to the 1948 UN Declaration of Human Rights. Further, this analysis has shown that food security, as a defined concept, gained considerable traction at a global level post-World War Two. This was partly through the establishment of international organisations such as the FAO with the goal to eradicate hunger. This chapter has also shown however that the securitisation of agriculture and food can actually be traced back to the Neolithic era some 10,000 years ago. Section 3.2.1 of this chapter presented evidence to support the claim that food security, physical security, agriculture and socio-economic and political forms have co-evolved since the birth of agriculture. Therefore this analysis has argued that a shift to sedentary populations drove security.

As mentioned in the introduction of this chapter, while food security has been the attention of various studies, they are often much shorter contemporary histories. The shift in political liberalism and Laissez faire economics in a much longer Western European politics has been used to show how food scarcity and hunger were conceptualised throughout history, and how they were managed (Nally, 2011).

However, to the best of my knowledge the research in this chapter is the first to make this claim. There is little in the existing literature that explores food security throughout history in the manner conducted in this research.

Attempts to achieve aspects of food security can be observed throughout each key era of agriculture, which further supports the argument that food security has always been apparent since the emergence of agriculture. The Neolithic era emphasised the need for physical security of food that coincided with a shift in lifestyle and attempts to ensure the availability of sufficient food were apparent. Further, the introduction and innovation of a variety of technologies throughout each of the remaining eras were by and large attempts to improve the cultivation, and subsequently the availability of plants and crops as food sources. Examples of this included the development of irrigation and fertilisation in Antiquity and the Middle Ages, innovation on the plough in the First Modern Agricultural Revolution and the GR and developments on biotechnologies in the Second Modern Agricultural Revolution. However, as will be discussed shortly, this did not always result in food security for everyone.

3.3.2 The co-production between technology and society

As the previous section of this chapter progressed through the history of agriculture and food production, it was evident that technological change cannot be reduced to particular physical implements. It also considers a number of other dimensions in the shape of social, economic and political forms that either contribute to, or hinder technology development or adoption. The plough presents a good example of this as it transcends multiple time periods throughout history and is therefore subject to different social and political forms within each. The purpose of the plough has been described as a tool "to break up and turn over the soil…exposing the layers underneath to the atmosphere. Regularly turning over the soil increases fertility and enables seeds to be sown more effectively" (Brunt, 2003:446). As shown in **figure 3.2** the plough was continuously innovated through history, which was an attempt to improve on this. However it is also apparent that social and political factors have had a role to play in how innovation occurred and how this was disseminated.

Innovation in the Neolithic era was a necessary development to meet the challenges faced with a shift to more sedentary based agricultural lifestyles. Eras up until the eighteenth century saw technology controlled through different social and political dimensions such as imperial relations and feudalism which emphasised concerns on access and distribution. This was in contrast to the First Modern Agricultural Revolution and the industrial revolution which brought a large shift to factory based work, urbanisation, population growth, and the need for revolutionary technological change as a result. Based on this observation it is clear that technological change cannot be referred to as an independent variable. Rather, change is very much dependent on the development of social, economic, and political factors therefore presenting a two tiered view in which we cannot only consider a change in technology, but also the evolving relationship throughout history that contributed to shifts in their development.

Previous works have suggested that technology is the dominant factor or driving force of this relationship. Pray (1981) for example, when considering the GR, notes that "increased food production and income due to the new technology also led to changes in the structure of society and to changes in government policy" (p.77) stating further that "the impact of technological change on society is determined by existing socioeconomic structure and the government policies, which in part reflect that socioeconomic structure" (p. 80). Romer (1990) also emphasises the importance of technology within this relationship when considering endogenous technological change as a whole, without focusing on a specific aspect or industry. He notes that whilst technological change lies at the heart of economic growth, it also acts as a source of social and political change. In addition, Skolnikoff (1993) argues that given the scale of scientific and technological enterprises, science and technology are the most persistent factors to societal change. Research conducted for this chapter however indicates that, when considering this relationship within agriculture and food production, this is not the case. Rather it agrees with the work of Brezina (2010) who found, using data for total agricultural harvest and total agricultural power potential in Austria, that "agricultural power potential means the sum of human, animal and mechanised workforces" (p.321), thus demonstrating that to achieve the maximum capability of agriculture, multiple contributing factors are required. **Table 3.2** summarises the examples of technological and social change drawn upon throughout this chapter, presenting the relationship between technological development and social change observed in each key era. It demonstrates that whilst social change impacts technological development, technological development also impacts social forms and as such they equally rely upon each other: they are coproduced. It is important to mention one caveat. This chapter draws on examples only within each time period. Identifying all forms of technological and social change within each era was not only beyond the scope of this work, but it was also not necessary. Therefore when considering additional types of technological or social change this may not be the case. However this does not detract from the current argument whereby it is apparent that co-production is present in some forms, regardless if this may not be the case in others.

These forms of co-production however don’t all speak to notions of food security. Rather there are clear observations of co-production aligning more with trajectories of food insecurity. This is particularly apparent within Antiquity and the Middle ages whereby class politics contributed to access challenges for the poor. By some accounts, this is also apparent in modern day examples such as IPR, and indeed this may well be observed in other eras but the evidence in which to make this claim is somewhat restricted. That is to say that food insecurity has always been present, however the examples used within this chapter particularly emphasise this in Antiquity and the Middle Ages.

Table 3.2 A summary of the relationship between technological development and social change in each key period of agriculture.

	Neolithic	**Antiquity**	**Middle Ages**	**1st Modern Revolution**	**2nd Modern Revolution**
Examples of technological development	- Domestication of plants and animals - Shift from wooden and stone tools to an ard (early plough)	- Introduction of fertilisation - Invention of iron improved tools for cultivation -Irrigation systems initially developed - Plant science and empiricism	- Shift from oxen to horse drawn implements was observed - Mechanisation in the form of mills - Expansion of fertiliser use	- Chemical, biological developments - Revolutionary development of the plough - Introduction of motor-mechanisation (i.e. the tractor)	Progression in genetics and biotechnology. For example, the development of HYV crops in the GR and GM.
Examples of social change	Shift from hunter-gatherer to farming communities (moving to sedentary)	- Increased poverty on the basis of expanding empires and hierarchies	Introduction of feudalism. A new hierarchy of power was established	- A move from agriculture to industrial skills (factories) - Urbanisation - Rise in population	- Development of international organisations (i.e. FAO) and emphasis on technology production for the alleviation of hunger and poverty - Global emphasis on food security - Rise of campaign groups and subsequent debates on the role of the GR and GM - Increased emphasis on corporate control of technologies with the development of IP.
Dominant modes of interlinkage	Technology development instigated social change. This in turn contributed to the development of agriculture, further technology and food security	Development of technology contributed to the restructuring of social organisations. Social change resulted in access and distribution concerns for poorer populations.	Technology further encouraged changes in structure of social classes which contributed to divisions in labour. Social and political developments shaped access and availability as a result of an uneven distribution of power	Technology development addressed the demands of social change (i.e. urbanisation). Population growth and other social, political and economic arrangements generated the need for revolutionary technological change.	Technology development and innovation contributed to the needs of an increasing global society. The need for technology was emphasised by a shift to a global approach in addressing food security. Further, technological change can be linked to a politics associated with the rise of campaign groups.

3.3.3 Different forms of co-production

It is well acknowledged the relationships between science and politics are shaped by different factors. Indeed this is, by and large, a considerable part of the literature mentioned in chapter two on the conceptual shift between linear models of science to models that recognise and acknowledge that science and politics always entwine, albeit in different forms (Weingart, 1999; Jasanoff, 2004). The analysis in this chapter highlights this further. It has not only identified this co-production between technology and society at all key periods of agricultural history, but also indicates that some differences exist in the character of these relationships.

As shown in **table 3.2**, and briefly mentioned earlier in this discussion, change in the Neolithic era were associated with shifts from active hunter-gathering lifestyles to sedentary farming communities. Antiquity and the Middle Ages were shaped by social changes in the form of class structure, before shifting to more social forms in the First Modern Agricultural Revolution that contributed to a more apparent trajectory of revolutionary technological change. A final observation from **table 3.2** related to this point was that more social changes occurred in the Second Modern Agricultural Revolution. This was perhaps influenced by the rise of various interest groups which introduced new forms of politicisation not previously observed, and a global politics as opposed to issues related to class. This provides one way in which co-production is shaped differently. Technology and society have always entwined however the nature of this it is partly determined by a politics of class and social structures alongside the use and development of particular technologies.

An additional example that emphasises the differences between each of these eras surrounds the access and dissemination of technological development. Issues on access arose within all of these eras and subsequently presented a similarity throughout each time period. As such it is apparent that this dimension of food security has long played a dominant role. However, as mentioned throughout this discussion issues, of access were identified to differing extents. Examples provided for the Neolithic era illustrated how social change and the securitisation of food was in some ways attempts to ensure access to food supplies. Whereas as shown in **table 3.2,** social changes in the periods of Antiquity and the Middle Ages presented issues for the availability and access to technology developments in such a way that contributed to food insecurity as opposed to security. The last two eras saw a shift in how knowledge was disseminated which partly relates to issues of access and availability. In the First Modern Agricultural Revolution farming groups, meetings, and associations were developed primarily for this purpose. The GR also emphasised the importance of disseminating knowledge with Norman Borlaug highlighting the importance of everyone benefiting from such technological advancements. However, it was the introduction of biotechnology, particularly GM, which coincided with private research and development and the rise of IP. Therefore as food security became global, the spread of technology and knowledge did too.

3.4 Conclusion

This chapter looked at the connection between food security, technology and society throughout key periods of agriculture in history. In doing this three main arguments were made. Firstly, it argued that rather than being a product of globalisation and an increased use of modern biotechnologies such as GM, food security can actually be traced back to the emergence of agriculture. Practices of food production, technology, society and security have been entangled since the invention of agriculture some 10,000 years ago.

Secondly, by considering different forms of technological and social change throughout history, it argued that these forms of science and politics have always been co-produced. The examples used within this chapter showed that both technological and social change relied upon each other. Technological developments contributed to forms of social change, and society reciprocated in an array of ways such as determining access and distribution, the establishment of international bodies, and critiques voiced by the public and various campaign groups. This argument is of importance as it not only shows that technology and society have always interacted, but it also validates the use of a co-production perspective in understanding how various forms of science and politics come together and divide in the present. This links to the third argument of this research: the character of co-production shifts according to different technological and social environments. While it has been established that the relationship between technology and social change has always been balanced, it has also been concluded that these relationships have been influenced differently. Co-production takes different forms as a result of particular technological advancements alongside particular social and political environments.

This chapter considered key examples of technological and social change in history based on available and accessible data. It did not however touch upon the food price crisis. There were two reasons for this. Firstly, this was introduced in sufficient detail in chapter one of this thesis and secondly, it contributed to reshaping global food security as it looks in the present. It represents an additional shift in the way food security and technology is understood. One of the take home points of this chapter is that it is apparent that the character of the relationship between science and politics has changed over time and thus this leads to question how co-production between science, technology, and politics currently appears. As such, this is the focus of the remaining chapters of this thesis.

Chapter four: Boundary work in food security

4.1. Introduction

The previous chapter of this thesis argues that co-production between technology and social and political change is not something new. It has always been present, albeit in different modes. This chapter is the first of three that uses empirical evidence to explore the shift in co-production between forms of science and politics in the present. To do this, it specifically focuses on what boundary work looks like when we consider the interaction between different food security communities in a broad context. In this case, the views of scientific communities and policy makers, practices, institutions and various structures. This arose as a core theme through the analysis of interview material.

Chapter one of this thesis details how the approach to food security has recently shifted, and therefore it is important to explore how boundary work occurs in the present. Further, chapter three illustrated how co-production has changed throughout time, as a result of various social, political, and scientific developments pertaining to specific eras. This chapter therefore asks what this looks like post 2008 and the recent shift in the food security narrative. This period has not only seen an increase in both academic literature and the number of academic fields contributing to food security research, but a global recognition for the need to further prioritise and address food security as a whole. Issues such as underinvestment in agriculture and food security, and the food price crisis, instigated a shift in how food security was approached at both a national and international level.

The importance of interaction between different communities is increasingly emphasised both in food security practice and academia (AFSI, 2012; IFAD, 2012; UN, 2015, FAO, 2016; Moreddu, 2016). However this chapter finds that there are still an array of challenges that must be addressed first. It shows how the creation of boundaries are emphasised, as opposed to the ways in which they are overcome. Three main barriers to interaction are considered: ownership, perception, and challenges formed by stakeholders not knowing who they can talk to. This chapter will argue a number of things. Firstly, as mentioned, there is a stronger emphasis on barriers and the ways in which boundaries are created compared to how they are bridged. Secondly, multiple forms of boundary work are apparent. Further, while these are independent, they all are shaped, in some regard, by operational differences between different communities. Finally, it argues that the identification of boundaries show some important national differences, which are further amplified by political controversies like genetic modification, and political uncertainties, such as Brexit. This chapter begins by providing a brief overview of the empirical data before presenting the results of each of the three barriers in greater detail. The core findings are then discussed and conclusions are then made.

4.2. Empirical data

A key theme that arose through the content analysis of interview material was the barriers that impede interaction between science and political communities and structures in practice. As shown in **table 4.1**, three main barriers were identified. Firstly, issues of ownership emerged as one barrier that contributes to the creation of boundaries. With the exception of the regulator stakeholder engaged with, this was identified as a challenge by all stakeholder groups. Secondly, perception was identified as a core challenge to interaction. This particularly spoke to two different, yet interrelated forms: the perception of civil society and other such advocate groups, and the perception of the public. Finally, stakeholders not knowing who to talk to was also identified as a barrier to interaction. This was on the basis that interaction cannot occur if you do not know who to approach in the first place. Each of these challenges are distinct, with forms of boundary work being identified in each of them. However, forms of interaction between them are also apparent, with operational differences being a dominant observation. The follow sections expand these results.

Table 4.1 perceived barriers to interaction between science and politics communities, institutions and structures that emerged in key informant interviews. Themes acknowledged are denoted by (✓).

	INTERACTION BARRIERS		
	Ownership (n=14)	**Perception barriers** (n=10)	**Don't know who to talk to** (n=14)
UK government bodies	✓	X	✓
US government bodies	✓	✓	X
Industry	✓	✓	✓
Trade Association	✓	✓	✓
Research Institutes	✓	✓	✓
International Organisations	✓	✓	X
NGO/CSO	✓	✓	X
Farmer Unions	✓	✓	✓
Funding Bodies	✓	X	✓
Regulator	X	X	X

4.3. Ownership

Ownership as a challenge to interaction was identified by fourteen participants (30%). As shown in **table 4.1** this was mentioned by the most groups of stakeholders. All but one group acknowledged this as a core challenge.

This may correspond with sample size – only one regulator was engaged with. While the purpose of this research was to get a greater depth of understanding with each stakeholder group, this was a smaller number compared to all other stakeholder groups and therefore may provide an explanation behind this observation[25].

However in this case it is useful to draw attention to this as it provides an explanation behind this observation. Ownership as a challenge coincides with operational differences between different communities such as universities and industry, as well as the public versus private sector. For example:

> *"I think the main barrier is IP issues. University based scientists have their own IP related roles, and industry have their own related IP roles so I think figuring those out becomes tricky"* [9]

Debates on ownership have also been argued to create friction between existing relationships. One industry stakeholder stated the following about their interaction with universities:

> "*...some universities also have become a little more commercial which is fine, however they then start to try and leverage that by trying to retain IP related to studies that maybe an individual industry partner has paid for. Now, if they are putting in a lot of time and effort and are balancing the investment in a project with what the industry partner is putting in then that is fair enough. But if the industry partner is putting in 100% of the money then this is where we struggle as a business. Why does that university think they own IP or should own all the IP related to it? So we can end up with some conflict there."* [20].

> *"…the public goal is really about making research openly available so everyone can benefit from it. Private research will eventually have an*

[25] See section 2.6.1 on sample sizes.

impact but initially they are obviously interested in holding that close until they can develop and perhaps put a patent on it or at least bring it to market and make a return on it” [34]

The following quote from the same participant further explains why IP is perceived to create challenges for interaction between different communities.

“On the industry side I guess intellectual property really is a key [challenge] because they have their own agendas and, you know, they face a trade-off between investment in something that they expect to generate a return and sharing that research too soon and basically letting others know what they are doing” [34]

This view has also been reinforced by industry trade associations:

“…it is important to have ways to provide incentives to companies to innovate and not only do they need reliability in the product approval process but they need to have intellectual property so they can be sure that after investing so much time and money they can also get a return on their investments” [25]

As such, challenges also corresponded with stakeholders not wanting to engage due to fears of ownership being diminished. These quotes indicated that ownership as a barrier to interaction predominately speaks to concerns on IP and access whereby boundaries are created by differing views on these issues.

4.4. Perception

Perception was identified as a barrier to interaction. Both the perception of civil society and the public were emphasised. While the perception of these groups are distinct, clear links could be observed whereby, in some respects, the view of the public coincides with existing views from advocate groups. This will become apparent in the following write up of results.

4.4.1 Civil society and the perception of technology

Civil society play an increasing role in global food security, with the FAO often appealing for their knowledge. This is due to their technical expertise and proximity to the hungry and the poor (FAO, nd (b)). To this extent, their role is not only increasingly emphasised, but they also hold considerable influence on policy decisions. When considering the perception of civil society in the context of this research it was apparent that boundaries are intentionally created through the denouncing of private interests within the food system by civil society. Concerns and critiques about the private sector emerged:

> "*When we talk about technology we talk about a combination of traditional knowledge and scientific competence and this is also the reason why we support mainly public funded research which doesn't respond to private interests or profit orientated outcome, but looks more at innovation as a public good for the interest of the public"* [41]

Civil society also noted that they are in opposition to the production and marketing of technologies by multinational companies:

> "*…when we talk about traditional seeds, we are against seeds that are produced and sold by companies and multinationals because these varieties are killing biodiversity in the sense that there are just a narrow number of varieties now that these companies now sell. They are very expensive and they do not realise the outcome. Most of the smallholder producers that get it are being trapped in a deep cycle…"* [47]

In this case, it is argued that the private sector take advantage of traditional small holder farmers, and operate in direct opposition to civil society.

> *"Corporate bodies are capturing public space, they are capturing the capacity of farmers to exercise their rights and so we are in a confrontational position now because we promote a completely different model of development."* [47]

These operational differences were also emphasised through the lens of access to technology which is increasingly emphasised as a concern by civil society. They argue that concentrated systems create access issues for the world's poorest populations. This provides a link to the theme of ownership as a barrier to interaction:

> *"I mean challenges are the loss of control on the resources. So for example when you have intellectual property rights preventing traditional*

knowledge, this is a way for the farmers and the produces to lose control on something that they have practiced for centuries. So this is one of the challenges." [47]

In contrast to the private sector, civil society support traditional smallholder farmers, reinforcing narratives of food sovereignty which were touched upon in chapters one and three of this thesis. The above quotes emphasis how civil society perceives industry to be impeding on this. Not only are they critical of their role, but there are clear differences in ways through which these communities operate with regards to technology. The perception of civil society was also highlighted by other stakeholder groups. For example, the criticisms of civil society have been recognised by industry and regulatory bodies:

"*There are a lot of NGOs out there for whom working with a chemical company or pesticide company is viewed as morally wrong. You know in some ways the whole reason why they exist is to be against 'nasty' people like us. They perceive us as 'for profit' and so not surprisingly that can be a barrier to progress…"* [18]

"…they look at the private sector with suspicion. For some reason they don't like that the private sector is making money." [34]

To this extent, the role of civil society and NGOs have been equally criticised from the opposing perspective:

"They tend to be politicised and therefore, essentially, more concerned of their ability to influence, their ability to shine, their ability to weigh in, rather than actually what that weighing in will produce…." [47]

It was recognised that the concerns of civil society and NGOs can lead to reputational risks for communities that work with the private sector:

"You can run the risk that the output of your research would not be considered if it is financed by industry – that's one of the risks. The second risk can actually be a reputational risk and I think we all run that reputational risk as a result" [47]

It has been argued that one outcome of the views of civil society and other advocate groups is that scientists fear working with industry (interview 31). In this case a second form of boundary work can be observed. That is boundaries are created through the overt influence of civil society perception.

4.4.2. Public perception of technology

The issues encompassed within public perception as a boundary predominantly focus on different attitudes to technology, which in turn creates difficulties for interaction. It was noted that people are increasingly caring more about food which subsequently heightens perception. As such, one participant representing an international organisation noted that this prevents them from accepting funding from industry. This links to how the perception of other groups, such as civil society, influences actions. Farmer Union representatives noted that different attitudes to technology throughout the world make interaction difficult for them, and industry representatives emphasised the influence held by media in driving change in perceptions. Industry trade associations stated that misconceptions of technology can prove challenging, acknowledging that a stigma exists with regards to how GM was previously handled, particularly in a European context. Further, the need for government bodies to respond to, and be held accountable to public opinions was also stated as a barrier to interaction. Decision making in this context goes beyond black and white science. It was also noted that as a result of this accountability, government bodies can be reluctant to talk about technology that is not universally accepted. However, an interesting observation is the lack of acknowledgement of perception as an engagement barrier by UK representatives. This may coincide with how wider public perception shapes operational differences. The following quote further emphasises the differences between the UK and US:

> "*I went to the states about four years ago and at the time we were literally able to pull over at the side of the road and walk through a field of genetically modified wheat without any hindrance whatsoever. At the same time in England's Rothamsted Research Institute there was a trial being carried out which had barbed wire, security guards, electric fences, you name it, around it and it was being watched 24-7 by security cameras. It just shows the huge gap in the different attitudes towards some types of biotechnology in different parts of the world*" [42]

A third of stakeholders who identified perception barriers as a challenge were US government body representatives, all of whom indicated concerns with social acceptance and attitudes on technologies – particularly genetic modification. It is apparent that US government body interaction with industry can be constrained by how technology is perceived by the public. This was highlighted in a discussion with a US government body representative:

> *"…there might be public perceptions about certain areas of the private sector…we try to always exercise good judgement in that but we also don't want to limit ourselves from working with a company because there might be a public perception about what they are doing, and I'm thinking in particular about genetically modified organisms. We work on things related to GMO's and we see them as a huge part of the solution to food security in some places and contexts but then, within the US in particular, there is a lot of criticism about GMO's and using GMO's and I think a lot of it relates to things that have been published in the media about GMO's or a lack of knowledge about how they work and it is not founded in science. But you know people are worried about GMO's and so if they see we work with somebody or a company who is putting out GMO's or doing research on GMO's or some types of development of GMO's like Bt modified products…in the United States right now there is a lot of push back about GMO's. But like I said it is part of the solution for us in some cases so it has been a tough issue sometimes."* [11]

This particular quote indicates that US government bodies acknowledge an element of public accountability as a government body and thus must consider this prior to interacting with the private sector. It acts as a barrier as it can impede and restrict forms of interaction with particular stakeholders, thus drawing a boundary between science and politics communities. It is perhaps not as unusual for anti-GM voices to be louder in the US at present due to a much higher saturation of GM food and feed crops being cultivated, particularly in comparison to the UK. **Figure 4.1** gives a very clear visual representation of these differences. It illustrates the number of cultivation approvals for GM crops both in the US and the EU as of January 2019[26]. While the US have approved 177 GM crops for cultivation to date, the EU have only approved ten. Differences can also be observed in the land allocated to GM crops. As of 2017 the US had allocated 75 million hectares. By contrast, the only figures available for any EU countries showed less than 0.2 million hectares in Spain, and less than 50,000 hectares in Portugal (ISAAA, 2017). This indicates quite a significant contrast, so much so that displaying this diagrammatically would not be beneficial.

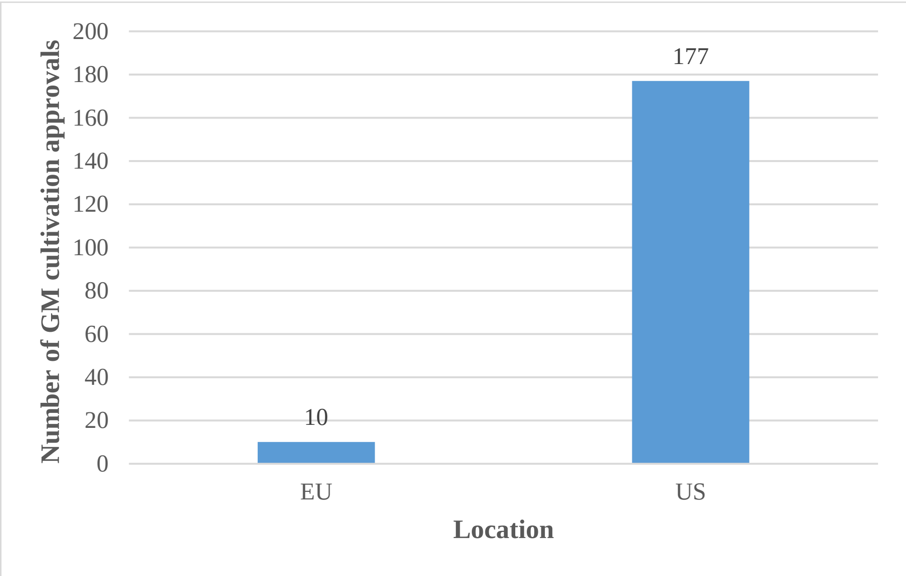


Figure 4.1: Number of total GM cultivation approvals in the EU and US (ISAAA, 2017).

The lack of acknowledgement by UK government bodies on public accountability or perception acting as barriers does not mean that these issues are any less of a concern. Rather, it could be said that strict legislation minimises types of interaction that are framed around particular technologies, specifically GM. This illustrates another key observation: the differences between how boundaries are prioritised corresponds with

[26] The ISAAA GM approval database used to obtain these statistics does not present figures for individual EU member states and therefore values for the EU as a whole are used to illustrate disparity between nations.

specific GM regulatory and legislative frameworks. The issue here is not public perception, but public perception anticipated through regulation.

The UK and the US have different legislative and regulatory frameworks on food technologies. Presently, the UK adhere to EU law which has established a comprehensive legal system for genetically modified food and feed, the traceability and labelling of GMOs and food and feed products deriving from them, the deliberate release of GMOs on the environment and the contained use of genetically modified micro-organisms[27]. The EU legislation and policy on GM is based on precautionary principle which aims to protect the environment, and the health and safety of humans, animals and plants. It does so via the framework of risk and preventative decision making, corresponding with the extent of scientific uncertainty. As such, precautionary principle is invoked for two reasons: when adverse effects have been identified through scientific or objective evaluation, or if such evaluations do not allow for risks to identified or determined with sufficient certainty (European Commission, 2000).

Conversely, the US employ a ‘substantial equivalence’ approach. This entails three elements. Firstly, it focuses exclusively on the end product as opposed to the production process of GM used. Secondly, in absence of verified scientific risk, it is understood that there is no reason to prevent a technology from being introduced. Finally, it is maintained that GM technology is similar to any other agricultural technologies and that any risks are the same as those posed by traditionally produced food (Marden, 2003). If a novel or modified food ingredient can be shown to essentially be equivalent in composition to an existing traditionally produced food or food ingredient then it can be assumed as safe. Only if a GM food product comprises of new traits or characteristics that no longer make it substantially equivalent to its traditional counterpart (i.e. a higher vitamin content or the presence of allergens) is it subject to additional forms of assessment (Arvanitoyannis et al., 2006; Varzakas et al., 2007).

The precautionary principle versus substantial equivalence approaches to creating legal frameworks indicates a difference between the US and UK which corresponds

[27] The EU legal framework on GMO’s consists of five building blocks that include two regulations (that are directly applicable in the legal systems of all 28 EU member states) and directives whereby members must comply with the requirements within them, but are free to choose how it is implemented. A concise summary of this legal framework can be found on the European Commission website (https://ec.europa.eu/food/plant/gmo/legislation_en)

with how these nations deal with food, genetic modification, and the treatment of risk. Perhaps related to this, the number of US food laws are smaller than that of the EU, with US GM legislation, in particular, being seemingly more lenient (Arvanitoyannis et al., 2006; Lucht, 2015). This is reflected in their response to the use of agri-biotechnologies such as GM. Whilst the EU imposes severe restrictions, the US adopt a much more permissive approval policy (Bernauer & Meins, 2003).

The seemingly more lenient approach to the regulation of GMOs in the US has resulted in a much more prevalent number of GM food/feedstuff on the market whereby in contrast, EU legislation has completely restricted the introduction of GM food products in the UK. This may explain why public perception, as a boundary, is prioritised differently between nations. That is, boundaries are not only drawn through the perception of civil society and the public, but are actually further shaped by, and occur through, regulatory and legal frameworks. In an area as contentious as genetic modification, lenient regulation and public perception perhaps goes hand in hand, in that the introduction of GM food / feed to the market strengthens the voice of both the general public and anti-GMO advocates. As such, regulations not only facilitate public perception in various ways, but may shape what boundaries to interaction are most relevant to particular nations.

4.5. Not knowing who to talk to

'Don't know who to talk' emerged as a core challenge to interaction that was identified by fourteen participants. This theme touched on a number of issues that act as interaction barriers. They range from the rapid turnaround of government officials and a perceived lack of overarching policy instruments for food security, to changes in political landscapes. Further analysis of these challenges drew attention to two factors that contributed to the creation of 'not knowing who to talk' to as a barrier to interaction between stakeholders: different institutional arrangements and political uncertainty. This section focuses on these two factors further. Particular attention is given to institutional arrangements, whereby examples that indicate the influence of different national approaches in the creation of boundaries are provided. That is, this theme indicates that boundaries are created by fragmentation in the approach to food security, and this form of boundary has important national implications.

4.5.1 Different institutional arrangements

A key observation from the theme 'not knowing who to talk to' was the emphasis on stakeholders not knowing who to approach because of both the diversity and amount of actors present within field of food and agriculture. For example, on a global scale it was stated that agricultural space is clouded, with no clear cut, separate roles for stakeholders (interview 24). However this point was predominantly made at a UK level. For example, concerns were voiced about a lack of an overarching policy instrument, and the rapid turnaround of government officials (Interviews 18, 23, 26). When discussing why a co-ordinated platform was necessary in food security, one UK government body stakeholder had the following to say:

> *"Agriculture and food security is very complicated and constitutes convoluted markets and supply chains, and there are lots and lots of people with fingers in the pie"* [1]

While this interviewee noted that this has both pros and cons, it was emphasised as a challenge to engagement and a key reason as to why more harmonisation is required. This view was shared by other UK government representatives. One in particular reinforced the need for messages to be targeted due to agri-tech and food security being such a fragmented sector "with hundreds and hundreds of end users" (Interview 2). For both of these interviewee's, this not only creates a challenge in which actors lack the knowledge in who to talk to, but also creates challenges for the dissemination of information. According to stakeholders, in a UK context, this is further exacerbated by a lack of single government department addressing food security and agri-tech. For example when asked about the challenges hindering interaction with other stakeholders, another UK based participant had the following to say about the UK government:

> *"With food, it doesn't really sit with one department so it is quite easy for people to pass the buck. That's the big challenge. It's too disparate and so it is very difficult for them to engage"* [7].

The lack of single departments was reiterated by another UK government official, who also noted that it was not just one department that dealt with food security, rather it works across a number of departments and as such - it is quite complex (interview 2).

This, they noted, may add to confusion for actors in trying to ascertain who to approach.

This is an interesting observation to emerge from empirical data: structural issues reportedly shape how interaction occurs. As shown in these quotes, stakeholders correlate this with a complexity associated with a variety of approaches to food security. This is what is meant when not knowing who to talk to was identified as a challenge. Further evidence obtained from interviews and additional research also highlights that different department's approach food security in different ways. For example, seven UK government bodies were engaged with throughout the research process, all of whom indicated that they had a role within food security and/or the use of technology as a solution. **Table 4.2** provides a brief overview of these perceived roles. They range from funding, building collaborations, developing technology, to consumer engagement. Three of these interviewee's specifically mention that they have a funding role, three facilitated collaboration, while others focused on the generation of new technology. This not only indicates a diversity among approach, but also similarities: some stakeholders undertake similar roles.

It should be noted that **table 4.2** is not an exhaustive list, and it provides just a few examples of how the UK government bodies address food security. Not all UK government departments/agencies with ties to food security were available for an interview, and it does not account for variation within departments that were interviewed. These limitations are important to acknowledge as they emphasise the challenge put forth by participants. The roles of UK government departments detailed in **table 4.2** stem solely from interview sources. While this indicates that multiple stakeholders exist within this field, other departments do exist. There are many people addressing food security within UK government, however without 'knowing who to talk to', we can't be certain of every single approach. This is perhaps what participants who identified this as a challenge were referring to.

Table 4.2: The role of UK government body participants in food security and technology

Participants	What would you perceive your organisations role to be in relation to food security and technological innovation?
[1]	- Invest in agricultural research and the generation of new knowledge - Getting new knowledge and technology into the hands that need it most
[2]	- Help develop technology that will be used by the sector to improve productivity - Develop the right environments for companies to pick and adapt that technology
[3]	- Support UK businesses by funding innovative projects - Connect businesses to allow for collaborations that otherwise would not happen (mitigate risk)
[4]	- Build partnerships and collaborations around agri-tech and food activities, including food security internationally
[5]	- Fund research on technologies that could potentially improve food security
[6]	- Help catalyse engagement - Signpost academics, funding mechanisms and facilities to help scale up technical projects for UK businesses
[7]	- Engage consumers on their views relating to food policies that are being developed / have been developed

Programs exist in the UK that aim to create a platform that brings together funders, government, and industry to undertake interdisciplinary research on food security. Six participants referenced the UK Global Food Security program. This included three UK government body (interviews 3-5), one research institute (interview 28) and two funding body representatives (interviews 45 and 46). In addition, separate email correspondence with two UK government representatives, both of whom were unable to participate in interviews at the time, also directed attention to this program. These recommendations were on the basis that this platform not only provides information on how funders and policy makers work together, but is a forum that brings science and government together.

The Global Food Security program is a cross-research council body that covers all factors of the global challenges related to food security. It does this by bringing together the UK's main public funders of food related research to work together on this forum (interview 3). Its vision is "to integrate, co-ordinate and disseminate research that will be influential in supporting food security goals" on the basis that working together can have a greater impact (UK Global Food Security Program, 2017:6). This represents a joint research strategy for food research that spans across the UK public sector, with partners of this program including all six UK research councils, UK government departments, agencies and devolved administrations (with the exception of Northern Ireland), the Met Office and the Wellcome trust[28]. These members jointly design, develop, implement and deliver research to promote added value and are involved in funding and commissioning it.

The presence of this group, and the roles of particular UK representatives to specifically build collaboration, does raise questions as to why not knowing who to talk to was identified as a barrier. There are two clear reasons that help understand this. Firstly, as already mentioned, the number of UK departments present within the field of food security creates a complexity. To the best of my knowledge, and through thorough research of the literature and government reports / websites, there are no existing documents or papers that detail exactly what each strand of government does and how it contributes to achieving food security. While this can be obtained by approaching individual departments, there is nothing that summarises how each strand

[28] A full list of partners can be found on the UK Global Food Security Program website (https://www.foodsecurity.ac.uk/about/)

of government contributes to the UK food security approach. Secondly, those that did acknowledge the UK Global Food Security as a platform for interaction had ties to it in a variety of ways, be it as partners and affiliates or members who contribute funds and/or the use of facilities for research purposes. There was a pre-existing awareness.

What is perhaps most interesting is that these challenges were only mentioned by UK based stakeholders. It was not an immediate concern to US participants in that it did not emerge among interviews with them. In this instance, there is a case to be made that variation on what is perceived as a barrier to engagement can relate to different institutional arrangements within the UK and US, and how these nations approach food security.

To illustrate this, UK and the US approaches to food security post 2008 are considered. The 2007-2008 food price crisis brought food security to the foreground of international development and subsequently marked a change in global food security governance (Page, 2013). Not only did a new global food security and nutrition narrative emerge, but alterations to different national approaches to food security also occurred as a result. The need to act on a scale of urgency to achieve food security, and ensure it remained a priority on the political agenda, was acknowledged at the L'Aquila 2009 G8 summit. It recognised that "the combined effect of long withstanding, underinvestment in agriculture and food security, price trends and the economic crisis have led to increased hunger and poverty in developing countries, plunging more than a further 100 million people into extreme poverty and jeopardising the progress achieved so far in meeting the Millennium Development Goals" (AFSI, 2009:1).

The L'Aquila G8 summit noted that action to address existing concerns required a comprehensive approach that included focusing on increasing agricultural productivity, and emphasising global trade, markets and economic wide growth (AFSI, 2009; MacMillen & Dowler, 2012). To achieve global food security, G8 members agreed to partner with vulnerable countries and regions to help them develop and implement their own food security strategies by providing financial and technical assistance. As members of the G8, both the UK and US pledged commitment to the approaches outlined within this summit, however, they both went about this differently.

Prior to 2008, food security policy in the UK was largely framed around self-sufficiency i.e. to ensure a country provides enough food to meet their populations demands (Pinstrup-Andersen, 2009). The UK approach to food security is now currently framed on the view that operating in a global trading environment is particularly effective (Barling et al., 2010). That is, local food and self-sufficiency has been put aside for a new prioritised approach whereby food security is ensured by relying on global markers (Kirwan & Maye, 2013). This was emphasised as early as 2006, in a report published by the Department of Environment, Food and Rural affairs (DEFRA) on food security and the UK. It noted that self-sufficiency was a misleading indicator of food security, and that risk was best mitigated and managed by the sourcing of food from a number of potential countries, and trading on the global market (DEFRA, 2006).

This principle has been further reinforced through a number of reports published in response to the global food price crisis which are all major documents that contributed to a shift in UK policy discourse from self-sufficiency to international initiatives promoting food security (Ingram et al., 2013). The Cabinet Office Strategy Unit published a report entitled Food Matters: towards a strategy for the 21st century in 2008. This report aimed to not only review and analyse existing production and consumption trends in the UK, but also evaluate the existing policy framework. A key conclusion of this report was the need for a joint research strategy within the UK. This commitment was fulfilled through the creation of the Global Food Security Program, which has been previously mentioned. Nevertheless, it further concluded that food security challenges in the UK were actually at a global level and as such focus needed to be placed on resilient supply chains, and provisions for the developing world (The Strategy Unit, 2008). Similar conclusions were made in DEFRA reports on ensuring the UK's food security in a changing world, and assessing the UK approach to food security (DEFRA, 2008; DEFRA, 2010). These reports noted that greater trade liberalisation would result in increased productivity and, as such, trading on international markets were essential in maintaining food security at a national and international level.

Challenges to food security was the focus of a report published by the HM treasury in 2010. In exploring these challenges, it set out UK priorities on food, calling for joined up policy, the importance of sharing knowledge and good practice with countries internationally, and basing work on sound science (HM treasury, 2010). Additionally, challenges on supply and demand up to 2050 were considered at a global level in the 2011 Foresight report. This report identified decisions policy makers need to make to ensure food security, stressing the importance of maximising the benefits of globalisation through food policy (Foresight, 2011). The importance of technology has also been emphasised as a priority for UK policy. This was acknowledged within the Foresight report, whereby to meet current and future challenges to food security it was stated that attention needed to be paid to sustainable food production through the use of existing technologies. The UK strategy for agri-tech, published in 2013, focused specifically on this bringing together science, food and farming based stakeholders to develop opportunities for agri-tech within the UK. This strategy was developed to better integrate science and technology with the governments approach to trade and international development (HM treasury, 2013).

These represent some of the most recognised reports that contribute to the food security policy approach undertaken in the UK. It also presents an insight into the UK response to the food price crisis. They also emphasise the need for global trade and the use of technology to increase agricultural productivity, as laid out in the L'Aquila summit. Over the last decade the UK has not only seen a policy transition that reinforces the need for agricultural and technological innovation, and the publication of multiple reports and documents on the matter, but it has seen the introduction of platforms, such as the Global Food Security Platform, to encourage collaborative research. However, while multiple departments with interests in the field of food security exist (as illustrated in **table 4.2**), the approach to food security is often assessed through the actions of DEFRA alone (Barling et al., 2010HM treasury, 2010; MacMillan & Dowler, 2012). Additionally, at present, no overarching law on food security exists in the UK. This is in direct contrast to the US approach.

4.5.1.1 The US approach to food security

Food security was a high priority under the Obama administration, who initially pledged $3.5billion over a three year period at the L'Aquila G8 summit. This was the first in a number of steps to prioritise food security in the US. Action was taken in the form of a law, which was introduced by congress in 2016. The Global Food Security Act of 2016 (GFSA) put a high emphasis on the nutrition component of food security, alongside agricultural led growth and poverty reductions (Interview 14). Coinciding with the commitments made in the L'Aquila summit, this act was established to set out a comprehensive and strategic approach for US foreign aid, in assisting developing countries to promote greater food security (GFSA, 2016). A requirement of this act was for the president to introduce a whole of government global food security strategy. The resulting initiative is known as the Feed the Future program.

Feed the Future is a whole of government initiative primarily related to funding streams for agriculture and nutrition (Interview 9). With approximately one billion dollars a year available for investment in nineteen focused developed countries, the overarching goal of this program is reducing poverty and hunger (Feed the Future, 2011; Interview 14). Led by the USAID, this program brings together eleven relevant departments and agencies across the US government, thus strengthening interagency co-ordination. It builds on utilising the advantages of each department, leveraging financial capabilities, technical expertise, data and resources (US Global food security strategy, 2017). This collaborative approach is embarked upon to reach three main objectives: inclusive and sustainable agricultural led economic growth, strengthened resilience among people and systems, and a well-nourished population especially among women and children (US Global Food Security Strategy, 2017).

Emphasis is placed on agricultural development and nutrition. In achieving this, one of the key pillars of Feed the Future is science and technology which is envisioned as a key component of a comprehensive approach to ending hunger and under nutrition (Interview 14). As such, Feed the Future significantly invests in research and its translation to practical tools. This focus on research indicates a similarity to the UK Global Food Security Program which, as mentioned, brings together UK public bodies to conduct and fund research on food security. An additional similarity between the UK and US is an emphasis on foreign aid and global markets which are approaches shaped by the L'Aquila commitments. However, key structural differences exist that contribute to explaining why 'not knowing who to talk' emerged only as a challenge to UK stakeholders.

Firstly, while the UK have prioritised improving policies that encapsulate the need for global trade and increased agricultural research, the US has taken the approach of implementing a law with similar requirements. No such legal framework comparison on food security currently exists in the UK. Secondly, both countries have many of departments or agencies that take action to achieving food security. While this has resulted in both the UK and US calling for co-ordinate platforms in the shape of the Global Food Security Program, and Feed the Future Initiative, a more structured approach can be observed in the US. That is, each of the eleven departments and agencies that have been brought together for a cross government approach have clearly defined roles, and their contribution to achieving global food security as a whole is well laid out. This is perhaps the most dominant observation that contributes to 'not knowing who to talk to' being identified as a challenge in the UK, and not the US. From a policy perspective the actions of DEFRA are important, but for other UK departments a lack of clarity exists, and no such definitions on their roles, like that observed within the US, are apparent. This contributes to the concerns identified by UK participants. By focusing on policy as a response to the food price crisis, and L'Aquila commitments, defining the roles of the multiple departments that address food security is not as clear, and thus, knowing who to talk to becomes a challenge. This is a clear indication of how structural differences between the UK and US result in the prioritisation of boundaries in this manner.

4.5.2 Political uncertainty

Political uncertainty was a further issue observed within the theme 'not knowing who to talk to'. While this will not receive the same amount of attention as institutional arrangements, drawing attention to what this means provides a useful contribution: political uncertainty as a challenge amplifies already existing structural divisions. For stakeholders, issues of political uncertainty predominantly correlate with changes in the political landscape. It contributes to the theme 'not knowing who to talk to' in that uncertainty in political change and a lack of knowledge dissemination surrounding it, creates a complex environment in which stakeholders do not know who to approach to obtain answers to their concerns.

A very topical example of political uncertainty that arose among participants is Brexit. The research for this thesis was conducted at a time when Brexit was prominent and a new reality. Interviews were conducted shortly after the UK referendum in June

2016[29]. It is therefore of little surprise that this arose as a concern among a number of participants. Those that mentioned this not only indicated a level of uncertainty as to how political changes (such as Brexit) would shape organisational and economic factors pertaining to their specific roles, but also how an overarching sense of uncertainty, particularly instigated by government, creates an environment in which interaction is fragmented. It is not only difficult to know who to approach, but also difficult to ascertain desired information. The following three quotes from industry, trade association and farmer union representatives illustrate this:

> *"There are you know, take something like Brexit in the UK, there's a lot of unknowns in that sort of issue where the barrier to engagement is that we haven't really got any ideas what the government is necessarily asking us to respond to when they ask us a question about something and to be fair government themselves might not have much of a clear plan or worked out plan at a particular point so I don't know"* [15]

> *"…we don't always get communication back [from government]…particularly at the moment over Brexit which has been incredibly frustrating [as] officials are not allowed to say anything still despite the fact that we are eight months after the referendum. So it's a bit of a one way traffic there at the moment"* [22]

> *"At the moment one of the biggest barriers is that everybody is trying to talk to government because everybody is very uncertain about what is going to happen with Brexit"* [42]

The above quotes show how these participants believe Brexit is, and will, impede on interaction with the UK government. A lack of tailored communication contributes to stakeholders not knowing where they stand. Further emphasising uncertainty as an interaction barrier is the variation among stakeholders with regards to how Brexit has shaped interaction. Industry implies that interaction still occurs, however the applicability of knowledge that is exchanged is inhibited by a lack of knowledge on Brexit. Such is this lack of knowledge that they are unable to provide tailored and relevant advice when asked. Trade associations have found that communication is effectively restricted with government where Brexit is concerned, and farmer groups

[29] Interviews were conducted between September 2016 and April 2017

allude to the issue of white noise. The volume of stakeholders trying to engage with government reduces the likelihood of getting specific responses - the potential for interaction is minimised. Participants have different experiences and different expectations.

Brexit, as an example of uncertainty among participants, amplifies structural divides in one main way. This was only mentioned in a UK context and it once again illustrates a national difference. This is to be expected. As a UK specific concern issues surrounding Brexit would not be an immediate concern to US participants, least not at present. Therefore uncertainty in this context, as a barrier to interaction, is specific to particular nations and their current political landscape. This reinforces already existing divides created by differing institutional arrangements.

4.6. Discussion

This chapter presents an insight into some of the main barriers perceived to hinder interaction between science communities and forms of political practices, institutions and structures. . The importance of interaction between different communities is increasingly emphasised in food security practice. For example, the L'Aquila food security initiative in response to the food price crisis pledged to contribute to the advancement of a global partnership to improve co-operation in achieving food security. This program intends to converge multiple forms of expertise in a committee of World Food Security including stakeholders from government, international and regional organisations, civil society, farming groups, industry and the private sector, and scientific communities (AFSI, 2012). The importance of partnerships have also been emphasised as a means for implementation for the SDGs. This is a core focus in SDG 17 ('partnership for the goals') which not only highlights the importance of private sector inclusion, but identifies the transfer of knowledge between different communities as a point of action (UN, 2015).

Further, public-private partnerships for agriculture and food security have been promoted and encouraged by a number of international organisations including the International Fund for Agricultural Development (IFAD), FAO, and OECD (IFAD, 2012; FAO, 2016; Moreddu, 2016). However, the findings of this chapter indicate that boundaries between science communities and political practices / practitioners actors are still prominent in a food security context, despite an increased call for partnerships.

That is, while an emphasis has been placed on interaction to achieve food security, there are still an array of challenges that must be addressed first. Analysis of interviews placed an inherent emphasis on how boundaries were created in comparison to how they were crossed, despite interviews being created in such a way that encouraged participants to discuss both. As such, it is apparent that factors contributing to divides between communities interacting at a broader level are currently a higher priority. Three core barriers to interaction were identified: ownership, perception and stakeholders not knowing who to talk to. The exploration of these challenges allowed for three main findings.

4.6.1. Ownership was identified by the most groups of food security actors

This thesis found that ownership (particularly concerns relating to access and IP) was mentioned by the most stakeholder groups, with representatives from all but one group mentioning this as a challenge. This consensus on ownership is not overly surprising. It is a global issues that largely entered the field of food security due to the development of biotechnology. Therefore the premise of IP is not restricted to, or defined by, geographical boundaries or cultures (Blakeney, 2009). Additionally, while this presents a standalone barrier to interaction, there are clear links to other barriers that emerged which may explain why this was acknowledged by the most number of stakeholder groups. This was apparent in the challenges posed by the perception of stakeholders. Civil society argued that access for small holder farmers was restricted by the use of IP by members of the private sector. Links to public perception could also be observed. This coincides with debates on transparency which was identified as a barrier to interaction between the public and private sector. As a public body, government are required to be open and transparent. By contrast, calls for transparency present a challenge for industry who fear this may diminish their IP.

4.6.2. Operational differences are dominant in the creation of boundaries

The research conducted for this chapter indicated that multiple forms of boundary work occur. Five ways that boundaries are created were identified:

- Boundaries are created by different views on ownership (access and IP)
- Boundaries are intentionally created through the denouncing of private interests by civil society

- Boundaries are created through the overt influence on civil society.
- Boundaries are created by different regulatory and legislative frameworks
- Boundaries are created by fragmentation in the approach to addressing food security

These boundaries are all standalone, but they are also all linked together by apparent operational differences. For ownership, the research conducted for this chapter highlighted that the main challenge was the different approaches to IP, and subsequently how this shapes views on its use. It not only highlighted debates on who has ownership of particular technologies, but the different ways in which this is used between government, academia and industry. When considering the perception of civil society, this emphasised criticisms of the actions of industry and other such multinational corporations. As previously mentioned, civil society argued that the contention between them corresponds with different operational models. Operational differences could also be observed through the exploration of public perception as a barrier. It was apparent through the analysis of data that public perception was anticipated through regulatory and legislative frameworks. This highlighted differences in the approach that these countries take, and the way they operate with regards to the assessment of risk. Finally, this chapter also highlighted how fragmentation of government bodies contributed to the creation of boundaries. It presents evidence that again illustrates the difference in approach between the UK and US. As such, it can be argued that operational differences are dominant in the creation of boundaries between types of science and politics communities, institutions and practices.

4.6.3. The creation of boundaries coincide with national differences

Important national differences were also observed through the analysis of data. This was apparent through the analysis of public perception and not knowing who to talk to. By identifying forms of boundary work in these barriers clear differences could be observed between the UK and US. While the US identified public perception as a challenge, the UK didn't. The opposite was observed for stakeholders not knowing who to talk to. The UK identified this as challenge whereas the US didn't. This further supports the previous argument on the importance of operational differences. The UK and the US operate in different ways with regards to risk management, legislative and regulatory frameworks and cross government approaches to food security.

The influence of national differences on how food security is approached and how technology is utilised as a tool to achieve it is not a novel observation. Globalisation, for example, has increased the need for more understanding on national and cultural differences in the ways in which technology is approached and considered (Finucane & Holup, 2005). From a co-production perspective, the exploration of how universal facts, science and technology are shaped (if at all) by different cultures and political settings have long been the subject of academic attention (Knorr-Cetina, 1999; Jasanoff, 2004). From a boundary work perspective, work exists that looks at how different nations utilise boundary making strategies (Lamont & Molnar, 2002). However this is determined by how countries define themselves in opposition to each other. The research conducted for this chapter shows that this is different in a food security context. Boundaries were not created to establish opposition or a 'them versus us' narrative but rather, this chapter finds that they are more representative of differing national differences and approaches to achieving food security. This was amplified by key examples of political controversy (genetic modification) and political uncertainty (Brexit) which contributes to the creation of boundaries. Differences between how boundaries are prioritised correspond with specific GM regulatory and legislative frameworks, partly as a result of public perception. Further, issues on uncertainty (Brexit in this case) can be specific to particular nations and their current political landscape, reinforcing already existing divides.

Finally, links to some of the core observations of chapter three can be noticed through the research conducted in this chapter. Firstly, Risk arose as an important dimension for public perception. This chapter has shown how the approach to science and technology is shaped by how risk is considered. This in turn shapes regulatory and legislative frameworks, which as shown in discussions with US interview participants, contribute to how challenges to interaction between different actors are shaped by perceptions, values and attitudes.

4.7. Conclusion

The purpose of this chapter was to explore forms of boundary work in food security practice. This not only arose as a key theme through the analysis of interview data, but also aided the understanding of how interaction between science and political communities, practices and institutions occurs in the present.

Several findings were made. Firstly, there was an inherent emphasis by interview participants on the barriers to interaction. The ways in which boundaries are created were much more prominent in discussions, as opposed to the ways in which they were overcome. This was despite interviews being designed in such a way that allowed for participants to identify both. While there is an increased call for interaction between food security communities it is apparent that challenges and factors contributing to divides are much more prominent in food security practice.

Three core barriers to interaction were identified. Issues pertaining to ownership and access, perception of both the public and civil society, and fragmentation within specific institutions that contribute to stakeholders not actually knowing who they can talk to. These barriers allowed for the identification of several ways in which boundary work occurs. However, the most prominent finding from this was the importance of operational differences. All barriers to interaction corresponded with this in some regard, thus highlighting the emphasis that this has on the creation of boundaries in food security practice. Also linking to this finding was the apparent influence of national differences. Differences could be observed between the US and UK whereby the prioritisation of boundaries corresponded with different regulatory frameworks and the different approaches to ensuring food security. This was further amplified by examples of political controversies (GM crops) and political uncertainties (such as Brexit in the UK).

While this chapter has begun to shed insight into how boundary work functions in broad food security practice, how this shifts when we consider different aspects of technology remains to be seen. The following chapter begins to explore this by considering technology research and development.

Chapter five: Boundary work in the research and development of technology

5.1 Introduction

So far this research has considered how boundary work appears when considering the bigger picture of co-production and food security practice. This chapter is the first of two that focuses on how boundary work is constructed in specific practices. It aims to understand this through the exploration of how boundaries between different types of science and politics communities are created and crossed within the research and development (R&D) process. That is, the data obtained for this chapter situated the terms ‘science’ and ‘politics’ in two ways. Firstly, the differences between different communities (i.e. industry versus government and those that develop technology versus those that regulate it) and secondly, in a research capacity (the relationship between scientific research and EU regulations / frameworks).

From a food security context, the R&D of technology has been acknowledged as an important factor. This is on the basis that the production of technology can increase productivity and meet food demand (Piesse & Thirtle, 2010). Further, the R&D of technology for agricultural purposes has long been an area of academic interest (Fuglie et al., 1996; Pardey et al., 2006; Alston et al., 2009). However this primarily considers investment patterns and the effect of R&D on productivity. Debates on how scientific research is conducted, and how this interacts with various dimensions of politics, has also received attention in the literature. Researchers have particularly looked at how politics shapes science and vice versa (see for example Pielke, 2004; Millstone, 2007; Pielke, 2014; Davidshofer, 2016; Sarewitz, 2016). However there is little that considers this interaction from a food security perspective or how this impedes engagement between various communities/actors involved in the R&D process. Further, co-production and boundary work frameworks are not utilised as a tool to explore these types of interaction.

This chapter identifies three main challenges to R&D: operational differences, the conceptualisation of scientific research (which incorporates debates on how science should be used and if it should be influenced by society), and finally a perceived politicisation caused by regulation and the EU system. By exploring these challenges through a boundary work perspective, a number of arguments are made. Firstly, evidence will be presented that suggests that science and politics always interact in some form. Secondly, it shows that like that observed in the previous chapter, operational differences play a considerable role in the creation of boundaries in the R&D process. Thirdly this chapter finds that boundaries are perceived by key informants to be created by a politicisation of science. Finally, this chapter will argue that risk plays a significant role in both making boundaries and overcoming them.

5.2 Empirical data / analysis

Three core challenges to R&D emerged through the analysis of interviews with key informants. These challenges, alongside the groups of food security actors that identified them, are shown in **table 5.1**. Firstly, concerns surrounding the conceptualisation of scientific research were identified as an issue. This corresponds with debates on whether scientific research is, or should be, autonomous from its surroundings and links to some of the discussion on pure science that was introduced in chapter two of this thesis. Like that observed in the previous chapter, operational differences were also identified as a challenge in an R&D context. This primarily relates to differing timelines between industry and government. The final challenge identified is a perceived politicisation. This particular theme corresponds with the influence of the EU system and associated regulatory frameworks.

For the most part, R&D and challenges that hinder the interaction between core actors within this were acknowledged by all groups of food security actors. However it is important to acknowledge one exception. As shown in **table 5.1** these broad challenges were not mentioned by NGO/CSO key informants. This may link to observations drawn in the previous chapter. Although R&D is an important stage in the creation of technology, civil society prioritise the importance of food sovereignty, traditional knowledge, and empowering smallholders. There was a greater emphasis on these factors in discussions with these actors.

The following sections present the data that constitutes each of the challenges that emerged in an R&D context. As will be illustrated throughout this chapter, each of these challenges are independent but when the overall impact is considered overlap can be observed. They all correspond with a politicisation of science.

Table 5.1 perceived challenges to the R&D process that emerged in key informant interviews. Themes acknowledged are denoted by (✓).

	R&D CHALLENGES		
	Conceptualisation of science (n=14)	**Operational differences** (n=12)	**Perceived politicisation** (n=18)
UK government bodies	✓	✓	✓
US government bodies	✓	X	X
Industry	✓	✓	✓
Trade Association	✓	✓	✓
Research Institutes	✓	✓	✓
International Organisations	✓	✓	X
NGO/CSO	X	X	X
Farmer Unions	✓	✓	✓
Funding Bodies	✓	X	✓
Regulator	X	X	✓

5.3 Conceptualisation of scientific research

This challenge references concerns surrounding research being solution led, opposed to being led by a specific problem:

> *"There is a whole litany on history of wonderful ideas that never went anywhere because it wasn't actually addressing the real need. It was addressing the perceived need that was perceived by the research. So some people would argue that it comes back to the 'I have a hammer so therefore the problem is nail'. Whereas, actually, it might not be the problem. The problem is seeing the solution of a problem as the solution that you already have, rather than the other way around"* [1]

As such, the driving force behind the quest for knowledge arose as a challenge to R&D. This corresponds with how science is conceptualised. Participants referenced two different types of science / research in interviews: basic (or pure) and applied. Basic, or pure science, is often characterised as acquiring or producing fundamental new knowledge (Davidshofer et al., 2016). It involves extending the boundaries of human knowledge (Shephard, 1956) and links into the post war paradigm conveyed by Vannevar Bush that was mentioned in chapter two of this thesis. This places an emphasis on a linear model of innovation as shown in **figure 5.1**.

Basic research → Applied research → Development → Application → Societal need

Figure 5.1: Linear model of innovation

The first three stages of this model present a standard for R&D. The link between basic and applied science occurs in a linear manner with little feedback between one another. One stage is complete before we move onto the next. In this case basic research represents a buffer between science and the rest of society (Pielke Jr, 2012). Some variations exist on the latter stages (see for example Stokes, 1997; Godin, 2006; Pielke

Jr, 2007). However for the most part this is a matter of how these are worded as opposed to differences in how they are framed. **Figure 5.1** incorporates an adaptation of this model from the three sources mentioned above that best aids understanding of the data obtained for this research. That is, there was a particular emphasis on basic research not engaging with society or the end user. It is noted that boundaries are created in part, due to epistemic approaches like the linear model of innovation. For example, as mentioned above, a key challenge to interaction between science, technology and society was conducting research without first engaging with the end user:

> *"Making sure that exciting basic research gets applied is always the challenge. There can often be a gap between what is needed and what science delivers for it…"* [4]

> *"One of the problems faced in the past about integrating new products of technologies is that they have been developed in a lab somewhere in the world. They have spent months and months and months developing it, they've pumped in lots of money and they've said great we are finished. They have then taken it to the field and have just tried to dump it from a top down approach"* [39]

The importance of interaction with society was identified as a necessity for the R&D process on the basis that *"you cannot have an impact if you are in your own bubble"* [29] and an understanding that:

> *"…the guidance from the community has been to make sure the end user is engaged or influences technology because we want a technology pull rather than push"* [45]

As such the utilisation of basic research was identified by a broad range of actors as a challenge to successful R&D. The use of basic research in academia was also emphasised throughout interviews with key informants.

> *"Academia are very much historically about publishing papers"* [7]

> *"Most basic academic researchers will always be driven by needing more and more knowledge. They can always propose experiments and always push the questions to a new level to obtain either more certainty or to*

explore potential alternatives and you can kind of go infinitively with that" [14]

"Academia is often driven by their academic credentials. So, how many peer reviewed papers, how many grants they have brought in and so forth and perhaps they forget who the end user is. So they write a paper and get it published and that is great for their personal career but if it then never sees the light of day or goes beyond a thesis, or its not actually translated into a practical result on the ground then that is also a barrier" [42]

These particular quotes place an emphasis on the importance of publications and the peer review process for academia. It notes that academia are historically about publishing papers. This of course may easily be disputed by academics, however this claim is representative of key informant perceptions. In this instance, the drive to publish peer reviewed studies may reduce the real world applicability of research. Furthermore, the peer review process itself also reinforces the importance of pure research and autonomous science. For example, Sheila Jasanoff writes that "…the process of peer review, devised by scientists to validate each other's discoveries, reinforces the position of science as an autonomous social institution requiring no external control" (1987:196).

The research excellence framework (REF) for UK universities presents an additional example that further drives pure research. As an evaluation for university based research, researchers are subject to assessments by expert panels on the quality of research outputs and the impact that their research has beyond academia. The purpose of REF is to provide public accountability, act as a benchmarking tool and to inform funding allocation for research (REF, nd).

5.4 Operational differences

Like that observed in the previous chapter, operational differences were identified as a key challenge to engagement. This particularly spoke to engagement between industry and government:

"…the public goal is really about making research openly available so everyone can benefit from it. The private research will eventually have an impact, but initially they are obviously interested in holding that close until

they can develop and perhaps put a patent on it or at least bring it to market and make a return on it" [34]

Unsurprisingly, industry were the most dominant group in acknowledging this as a challenge. Out of the six industry key informants interviewed, four identified this as a significant barrier. The identification of operational differences was predominately on the basis that R&D can be challenging as industry and government work on different time lines. Such temporal factors contribute to the creation of boundaries. The R&D process is both timely and costly. For example, a survey that looked at the resources required for getting biotechnology crops to market found that on average the cost of the entire R&D process was US$136 million (the sum of discovery, development, regulatory testing and registration expenses) and the average investment time was 13.1 years (McDougall, 2011). Interview participants noted that this was problematic given the nature of government. They can't take a long term view:

> "*…often they are governing for the five years, certainly for the UK anyway. They are governing for the five years they are in power for and don't really like to take a long term view. Whereas organisations likes ours, from a crop protection perspective…we are talking about from us discovering a molecule to bringing it to the market base for a grower to use which could be up to ten years. So you know, we have different times lines"* [20]

> *"We need the government to understand that research is very important and they need to spend a little more time and give us a bit of flexibility as well. So sometimes they would like to see very quick results, which is difficult because you won't be able to find a solution that would fix all these problems in one go. Sometimes they just want to listen to what they have thought in their minds but it's not the case. They would just like to see a quick fix…"* [31]

> *"Governments are political institutions and they are responsible to their constituents. That means they have short term time horizons. They would like to see results in the next year or the next three years for example. But to think 20-30 years into the future is very difficult politically…"* [34]

In this instance, different organisational structures reportedly contribute to the creation of boundaries between groups involved in the creation of technology, and those that govern or regulate the R&D process.

5.5 Perceived politicisation of science

The perceived politicisation of science was acknowledged by 38% of participants. This was a broad theme that spoke to a number of interrelated concerns that all correlate with regulatory issues. Firstly, a link to operational differences was identified. The previous section of this chapter noted the timely and costly nature of R&D. However in addition to this, it has also been stated that on average five and a half years are spent dealing with regulatory testing and regulations (McDougall, 2011). This was identified as a challenge by industry in that significant foresight is required to ensure that new product developments will meet future regulatory systems:

> *"…this is the sort of fundamental problem with the regulatory system in Europe not working. That is kind of the final stage. So if the regulatory system is unpredictable – you know – you need to know when you are choosing your potential product leads ten years before. You need to have a clear idea about what is going to be able to pass the regulatory system in ten years' time"* [19]

EU regulation was noted to inhibit R&D as a result of a perceived politicisation. For example:

> *"…you can pass all the tests that you need to pass but politically there is a decision that this technology won't be allowed to be used in Europe. So our ability to deal with legislation is always a big problem. But this is legislation in terms of politics rather than necessarily passing tests that are put in front of us"* [18]

> *"…decisions have become very politicised and that's kind of affecting the regulatory framework in the sense that in Europe, rather than supporting innovations in agricultural biotechnology, at the moment it is actually being prevented"* [25]

Participants identified boundaries or challenges in their own social political contexts, with it being stated that R&D is inhibited by politicisation at an EU level:

> *"So the EU has been like a drag anchor on access to innovation for the past twenty odd years because it isn't fostering innovation. It is supressing and stifling new technologies like GM, like other plant breeding innovations, and other crop protection tools. It presides over a support regime that doesn't foster enterprise either"* [23]

> *"…clearly in respect to GM technology, specifically, the regulatory system for it across Europe has become highlighted politically. The level of politicisation and the weight given to scientific evidence versus political decision making has steadily diminished and the degree to which decisions are political has steadily increased over the last couple of decades. It is to a point where it is not practical to try and invest in those technologies in Europe." [19]*

Political uncertainty draws on scientific research into various technologies to continually adjust. However, evidence suggests that politics shaped in this manner also acts as a deterrent. In agreement with the previous quote one key informant noted that:

> *"…that kind of politicisation at the regulatory level means a lot of companies are turning away from Europe and are turning away from investing in Europe, investing in R&D, investing in innovation and bringing new productions to the European market. It is because of the level of uncertainty" [21]*

The risk averse nature of the EU system was also identified as a barrier to interaction between industry and government. Key informants noted that they cannot risk investing if there are no existing regulations in place. Further, the risk associated with changing regulatory frameworks also hinders action. This links into debates on risk and precautionary principle that were introduced in the previous chapter. Participants argued that technology was politicised by precautionary principle at an EU level. As such it was noted that the risk averse nature of the EU was a significant challenge to the R&D process. The aim for a zero risk environment was noted to be problematic:

> *"I don't think there is trust or a strong relationship and a lot of that is fuelled by this need to have a zero risk environment which never exists."* [20]

Finally, concerns on how risk is approached in the EU also correlated with public perception:

> *"The main barrier is that really, government can't be seen to be helpful. It's really not good in that way. Countries at an EU level just won't come out and say this technology is important so we have to allow it to move forward, we've assessed the safety, we can't find any risks so it's safe as much as prevention"* [16]

5.6 Risk

In the previous section, risk frameworks were identified as one way in which boundaries are perceived to be created between industry and government / regulators. It was noted that the risk averse, precautionary principle approach undertaken at an EU level can hinder R&D. However, it was also apparent through this research that risk frameworks can also contribute to bridging these boundaries.

The influence of pressure by various campaign and interest groups were identified as a concern coinciding with how risk is assessed. Historically, this has had a significant influence in how risk is approached and defined within an EU context. In response to pressures exerted by various campaign groups, interest groups, and general public perception, the EU not only introduced a white paper on food safety, but also established the European Food Safety Authority (EFSA). The purpose was so that the "interrelationships between the state, the private sector and public are rearranged, and their responsibilities are redistributed" (Marden, 2003; 196).

As such effort has been made to facilitate interaction in practice. The importance of this also arose in key informant interviews. In order to bridge boundaries created by regulatory and risk analysis frameworks, engagement with risk managers and assessors should be sought.

> *"Maybe one of the big challenges is the precautionary principle and this is basically saying if we don't know whether something is safe or not then we aren't going to allow it on the market until we are convinced it is safe. For radically new technologies, of course, this could be quite difficult to come up with the information to convince someone that this something is*

safe. So that is a challenge and of course the best way to resolve it is to engage with risk managers and risk assessors at an early point. It would be quite naïve to go ahead and develop a technology and only at the end start talking about the safety of what is being produced by this technology." [30]

The Codex Alimentarius Commission emerged in key informant interviews as one way in which risk is assessed, communicated, and managed, and allows for some insight into the ways in which this contributes to the bridging of boundaries. Codex was established as a joint FAO/WHO food standards program in the 16th world health assembly in May 1963. As of 2016, Codex represents 99.8% of the population and is acknowledged as an international reference point for food standards development (FAO&WHO, 2016). Codex has been described as "the product of an evolutionary process involving a wide cross-section of the global community" whereby a global panel of experts are consulted to set standards relating to health and trade (FAO&WHO, 2016). To this extent, Codex plays a considerable role in bringing together the global community at multiple levels, and thus presents an approach to overcoming key barriers to interaction. The following quote presents some insight into how this is done:

"When you look at the composition of codex…you have in fact more observers. So more non-members than members, because essentially the members are the countries and any organisations that represent the countries and in fact there is only one now – it's the European Union…but in terms of observers, any governmental or non-governmental organisation that has a stake in the business of food regulations whether it be food safety, food quality, nutrition…and actually as an international representation, usually has a stake in Codex and could in fact seek the status of an observer. Codex recognises that there is no way you can achieve sound regulatory decisions unless in fact you interact with those partners in fact…if you look they are called the observers but they are in fact partners" [47]

The risk analysis paradigm is an essential driver of Codex. Regulatory decisions relating to food safety in this context are based on three principles. These include risk assessment, risk management (standards, guidelines, consumer advice) and risk communication. Risk communication is important in that it acts to bring together all the partners and stakeholders involved in any decision making process. In this instance risk communication is not defined as a recommendation to avoid a particular food ingredient, but rather encouraging engagement with everyone. Regulation cannot occur without such partnerships [interview 47]. While further research is needed to understand exactly how this form of boundary work occurs, it illustrates that risk also acts to bring together different communities to facilitate trade.

5.7 Discussion

This chapter has identified three main challenges facing interaction between core actors in the R&D of technologies: the conceptualisation of science, operational differences and the perceived politicisation of scientific research into novel technologies. Exploring these challenges further identified a number of findings corresponding to boundary work in the R&D process.

5.7.1 Operational differences contribute to the creation of boundaries

This chapter showed that operational differences contribute to impeding interaction between industry and government. This presents a similarity to the previous chapter. In this case temporal differences were emphasised. By working on different timelines, barriers to interaction arise. Were R&D is timely and costly, government cannot take a long term view. Operational differences between industry and government not only prevent engagement, but it shows that different organisational structures contribute to the creation of boundaries.

5.7.2 The conceptualisation of science and boundary work

The data for this chapter found that boundaries between groups of science and politics practitioners in the R&D process are caused by a lack of end user engagement. This was apparent when considering the ways in which scientific research is conceptualised. One of the biggest concerns was a lack of applied scientific research. As such there was a recognition that scientific research and social / political decisions should not be separated. In fact, interaction between the two are a necessity for the successful R&D of technologies.

This research also shows that all types of science are politicised, regardless of whether this is basic / pure or applied in nature. However, where one actively seeks for interaction with political dimensions, the other does not. As mentioned by key informants, applied research is often advocated for as it addresses a need. It stipulates that science communities engage with society to ensure technology has a real world context. While pure science aims to keep science separate from politics and policy decisions, it actually engages with political dimensions, albeit in a different way. This research briefly touched on two examples that illustrate this. Peer review and the use of REF in the UK shapes the ways in which research is conducted and act as a driving force for conducting basic research in the first place.

By considering how the conceptualisation of science in an R&D context contributes to the creation of boundaries, the data for this chapter has therefore illustrated that forms of science and politics always interact. For example, one challenge acknowledged by participants was a lack of interaction with the end users of potential technologies. In this instance there is an importance placed on the need for interaction with political dimensions in order for R&D to be considered successful. There is an intentional interaction between the scientific and technical, with the social and political. By contrast, it is noted that pure science neglects this to strive for scientific credibility. The research conducted for this chapter shows that pure science is not always pure.

Basic research has been defined as “the free play of intellects” in which science is given “a free pass to define progress without the world beyond it” (Sarewitz, 2016: 16). The research conducted for this chapter indicates that this is not actually the case. While basic science aims to keep science, politics and decision making separate, forms of politicisation are actually apparent and as such pure science is never actually pure. It is politicised in different ways such as the requirements for REF within the UK and the broader emphasis on peer review for credibility. These are just two examples that this research touched upon, based on the comments from research participants. Existing research has also emphasised that pure science is a myth whereby even the funding of basic research is politicised. Funding has to be justified and this is often based on societal value (Pielke Jr, 2004).

This was also argued by Sheila Jasanoff who explored the legitimacy of science based decisions within US regulatory bodies. Jasanoff argued that “in fact experts themselves seem painfully aware that what they are doing is not science in the ordinary sense, but a hybrid that combines elements of scientific evidence and reasoning with large doses of social and political judgement" (Jasanoff, 1990: 229).

5.7.3 Boundaries are created through the perceived politicisation of science

The need for forms of science and politics to interact is well acknowledged in the literature. Scholars have argued that science cannot solve everything on its own (Pielke, 2004; 2014), different values on science can prove problematic (Sarewitz, 2004), and the need for scientific practice and political decision making to come together by meeting the needs of the end user (Pielke, 2014; Sarewitz, 2016). However, the empirical evidence for this chapter finds that the perceived politicisation of scientific practice contributes to the creation of boundaries. In this case it is noted that political factors create the divide between scientific and political practice.

Most of the challenges identified in this chapter illustrate this. Operational differences and the influence of different temporal factors linked into regulatory challenges. In this case this acts as a barrier as regulations shape the way in which particular organisations can function and work together. Regulatory frameworks and risk analysis paradigms were both perceived to hinder scientific practice in various ways thus resulting in the perception that boundaries were created intentionally by political dimensions restricting the actions of science in practice.

This research also shows that while science communities involved in the R&D of technological solutions welcome interaction in some ways (such as recognising the necessity of applied research), they are more wary of it in other ways. This was apparent through views on EU regulatory and risk frameworks; particularly those forms of regulations that they perceive as not attuned to the practice of science in R&D.

5.7.4 Risk both intensifies and minimises boundaries

Risk was a prominent theme when considering R&D with this chapter finding that the concept of risk contributes to both the creation and bridging of boundaries. Key informants noted that science is politicised by precautionary principle as it hinders R&D. This in turn contributes to regulatory uncertainty resulting in a lack of willingness to risk investment. Furthermore, key informants also highlighted the influence of public perception and strict risk analysis paradigms on the creation of boundaries. By contrast however, the exploration of the Codex Alimentarius commission illustrates that such risk analysis paradigms have the potential to bridge boundaries by bringing together multiple groups to make regulatory decisions that further facilitate trade. While further research is necessary to fully understand this as a boundary organisation, it indicates risk as a concept also has the potential to minimise these divides.

5.8 Conclusion

The purpose of this chapter was to explore how different communities come together and divide for the R&D of technology. More specifically, it considered industry and government, those that create or develop technology and those that govern or regulate it, and the conceptualisation of science. R&D was a particularly important practice to consider in that it arose as a key challenge through the analysis of interview materials. Three R&D challenges emerged in key informant interviews and allowed for an understanding behind how boundaries are created. Firstly, similar to that observed in the previous chapter, operational differences were identified as a barrier to interaction between those that develop technology and those that regulate it. Secondly, this research showed that barriers are created due to a lack of end user engagement. This linked into how scientific research is conceptualised. Key informants argued that it was necessary to engage with the potential users of specific technologies and, as such, scientific research needs to be applied. However the challenge lies with conducting pure research. This chapter discussed the importance placed on the autonomy of science, which is amplified by the need for peer review and REF, for example, in the UK. However, it argued that pure research is actually politicised as a result. Scientific and political practice always interact, but in different ways. Where one form of interaction is actively sought, the other is a necessity to achieve scientific autonomy and credibility.

This chapter further argued that boundaries are perceived to be created by a politicisation of scientific practice. Regulatory frameworks, institutional frameworks at an EU level, and risk analysis all reportedly hinder how R&D is conducted. While communities involved in R&D welcome interaction in some ways (such as recognising the necessity of applied research), they are more wary of it in other ways. This was apparent through views on EU regulatory and risk frameworks: particularly those forms of regulations that they perceive as not attuned to the practice of science in R&D. Finally it was also argued in this chapter that risk both intensifies and minimises boundaries. It was perceived to contribute to the creation of boundaries, but it was also apparent that situations exist whereby it also bridges boundaries.

Chapter six: Boundary work in the adoption of technology

6.1 Introduction

This chapter explores the forms of boundary work that occur in the adoption of technology. It not only identifies ways in which boundaries are created, but provides a clearer picture than the previous two chapters on ways in which they are crossed. The aim of this chapter is two-fold. Firstly, it aims to explore how forms of science and politics interact, if at all, in the adoption process by identifying forms of boundary work. The research for this chapter emphasised the relationships between those that develop technology and those that use it, alongside what core food security actors perceive to be political, social and economic barriers to adoption. Secondly, it aims to identify commonalities and differences between the R&D of technology and its adoption. That is, how do participant views and responses differ when we consider the adoption of technology?

The successful adoption of technologies in an agricultural context have been associated with an increase in food and feed production, food security, and poverty reduction (Foster & Rosenzweig, 2010; Kuijpers & Swinnen, 2016). As such attempts to explore and explain adoption patterns have long been the subject of academic research (Feder et al., 1985; Fuglie & Kascak, 2001; Sunding & Zilberman, 2001; Doss, 2006). However this research has faced criticism from scholars on account of being too descriptive. Focus has been placed on the importance of different adoption barriers, when a level of understanding behind the adoption process is required in order to take action (Doss, 2006; Straub, 2009; Kuehne et al., 2017). In addition, while research on the adoption of agricultural technologies is not limited, these studies tend to ask normative questions that don’t allow for the consideration of translation and interaction between various forms of knowledge.

This chapter explores the interaction between those that develop technology and those that use it (i.e. its adoption). In doing so it will argue a number of things. Firstly, it finds that participants are more aware of the ways in which these forms of science and politics communities come together and divide in an adoption context, particularly compared to that observed in the previous two chapters. Secondly, it argues that boundaries are created by a lack of knowledge exchange. The introduction of technology without context reinforces a divide between those that create technology and those that use it. Thirdly, this chapter will argue that in contrast to that observed in R&D (where boundaries are reportedly shaped by a politicisation of science), boundaries are partly created due to the influence of technology on society. The ways that boundaries are perceived by participants correlate with specific social, economic and political contexts. Finally, the research conducted for this chapter finds that boundary work to bridge gaps between different communities emphasises the interwoven nature of the transfer or diffusion of knowledge and its adoption. There is a deliberate convergence of the two.

This chapter begins by introducing the key barriers to adoption identified by interview participants. Following this, the ways in which these challenges are overcome and the ways in which boundary work occurs through this are presented. The key findings that emerge from both of these aspects, and the ways in which boundary work function within them are then discussed and conclusions are made.

6.2 Empirical data: barriers to adoption

That data for this chapter largely stems from participant responses to two specific interview questions (see appendix A):

> **Q11.** What are the challenges to introducing new technologies in practice?
>
> **Q12.** For your organisation, what is the process of getting new technology, knowledge or data to end users?

This section will focus on the barriers to adoption that were identified by interview participants, primarily in response to question 11. It is important to note that challenges that emerged to introducing new technology into practice were not restricted solely to this question. They also arose elsewhere in interviews. These were also included in this analysis. There was a 100% response rate. All participants had some perspective on the challenges to technology adoption. This illustrates an initial difference to that observed in the previous two chapters. While challenges to interaction between different types of science and politics communities were identified in both a broader food security context and R&D, this was not to the same extent as that observed from the data for this chapter. There is a greater awareness among interview participants on the reasons why technology adoption does not occur.

When compared to the R&D process, a change in pattern for the ways that boundaries are created was observed. As shown in chapter five, R&D challenges were particularly identified in an EU and developed country context. Conversely, participant response on adoption and decision making was largely considered in a developing country context. This was not based on an intentional inclusion or exclusion criteria, but rather illustrates the unprompted contexts that interviews took. This however is not a significant surprise. As shown in **figure 6.1** the majority of employees in the developing world work in the agricultural sector (68.9%), compared to 3.1% in developed countries. Agriculture not only provides a key form of employment and livelihood, but also contributes to significant income sources in the world's poorest countries with it being argued that research is more pertinent in these areas due to under adoption being particularly high (Feder et al., 1985; Doss, 2006; Foster & Rosenzweig, 2010; Wheeler et al., 2016).

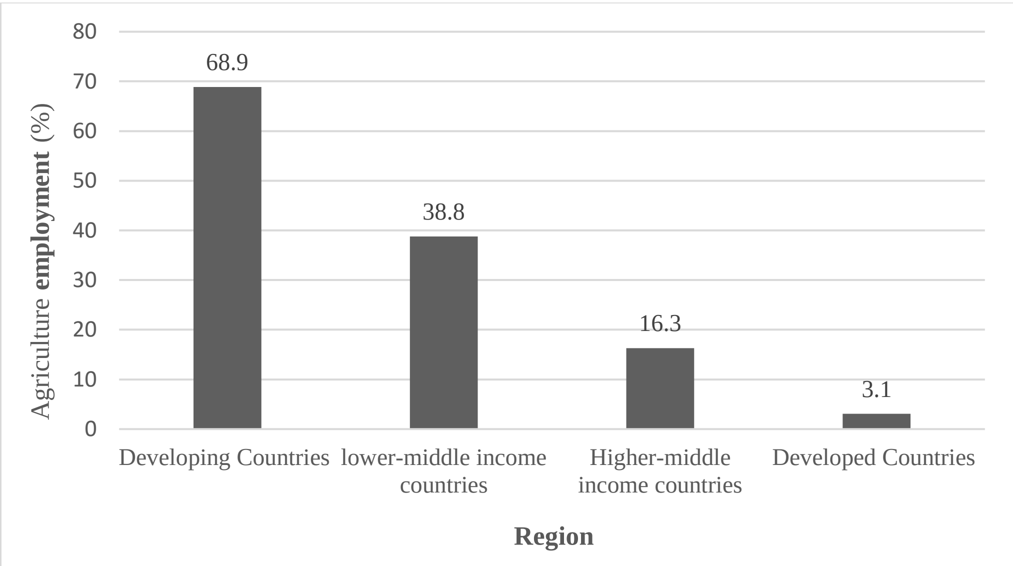


Figure 6.1 Agriculture employment figures in different economic regions as of November 2017 (source: ILO Key Indicators of the Labour Market, ILOSTAT database)

Content analysis was used to group participant responses into codes and themes. A number of challenges emerged through this analysis. This chapter considers the most dominant adoption barriers that arose in discussions with key informants. These are shown in **table 6.1** and were all mentioned by over 20% of participants. These include economic factors relating to cost and market concerns, a lack of knowledge exchange between those that develop technology and those that potentially use it, and no end user engagement whereby the key challenge is the development of technology out of context. The remaining challenges include behavioral change (on the basis that new technology often requires a diversion from tradition), and regulatory issues which mirror the concerns identified in the previous chapter on R&D.

The following sections present these adoption barriers in greater detail, illustrating how these were identified as challenges by key informants in the context of this research.

Table 6.1: Perceived barriers to adoption that emerged in key informant interviews. Themes that were acknowledged are denoted by (✓).

	Adoption Challenges				
	Economic Concerns (n=28)	**Knowledge exchange** (n=16)	**No end user involvement** (n=11)	**Behavioural Change** (n=15)	**Regulatory issues** (n=12)
UK government bodies	✓	✓	✓	✓	X
US government bodies	✓	✓	✓	✓	✓
Industry	✓	✓	✓	✓	✓
Trade Association	✓	✓	X	X	✓
Research Institutes	✓	✓	✓	✓	✓
International Organisations	✓	✓	✓	✓	✓
NGO/CSO	✓	✓	✓	X	X
Farmer Unions	✓	✓	X	✓	✓
Funding Bodies	✓	X	✓	X	X
Regulator	X	X	X	X	X

6.2.1. Economic concerns

Economic concerns hindering adoption were identified by the most number of stakeholders (60%). Cost and financial issues were prominent in this theme. Participants highlighted issues with affordability and access to finance:

> *"Financing is huge. I mean if you're trying to make purchases of new technologies and things like that but you have no credit history and you have no transactional history or financial identify, as many smallholder farmers do, then it is really difficult to get the credit you need to purchase farm equipment or things like that. And this applies to simple innovations as well as the more challenging ones"* [32]

It is it is important to highlight that when 'cost' is considered as a barrier to adoption, it goes beyond considering the fixed cost of a particular technology. Many technologies require complementary inputs and additional investment. For example, fertilisers and irrigation are associated technologies with the adoption of new seed varieties (Doss, 2006). This was also acknowledged in key informant interviews.

> *"…the farmer may not have the money and the resources to actually go out and buy the newest seed, or machine, or fertiliser. They may not have the complimentary inputs especially in agriculture that you need not just for one technology, but you need to have multiple pieces. You need to have water, you need to have seeds, you need to have fertilisers, you need to have pesticides to really make that plant grow properly and healthily"* [34]

While access to finance is a concern, the risk associated with such expenditures is sometimes as apparent an issue. This is well documented in the literature. Risk is a predominant social-economic concern, with decisions often taken at an individual level to avoid personal risk (Stark & Levhari, 1982; Kebede et al., 1990; Pannell et al., 2006). Economic uncertainty and risk were also identified by participants as issues that present a barrier to technology adoption:

> *"…if you try something new and it costs you something, the risk of failing is huge – particularly if the rain fails or something like that in Africa for example. [So] access to finance and risk"* [1]

> *"If you say change from this chemical to this seed that is resistant then the farmer might think 'but if I don't use this chemical I am risking my entire crop if the new technology doesn't work.' That is what I think is most difficult, this risk factor. So they are risking their profit, their margins and in the case of some farmers, their livelihood. And when you go outside the UK into developing countries I imagine that gets worse."* [26]

> *"Sometimes it's the cost of the technology and that cost itself has different components, it might be the initial cost of purchasing some new equipment or it might be the fact that a technology involves a certain amount of uncertainty for a new user. It might ultimately become very profitable for them but in the first few years when they are learning how to use it – it might even be a new variety which doesn't really involve any change in management practices – but they aren't quite sure yet how it is going to respond in their particular local conditions. So adopting that is a bit of a gamble in some cases and for a poor farmer who doesn't have much in the way of reserves. That might be too risky…"* [34]

Issues surrounding market access also arose among interview participants, with ten out of the twenty-eight participants that acknowledged economic barriers referring to this. The following quote summarises these concerns:

> *"Then the other constraints they have is markets. So when the farmers produce more they need to be able to sell it, otherwise investments made basically go to waste. If it's not profitable for them they are not going to adopt it. The profitability requires that there needs to markets in place."* [35]

It was stated that markets affect the adoption of technologies as a result of a lack of access to market information by both those that produce technology and those that use it. Further concerns included returns not justifying the cost and a lack of demand. Technology will not be adopted if there are no existing markets.

6.2.2. Knowledge exchange

As established in the previous chapter on R&D, there is an emphasis on the need to conduct research with a specific and necessary application in mind. It is the knowledge and technology that is derived from this process that is transferred to farmers and other end users. As chapter five also shows, challenges to this do exist. This particularly relates to conducting research for the production and enhancement of knowledge alone i.e. pure science (Pielke Jr, 2007). When considering the barriers to adoption however, establishing the driving force of knowledge producers is not the key issue. It is not those that develop knowledge that drive the adoption of technology, but the motivation behind the decision making process of the end user. While technology transfer is in the interest of the knowledge producer, its adoption is predominately located in the decision making process of those that may use it. It is an individual concern (Rogers, 1965).

Sixteen participants made reference to how issues surrounding knowledge exchange can hinder the adoption of novel technologies. This was identified as a challenge in a number of ways. Firstly, it was noted that scientific jargon is difficult to explain and the impact of different language barriers was emphasised:

> *"…so you have something which is good and you are pretty sure it's going to do well, even if it has the potential to do very well, [the end users] have no evidence to suggest that this is the case. You might throw lots of randomised control trial data and scientific evidence to them but until they see for themselves, it's not…it's not so much that they don't believe it, it's just not a language they understand."* [1]

This was particularly emphasised between developed and developing countries, with one industry representative highlighting the challenges of transferring knowledge and technology to the developing world:

> *"…well it would depend on where you were in the world. I suppose in a way we're having this conversation, we're very fortunate that we're in a very developed, very advanced mid shore agricultural economy, so there's very little that comes into market were people think well I don't really understand what this is. In other parts of the world it may be that people ... you know we struggle with the technology transfer piece which goes down to even basic technologies, you know, why use a seed variety? Just explaining these differences can be challenging."* [15]

Other challenges pertaining to knowledge exchange that emerged among participants included a lack of access to knowledge (which links into the following theme) and a lack of translation into practice:

> *"We are not seeing that joining up of the pipeline [between those that develop knowledge and those that use it]. A challenge is that there is a lack of actually making sure that bright ideas are properly translated into practical solutions on the farm"* [42]

This barrier is a result of a technology push onto the end user. That is, introducing a technology to farmers or end users without any prior engagement to establish exactly what they need. However it was also noted that a challenge for adoption was farmers not knowing who to approach about technological developments:

> *"The whole knowledge exchange network is very fragmented. So if I was a farmer and I wanted to find out about the best way to grow my wheat then it's quite a confusing landscape on where to get that information. So I think that is also a barrier"* [42]

6.2.3. No end user involvement

No end user involvement strongly links to the previous barrier on a lack of knowledge exchange. In this instance it is treated separately. While it was acknowledged by 23% of participants, it was also identified by the majority of food security actors. Representatives from civil society and funding bodies were the only groups to not acknowledge this as a specific concern.

It is noted that this acts as a barrier to adoption as it neglects end user input. As such technology does not fit with existing choices and it has no real world context:

> *"…you can have great ideas but if you don't translate it to practical pieces of kit that people can use on their farm, then that's one problem because people…if you've never developed something that is useful then it never gets taken up. It may be a great idea but if it's never taken up then forget about it"* [42]

No end user engagement predominantly stems around a lack of communication between the knowledge producer and the knowledge user. A lack of end user involvement however indicates that knowledge producers (i.e. those that develop technology) are the more dominant actors in this relationship, and thus, play a bigger role in creating challenges. The following quotes from a range of food security actors (US government bodies, international organisations, and funding bodies) highlight this.

> *"The reason a new technology isn't adopted by whoever is because it was developed out of context and it wasn't developed with…it might have been developed with the use in mind but it wasn't developed with the user actually designing and helping with the development of the technology. So there might be barriers that the developers of the technology didn't even think of because it wasn't developed in that context"* [13]

> *"I think one of the challenges, or one of the problems faced in the past about integrating new products or technologies is that they have been developed in a lab somewhere, anywhere in the world. They've spent months and months and months developing it, they've pumped in lots of money and they've said great we're finished and they've taken it to the field and they've just tried to dump it from a top down approach."* [3]

> *"one of the things that is not getting technology adopted has been pushing it upon the user without engaging with them first and then finding out that it doesn't work on their system, it doesn't work on their farm, they don't like the look of it, it is too technically minded [so] they can't use it because they don't have the staff that can work the system…"* [46]

Each of these quotes emphasises the adoption issues associated with knowledge producers not involving knowledge users within the development process. No end user engagement as an adoption challenge links into the debates that arose in the previous chapter of this thesis on the conceptualisation of science. Pure or basic science is problematic for the adoption of technology:

> *"Assuming your researchers and scientists have done their job properly and have developed an innovation that tackles a genuine problem then adoption of technology should occur. That is a big problem. Researchers research something that the end user does not see as an issue"* [1]

"…one of the things that is preventing technology adoption has been pushing it upon the end user without engaging with them first and then finding out that it doesn't work on their system or it doesn't work on their farm" [45]

6.2.4. Behavioral change

Behavioural change was identified as an adoption challenge by 32% (n=15) of participants. In some respects, this corresponds with debates on the shift from traditional to scientific knowledge that is encompassed in the food sovereignty narrative introduced in chapter three of this thesis. Participants noted that the introduction of novel technologies to farmers (particularly in developing countries) was a challenge due to deep traditions:

"…it can sometimes be a social risk. If you do something that is different to established practice, it could get you into trouble with your community" [26]

"In the context of low and middle income countries farming practices are deeply traditional and have been passed down. So if you have gotten a technology there it may be difficult to introduce it or to help people evolve in farming practices." [32]

Participants that identified behavioural change as a challenge stated that as a result of traditional farming practices, farmers (particularly older generations) were resistant to change and as such behavioural change was slow to happen. Adoption will not occur if change does not fit into farmers existing choices.

"Farmers are use to doing what they know, so breaking that barrier is not as simple. It is not that easy and teaching farmers to incorporate new practices that are more responsible is definitely a challenge" [17]

Like that observed in the economic challenge previously mentioned, risk was acknowledged as a reason for why behavioural change is also slow to happen:

"Behavioural change is slow to happen and a lot times – especially for small scale producers – they very often risk averse. So if there is new technology and new types of seed that is something different to what they

traditionally use, or if there is a new way of irrigation or fertilisation for example, they won't necessarily do it without there being some sort of incentive provided through a development program. Even with that incentive, it has to carry them through so that they use it long enough to see the benefits without the incentive being there. This is a huge part of the uptake and continued use and adoption of technology. It is difficult, particularly among the really poor and vulnerable populations. They can't just risk trying something new in case it fails and they may not have food for a few months." [11]

6.2.5. Regulatory challenges

Legal and regulatory concerns identified as a challenge to adoption were mentioned by 26% of stakeholders. This included US government bodies, industry, trade association, international organisations and farmer union groups. Representatives from international organisations noted that regulation can be off-putting for adoption in the developing world [33], and an interview with a farmer's union representative emphasised the influence that regulation has on growing crops in different countries [42]. This closely mirrors the challenges faced by different regulatory frameworks on the growing of GM crops between the UK and US mentioned in chapter four of this thesis. However regulatory challenges as a perceived barrier to adoption were predominately identified by industry and trade association participants.

When industry and trade associations were asked what they felt the key challenges were for technology adoption answers received stemmed around regulatory issues, particularly at an EU level, or the politicisation of science. As such, there was a continuation from that observed in the R&D process. Regulation hinders adoption as it prevents technological solutions from reaching them in the first place. For example:

"So for us the challenges are massively regulatory focused and that is obviously regulation at an EU level. It takes around eleven years and costs over £200 million to get a crop protection product to market. Now obviously a lot of time is spend in ensuring it is safe and things, but a vast amount of that time is based on overcoming regulatory hurdles…" [21]

Another interviewee representing a trade association noted that these 'hurdles' impact the transfer of technology to the farmer or end user:

> *"…so regulatory barriers to introducing technology are a challenge. That delays innovation, be it from the private sector or the public sector. It delays innovation and getting those solutions to the farmer's hands. I think the regulatory hurdle would be the most significant…"* [24]

A reemphasis on operational challenges and regulatory challenges identified within the previous two chapters was also acknowledged in an adoption context:

> *"So the regulatory barrier would be the greatest barrier I think, probably. It takes a long time, it costs a lot of money and this is not good for innovation, especially with a technology that has the most exemplary history of safe use in the history of agricultural technology. So regulatory barriers to introducing the technology, and that delays innovation be it from the private sector or the public sector. It delays innovation getting those solutions to farmer's hands."* [24]

This same participant also argued that the challenges posed to adoption were not as a result of a lack of communication with farmers and other end users. Environments are created to facilitate adoption, but this is prevented by regulatory systems:

> *"When we engage and talk about the benefits of the technology, we have seen a greater adoption. There is a greater acceptance of the technology, farmers come to use the technology, appreciate the benefits it offers and the safety of it. So there is certainly a relationship between the exposure to the technology and the confidence in using it. So the regulatory systems of the world, in some places, present a barrier to the entry of technology. You know, just not approving the technology etc. So that is the sort of chicken-egg scenario that we have where there is a hope someday from the farming community that they will be able to utilise the technology, but they don't have access to it. So it is hard to get confidence in the technology if you aren't allowed to use it and that is where the regulatory system sometimes prevents exposure to technology"* [24]

While framed as a challenge to adoption, regulatory barriers differ from the previous five barriers to adoption in that this is not necessarily challenges that are faced by potential end users of specific technologies. Rather, these are challenges faced by those that produce and develop technology. Like R&D, this challenge has been conveyed from participants own social and political contexts, with the challenges predominately perceived from an EU and developed country perspective.

6.3 Overcoming adoption barriers

So far this chapter has presented empirical findings on what participants perceive to be the main barriers to adoption. This section looks at the ways in which they are overcome. This presents a contrast to the previous two chapters in that the ways in which barriers are overcome were much clearer. This was not apparent in a broad food security context (chapter four) and links to ways in which barriers are bridged in an R&D context were much more tentative (chapter five). For the most part the ways in which adoption challenges are overcome were in response to interview question 12 (for your organisation, what is the process of getting new technology, knowledge or data to end users?). Interestingly, this was not conveyed to the same extent as adoption challenges. Were 100% of participants had some form of insight on barriers to adoption, less than half identified processes utilised to address this (n=22 / 46%). This in some respects mirrors the core finding in the previous two chapters: the ways in which barriers (and boundaries) are made receive much more attention from participants than the ways in which they are overcome. However, it also illustrates that there is a greater awareness behind bridging barriers to adoption as opposed to other stages of technology.

Table 6.2 summarises participants views on the ways in which adoption barriers are overcome. These include offering insurance schemes to reduce risk, demonstrating to the end user that the technology works, providing training, and utilising extension services[30]. All of these approaches deal with addressing barriers that relate to knowledge, including different understandings and concerns associated with access. This section will focus on two of these themes that allow for the identification of forms

[30] Extension is the process of providing farmers with insights from science to enhance agricultural productivity (Leeuwis, 2004; Klerkx, 2012).

of boundary work: train-the-trainer models, and extension services. Examples of both of these approaches were provided by interview participants.

Table 6.2: The ways in which technology or knowledge can be transferred to facilitate adoption[31]

Process for overcoming adoption challenges	**Codes summary**
Insurance	Insurance schemes to reduce risk [1] Provide insurance to minimise risk [11] Provide insurance [35]
Demonstrate that it works	Demonstrate effectiveness / field trials [1] Provide exemplars / case studies where it has previously worked [3] Small scale pilots [11] Demonstrate advantages [12] Rely on word of mouth [15] Free to a select number of farmers to trial and provide feedback [18] Evaluation trials [20] Self-demonstration among farmers [36]
Training	Provide training [11] Train volunteers in cultural and technical skills [13] Provide technical training to increase knowledge and ensure understanding of particular technologies and legislation / provide accreditation for attending training [18] Provide training and capacity building for farmers / lead farmer models [17]
Extension	Extension agents as a channel of communication [1] Via agronomists (utilise pre-established relationships with farmers [2] Specific country extension services [11] Use extension services to disseminate information [9] Extension programs [14] Public and private extension services / use of cell phone technology for public sector extension activity [12] Sell through distributors or other intermediary organisations including independent agronomists [15] Education and extension to resource poor farmers [19] Extension services to farmers [23] Good network of extension services to provide farmer exposure [32] Public, private and civil society extension services [33]

[31] Other examples that emerged, and do not fit into particular categories included the use of blogs, exhibitions and meetings [18], the use of mobile phones to spread knowledge [19], partnering with independent research organisations to minimise bias [20], tailoring business models for each country [17], linking new technology to existing networks [32], ensuring access to finance [36, 40], trade media coverage 15] and partnering with other stakeholders for knowledge exchange [2, 9].

	Extension services / advice / offer agricultural education [35] Education and access to extension services (and, subsequently, knowledge and market information) [40]

6.3.1. Trainer the trainer models

Training was identified as a way to overcome adoption barriers in that it addressed key concerns associated with a wide number of challenges. Participants acknowledged training as way to overcome cultural challenges that were encompassed within the theme ‘behavioral change’ as a barrier to adoption. Further, training reportedly addresses barriers caused by a lack of knowledge exchange by allowing for an understanding of particular technologies and legislation. However there was one specific example that emerged in interviews that allows for an understanding behind the bridging of boundaries in an adoption context – the lead farmer model:

> *“Something that is very common is the use of lead farmer models which are very successful in countries like India or Indonesia, or many African countries, where we have lead farmers who are receiving special support from our trainers. They can follow a trainer program where they are trained to transmit messages and information to their followers and because of their role in their communities they have much easy access to all the farmers. So that’s just one way to deliver or grant access to technology to farmers and to also spread the knowledge, because that is of course a challenge. I mean [in] a country like India, we train four to five hundred thousand farmers every year but it still is relatively small when you see the size of the country. So just to give an example in the case of Indonesia, we have a rice program where we have 4000 lead farmers and each of these lead farmers has around 20 followers. So that basically means that we have a reach of 80,000 farmers for that particular program, through our 4000 lead farmers.”* [17]

The aim of this approach is to empower smallholders who may lack access to agricultural technology, and help them increase productivity. While this is an industry specific example it allows for some important insights. Firstly, it demonstrates how these types of models can act as boundary objects whereby “members of different communities work together, yet maintain their disparate identities” (Guston, 1999: 89). **Figure 6.1** presents this approach diagrammatically. In this case industry (knowledge producers) provides technical knowledge to support the use of agricultural technology by the farmer. Reciprocally, smallholder farmers receive access to knowledge and inputs that reflect their specific concerns and circumstances. Actors on both sides of the boundary not only benefit, but contribute to the creation of a model or framework that they perceive as relevant or applicable. Each group interact through the transfer of knowledge.

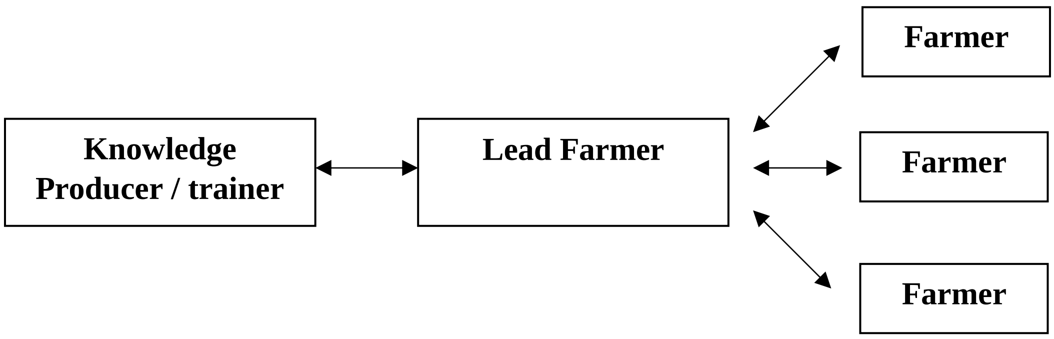


Figure 6.2. Diagram illustrating the lead farmer model approach to knowledge transfer

Secondly, it highlights the importance of social or peer learning for farmers where decisions are based on the experience of their neighbours decisions (Ellison & Fudenberg, 1993). This concept has been applied considerably to understanding agricultural adoption patterns whereby scholars have argued that adoption decisions from crop farmers in developing countries can be strongly correlated with the behavior and opinions of other people within their immediate environment (Case, 1992; Foster & Rosenzweig. 1995; Munshi, 2004; Conley & Udry, 2010; Krishnan & Patnam, 2013). These studies all indicate a requirement for the understanding of social and cultural factors in which knowledge is embedded. This is to not only understand technology adoption patterns, but to also shape the transfer of knowledge for decision making. This presents one probable reason behind the use of lead farmer models within training frameworks. They are not only culturally aware, but grow in similar biophysical conditions i.e. they are aware of the quality of the land, the nature of soil in specific areas, the biology of particular crops, specific weather patterns, how water is accessed and so forth. As such, lead farmer models as a type of knowledge transfer not only rely on the technical expertise of those that develop or produce knowledge, but also the authority of local expertise derived from their experience in farming and inclusion in specific social groups.

Boundary work in this case functions due to a combination of expertise whereby technical and local knowledge is coproduced. It not only coincides with the nature of boundary objects, which often comprise of multiple types of expertise in their formation (Cash et al., 2003; Clark et al., 2016), but draws on the role of experts as intermediaries who operate a boundary position by transferring knowledge between different actors (Berling & Bueger, 2015). Further, both sets of actors provide a legitimate contribution to the development of lead farmer models to facilitate technology adoption in developing countries. Industry actively seek to understand the challenges of farmers to give technical knowledge context and a purpose. Likewise, farmers seek to understand how technology can be used to increase productivity, how to improve market access, and increase security. Knowledge is not unidirectional. As such, they both contribute towards efforts to increase food production, market access and overall food security.

6.3.2 Extension services

Extension services were the most emphasised way to overcome barriers to adoption by interview participants. Thirteen participants (28%) acknowledged the importance of extension. This has long been recognised as a relevant approach. Extension has been identified as a key characteristic of farmers who adopt technology (Wheeler et al., 2016). They have been shown to have a beneficial impact on poverty growth (Dercon et al., 2009), and are often used as a measurable variable for access to information (Doss, 2006). Extension mainly raises awareness, and to some extents changes perceptions. It has been noted that the main goal is the acceleration of adoption rather than enforcing it (Pannell et al., 2006).

It was noted within this research that a lack of extension services hindered adoption:

> *"…extension services are spotty at best in a lot of places so it may be that new technologies aren't even being introduced to farmers because they don't have access to an extension agent and that sort of knowledge is not*

> *being funneled into that area. So a good network of extension services can be really critical in making sure farmers have exposure to new things"* [32]

This particular quote arose in discussion with a participant from a global research institute. However this was a sentiment shared by all other groups of food security actors that identified this as a way in which adoption challenges are overcome. The importance of extension services was acknowledged by a range of participants including those from UK government bodies, US government bodies, industry, trade associations, research institutes, international organisations and civil society. However, discussions with US government bodies allowed for greater insight into how extension work occurs in practice.

One example that emerged in US government body interviews was the use of volunteers who are involved in the last stage of technological development and the diffusion of technology. It was noted that volunteers undergo significant cultural training in developing countries to facilitate a relationship with the farming communities:

> *"Volunteers spend the first two months of their service in very intensive technical, language and cultural training and that all happens in the country which they serve. So during those first two months it's really where our organisation is able to help the volunteers get the language and the skills they need, get the cultural understanding that they need, to give any more technical skills that they need and help them to be really able understand the situation…"* [13]

These volunteers operate a monitoring and evaluation role, and pass any information obtained to the producer of knowledge. In this case, it was stated that any data obtained was transferred to USAID (who operate the Feed the Future initiative), to make informed decisions on the best way to transfer technology and knowledge to those that need it most. This represents a whole of US government approach, however, the US government also work with extension services that are already existing in particular countries [interview 9]. In any case the extension approach to knowledge transfer is shown in **figure 6.2**. Volunteers act as extension agents or mediators between the producers of knowledge, and the end users.

Figure 6.3. Diagram illustrating the extension approach to the translation of knowledge

Boundary work in extension services functions through the translation of knowledge between those that create knowledge and those that use it. This particularly corresponds with notions of boundary organisations. As mentioned in chapter two of this thesis, boundary organisations encourage communication by actors and negotiates a space through which this may occur (Guston, 1999; Cash, 2001). In this case volunteers not only negotiate a space for interaction to occur, but do so in a way that allows them to exist in two different social worlds. They not only have a strong working relationship with those that produce knowledge, but they become accustomed to cultures and farming methods, and create relationships with farmers that allow for a build-up in trust.

Another interesting observation from this data is the contrast between US and UK government bodies on the acknowledgement of extension services. Four out of seven US government body representatives engaged with highlighted the importance of extension services. Whereby only two out of seven UK key informants mentioned extension services. While this does not present a significant finding, the content of these responses are what are of interest. The previous example gives an indication on how US government body interviewee’s talked about extension. Conversely, those UK representatives that did mention extension did so as a passing comment included in a list other possible approaches to overcome adoption challenges. For example:

> *“You can communicate things better by having channels of communication through extension agents or whatever…so there are ways you can get*

around knowledge barriers like demonstration, by doing field trials, lead farmer approaches, using extension services etc." [1]

A similar observation can be made from key US and UK documents. The US Feed the Future program and 2016 Global Food Security Act particularly focus on foreign aid, and extension is widely acknowledged to assist this. In both the Global Food Security Act and the US Global Food Security Strategy, that lays out the Feed the Future Initiative, extension is mentioned twenty-seven times. Conversely, extension is not referenced to the same extent by UK government body officials. This can be seen in **table 6.3** which indicates the number of times that extension is referred to in key reports on food security. As mentioned previously in chapter four, these are all major documents that contributed to a shift in UK policy discourse from self-sufficiency to international initiatives that promote food security. To consider the context of foreign aid, this table also includes the UK Department of International Development's conceptual framework on agriculture.

Among these seven core reports 'extension' is referred to a total of forty-three times. The majority of these references can be found in the UK Foresight report (n=39) which explores the future of UK food and farming until 2050. Given that this is a report that comprises of two hundred and eleven pages, the significance of the amount of times extension was mentioned does not seem that relevant. Extension is mentioned briefly throughout this report as a solution to challenges that face the food system, and specific focus is limited to half a page. Furthermore, by contrast to the US reports, rather than discussing the use of extension in a definitive sense to achieve goals, this report puts forth this advisory service approach as a recommendation for the UK government in achieving food security.

For the remaining core reports, reference to extension is extremely limited. What's more, when it is referred to it is mentioned once or twice in passing, and does not receive sole attention. These differences between the US and UK may correlate with the different approaches to food security that have been detailed in chapter four of this thesis. Furthermore, the privatisation of UK state funded advisory systems may present some insight into this observation. The government retreat from extension services was the first stage of privatisation observed as early as the late 1980's. Cuts to near-market applied research were made, and responsibilities were passed onto industry. As a result research institutes began to receive a lot more funding from private sources as well as public sources (Prager & Thomson, 2014). While this data is not suffice to make any firm conclusions, it does indicate a possible area for further research. That is, do different organisational factors shape how boundary work functions?

Table 6.3 The number of times 'extension' is mentioned in major UK reports and statements

Report	Number of times 'extension' is mentioned	Reference
Food security and the UK: An evidence and analysis paper	0	DEFRA, 2016
Ensuring the UKs food security in a changing world. A DEFRA discussion paper	0	DEFRA, 2008
Food matters: towards a strategy for the 21st century	2	The Strategy Unit, 2008
UK global foresight report	39	Foresight, 2011
A UK strategy for agricultural technologies	1	HM treasury, 2013
DFID conceptual framework on agriculture	1	DFID, 2015
Global food security strategic plan	0	UK global food security program, 2017

6.4 Discussion

This chapter has identified a number of barriers to technology adoption. What's more, all participants that were interviewed for this research had some views on what the biggest challenges to the implementation of technology are. This 100% response rate is important to highlight for two reasons. Firstly, it signifies a change in pattern. While challenges were dominant in the previous two chapters (with boundary making receiving more attention than boundary crossing), the response was not to the same extent as that observed when the topic of discussion was technology adoption. This indicates that participants have greater knowledge on the barriers to adoption compared to that of R&D.

Secondly, this response rate is perhaps to be expected. Researching the barriers to technology adoption is common place within academia and the barriers that were identified by participants for this research have all received attention in the literature. For example, economic concerns are often identified as significant determinants in technology adoption, were it has been argued that farmers lack economic incentive for investment (Marra et al., 2003; Shiferaw & Bantilan, 2004) and that economic conditions have to be suitable for adoption to occur (Kuan et al., 2015). The importance of knowledge transfer and engaging with the end user has also received academic attention, with it being acknowledged that a lack of this can create barriers to adoption (Doss, 2006; Pannell et al., 2006; Straub, 2009; Lambrecht et al., 2014; Corner-Thomas et al., 2017). Finally, research has been conducted into the behaviours that shape adoption decision making. Examples include exploring the impact of age differences (Morris & Venkatesh, 2000), gender differences (Venkatesh et al., 2000; Doss & Morris, 2001) and, more prominently, the influence of peers or social networks on decisions (Case, 1992, Baerenklau, 2005; Conley & Udry, 2010; Krishnan & Patnam et al., 2013; Ramirez, 2013; Chatzmichael et al., 2014).

There is an array of existing literature and therefore, this may present one reasons why there is an apparent emphasis on adoption over R&D with interview participants. However this research has not only identified the dominant barriers to adoption that arose in interviews with key food security actors, but it also allows for the identification of the ways in which boundaries are made between those that develop technology and those that use it.

6.4.1 Boundaries are created by a lack of knowledge exchange

The data collected for this chapter allows for the conclusion that boundaries between those involved in the development of technology and those that use it in the process of technology adoption are created by a lack of knowledge exchange. This research identified five main barriers to adoption. All of these barriers are standalone, yet with the exception of regulatory differences they also link together by factors contributing to how knowledge exchange is transferred and managed. Knowledge exchange itself was identified as an adoption barrier. Stakeholders perceived this to be a challenge in that scientific jargon impeded interaction between knowledge producers and knowledge users, there is a lack of translation into practice, and a lack of access to knowledge. The link with 'no end user engagement' is also clear and self-explanatory. This was identified as a barrier to adoption as a lack of communication between those that produce knowledge and those that use it may result in the introduction of technologies with no real world context.

While economic factors primarily relate to affordability, access to finance and risk of spending, links to the importance of knowledge exchange are also apparent. For example, one issue identified was placing technology into a situation were no economic markets are in place because of a lack of communication. Finally, for behavioral change the biggest challenge is a lack of understanding behind specific behaviours and actions. There is a lack of awareness on basic requirements of the end user. By not engaging, and subsequently being aware of existing traditions and environments, technology may be introduced with no context.

The importance of interaction is not an uncommon claim. It has been long acknowledged in the literature that if an idea does not pass between actors then it will not circulate in a population (Rogers, 1965; Foster & Rosenzweig, 1995; Doss, 2006; Pannell et al., 2006; Straub, 2009). Access to information is therefore important for increasing agricultural technology adoption, and its transfer is one approach to bringing different groups together (Doss, 2006; Lambrecht et al., 2014; Corner-Thomas et al., 2017). As such, knowledge exchange has a role to play in bridging boundaries. Yet in this instance, this potential form of boundary work has been identified as a challenge to the adoption of technology. There is little in the literature that definitively considers various types of boundaries as a challenge or as a boundary in itself. Rather, scholars particularly emphasise the role of boundary work in promoting collaboration and bringing together forms of science and politics (Gieryn 1983; Jasanoff, 1987; Star & Griesemer, 1989).

6.4.2 Social and political contexts matter

Regulatory issues present a clear exception to the previous observation. That is, regulatory challenges to adoption were acknowledged from the perspective of the knowledge producer, mirroring the concerns observed in the R&D process. In this context regulatory challenges were predominately mentioned by industry and their trade associations, with a particular emphasis placed on the politicisation of science. These participants talked about how adoption cannot occur because of regulatory restrictions on the development and application stages of technologies. This was a concern of those that produce technology and knowledge and little reference was made to the end user. Conversely, the remaining adoption barriers mentioned by participants all related to decisions made by the end user. These challenges focused on the social construction of decisions, and all of these barriers were identified at an individual level. Concerns were placed at a developing country farmer or end user context. Regulatory issues were not only identified from the perspective of those that produce technology, but also in a developed world context, through the lens of EU regulatory and risk analysis frameworks.

In this case, it could be said that there is an apparent importance placed on political and social contexts and how this shapes the ways in which boundaries are made. As mentioned, barriers to adoption were all identified through the perspective of the end user in the developing world. In this instance, boundaries were created by a lack of knowledge exchange. Regulatory issues as an adoption challenge was an anomaly to this finding. Not only was it portrayed as a challenge from the perspective of those that create technology, but also as a challenge situated predominantly in the developed world. Mirroring the concerns identified in chapter five of this thesis on R&D, it further contributes to the argument that boundaries are perceived to be created by a politicisation of science. This not only highlights a difference in how boundaries are perceived to be created between R&D and adoption, but also emphasis how different social and political contexts contribute to this.

6.4.3 Boundaries are created by the influence of science on society

The differences identified in the previous section also allowed for identification of another key finding. As mentioned, rather than speaking to concerns facing the end user, regulatory challenges were described from a knowledge producer and EU/developed country context. This corresponds with R&D concerns in that boundaries are perceived to be created by a politicisation of science. Technology is restricted by regulatory frameworks, risk analysis frameworks and so forth. The opposite was observed for adoption barriers. These barriers alluded to the influence that science has on society.

Two factors make this clear. Firstly barriers were largely social and economic, as observed through the barriers behavioural challenges and economic concerns. Secondly, these challenges were exemplified by pressures placed by science dimensions. For example, a prioritisation of pure science and basic research has been shown to limit knowledge exchange and end user engagement. Focusing solely on scientific research not only limits interaction, but contributes to the creation of adoption barriers.

This is to be expected given that the adoption process is widely recognised as being heterogenic. While technical knowledge proves essential for the adoption of a particular technology, it is not the only prerequisite. Action actually requires a mix of scientific, economic, social and political knowledge (Sunding & Zilberman, 2001; Pannell et al., 2006; Van Kerkhoff & Lebel, 2006; Klerx, 2012). However what is important is the difference between R&D and adoption. Boundaries are perceived to be created differently based on social and economic contexts and whether it is through the perspective of those that produce knowledge or those that use it. Boundaries are either a politicisation of science or vice versa.

6.4.4 More awareness of the ways that forms of science and politics interact

Twenty-two key informant interviewee’s (46%) clearly communicated ways in which adoption challenges are overcome and subsequently, how boundaries are crossed. This chapter looked at two examples: train the trainer models and extension services. It showed how both of these act as forms of boundary organisations in that they facilitate interaction between different actors by acting as a space of negotiation to allow for both the transfer and translation of knowledge. This not only highlighted the different ways in which boundaries are overcome, but it also shows that participants are much more aware of how political, social and economic impacts on technology in an adoption context. This is particularly pertinent in comparison to R&D, and considering boundary work in a broader food security context. There was no clear acknowledgement to how boundaries are crossed in these different areas and thus presented a shift in pattern between different practices.

6.4.5 Conceptualisation of adoption

The research conducted for this chapter has placed an emphasis on knowledge exchange. Not only are boundaries created by a lack of it, but it also plays a role in the ways in which boundaries are bridged. It has been argued that diffusion occurs among groups of people, whereas adoption is solely an individual concern. As such, diffusion should not be confused for adoption (Rogers, 1965). Conversely, these definitions can be seen as tentative. Sovacool & Hess (2017) for example note that cases exist whereby diffusion has been referred to as adoption, attitudes, or support, arguing that these terms all essentially refer to the same thing: the use or adoption of technology as opposed to inhibiting or resisting it. This chapter does not aim to amalgamate these terms. Like Rogers (1965) it perceives adoption to be an action or decision undertaken at an individual level, with diffusion understood to occur between differing actors and artefacts. However, in contrast to Rogers' deterministic approach, it recognises that these entities are interwoven and must be studied as such. Adoption cannot be fully explored without an explanation behind its diffusion. Exploring forms of boundary work indicate a deliberate convergence of the two processes. They are increasingly made to work together and this happens through the emphasis on knowledge exchange in both the creation and bridging of boundaries.

6.5 Conclusion

This chapter aimed to explore the ways in which science and politics comes together and divides in the process of technology adoption. It not only set out to explore forms of boundary work, but to also identify changes in patterns between different practices. In doing so, this chapter found that a greater prioritisation by key informants has been placed on adoption. While barriers to interaction were identified in the previous two chapters, this was not to the same extent as adoption which elicited a 100% response rate. Furthermore, there was a greater awareness of the ways in which these barriers can be overcome – both forms of boundary objects and boundary organisations emerged in the data.

The data collected for this chapter emphasised the importance of knowledge exchange and transfer for the adoption process. Four out of five adoption challenges that were identified in this research all linked to a lack of knowledge exchange which played a considerable role in the creation of boundaries. The data presented in this chapter also allowed for the conclusion that social and political contexts matter in how different forms of knowledge are prioritised and how this occurs between different practices. This chapter also argued that rather than boundaries being created by a perceived politicisation of science observed in the R&D process, it was actually the opposite for adoption barriers. That is, these barriers were partly created by pressures placed by science dimensions. Finally, this research indicates that rather than the diffusion of knowledge and adoption being separate processes, they are made to work together.

Finally, this chapter also suggests that national differences may be prominent in how boundaries are crossed. This was apparent by how extension services was mentioned by both the US and UK governments. A much clearer and definitive sense of the importance of this approach could be observed by US government bodies. Further research is necessary to understand whether these factors have an influence on how boundary work functions.

Conclusion

This thesis has sought to understand how technology and various social and political forces relate within the context of food security. Specifically, it aimed to explore where forms of science and politics come together, where forms of science and politics divide, and the impact that this has on food security practice.

Food security practice increasingly emphasises the need for social, political and technological dimensions to interact. However, as of yet, there has been insufficient exploration of how these fields connect and affect each other. A review of the literature on technology within food security indicated that while there is an increased call for interdisciplinary research, the fields of biological science and the social and political sciences approach food security as two different academic fields. In doing so, they have a limited understanding of each another. There is little in the literature that considers how these fields of science and politics connect and affect each other.

To address this gap, and therefore explore where forms of science and politics connect and disconnect, the following research questions were established:

- What forms of knowledge are being prioritised?
- How is this organised and translated in particular practices?
    - What ways are forms of science and politics entwined? How are these interactions negotiated?
    - How are practices represented and undertaken at different levels?
- What impact does this have on food security?

This thesis has answered these questions through the exploration of co-production. Co-production operates on the understanding that different knowledge forms are simultaneously produced; one cannot function without the other, and thus it acts as an appropriate conceptual tool to establish interaction between various forms of science and politics. This research recognised co-production as more than an alternative relationship between forms of science and politics, rather it acts as a mechanism that shapes the way relationships look between them. Boundary work was introduced as a tool to explore these relationships by identifying not only how boundaries were created, but also how they were crossed through the development of boundary objects and organisations. Functioning through the creation of platforms and knowledge solutions that meet the needs of multiple and often different epistemic groups, the identification of these forms of boundary work, how they are constructed, the ways in which they bring forms of science and politics together and the level of negotiation that occurs within this not only addressed the core research questions of this thesis, but allowed for a clearer sense of how co-production occurred in food security practice.

To address the research questions of this thesis through a co-production perspective, four research chapters were conducted. The first of these four research chapters looked at co-production between science (technology) and politics (society) through key stages in agricultural history. The main purpose of this chapter was to attempt to understand how forms of science and politics has entwined in the past. This chapter argued that technology and society has always been co-produced. Specifically, practices of food production, technology and security have always been deeply entangled since the invention of agriculture some 10,000 years ago. There has always been political implications to the use of technology within agricultural development. This was a particularly interesting finding for two reasons. Firstly, it illustrates that the politicisation of technology (and vice versa) is not something that has just occurred post-World War Two or in tandem with increased globalisation and the introduction of novel modern biotechnologies, such as GM. Secondly, by establishing that food security has always co-produced technology and society throughout key stages in history, it validates the use of co-production as a conceptual tool to explore how this looks in current practice. By exploring five key eras of agricultural history (Neolithic, Antiquity, Middle Ages, First and Second Modern Agricultural Revolutions) forms of entanglement were not only identified within each stage but there was apparent shifts in the way that this looks. This therefore raised the question of how co-production between differing forms of science and politics currently looked in practice, especially post the 2008 food price crisis. This was particularly pertinent as the food price crisis represents an additional significant stage in the history of food security. It pushed food security back into the spotlight both at an academic and global governance level. The remainder of this thesis was interested in how different science and politics communities currently came together, and therefore aimed to understand how this conveyed in current practice.

To explore this, a qualitative research methodology was designed to help identify and explore forms of boundary work currently in practice. Key informant semi-structured interviews were conducted with actors representing different food security communities and deductive content analysis was conducted to identify key patterns and themes corresponding with how these communities interact. This thesis looked at the broader picture of food security and boundary work before specifically considering this within the R&D and adoption processes.

Chapter four focused on boundary work in food security, providing a broader understanding on how boundaries are made in practice. This chapter argued that despite the need for and importance of partnerships to address food security being emphasised through global platforms, the findings of this research put an emphasis on the barriers to interaction between various science and politics actors from scientific communities and policymaking practices, institutions and structures. That is, opportunities were also presented to participants to explain ways in which different communities come together, however responses on how and why interaction is challenging were more dominant. These challenges included issues of ownership, perception (civil society and the public) and fragmentation in institutional approaches on food security. Each of these concerns created boundaries in their own ways and while there were some observable links between them (i.e. ownership and perception) they all were equally standalone. However, how these boundaries manifest and entangle with each other shows some important national differences that are constituted through different institutional and regulatory arrangements that coincide with different approaches to risk analysis. Further, this chapter argued that political controversies, such as GM, and uncertainties, such as Brexit, can amplify the institutional and regulatory boundary forming process.

While chapter four considered boundary work in a broader food security context, the remainder of this thesis aimed to understand how this pattern shifts, if at all, when we considered specific practices. Chapter five explored boundary work in the R&D of technology. Three R&D challenges emerged in key informant interviews and allowed for an understanding behind how boundaries are created. Firstly, similar to that observed in the previous chapter, operational differences were identified as a barrier to interaction between those that develop technology and those that govern it. Secondly, this research showed that barriers are created due to a lack of end user engagement. This linked into how science is conceptualised. Key informants argued that it was necessary to engage with the potential users of specific technologies and, as such, scientific research needs to be applied. However the challenge lies with conducting pure research. This chapter discussed the importance placed on the autonomy of science, which is amplified by the need for peer review and REF, for example, in the UK. However, it argued that pure research is actually politicised as a result. Scientific research and political practice always interact, but in different ways. Where one form of interaction is actively sought, the other is a necessity to achieve scientific autonomy and credibility. This chapter further argued that boundaries are perceived to be created by a politicisation of scientific practice. Regulatory frameworks, institutional frameworks at an EU level, and risk analysis all reportedly hinder how R&D is conducted. Finally it was also argued in this chapter that risk both intensifies and minimises boundaries. It was perceived to contribute to the creation of boundaries, but it was also apparent that situations exist whereby it also bridges boundaries.

Finally, chapter six looked at the adoption of technology. It aimed to not only explore forms of boundary work in this process but also how this differs, if at all, from other practices. In comparison to the previous two research chapters it was apparent that stakeholders had a much broader understanding of how different forms of science and politics interacts when it comes to the adoption of technology. It considers those that develop technology and those that use it, as well as influence of social, political and economic factors on the implementation of technologies. Not only was there a 100% response rate when asked about the challenges, but the ways in which they may also be overcome were also acknowledged. Boundary objects were identified through a train-the-trainer model, and boundary organisations in the form of agricultural extension services were also acknowledged by stakeholders. This was not the case when considering food security and in R&D. However, while this chapter illustrated a much greater awareness on the ways in which challenges can be addressed, this was not acknowledged to the same extent as the barriers to adoption. Thus, it was argued that there is still a prioritisation of understanding among stakeholders on the ways in which these forms of science and politics divide. This chapter placed a significant emphasis on the importance of knowledge transfer in the creation and bridging of boundaries. Four out of five adoption challenges that were identified in this research all linked to a lack of knowledge exchange which played a considerable role in the creation of boundaries. The data presented in this chapter also allowed for the conclusion that social and political contexts matter in how different forms of knowledge are prioritised and how this occurs between different practices. This chapter also argued that rather than boundaries being created by a perceived politicisation of scientific practice observed in the R&D process, it was actually the opposite for adoption barriers. That is, these barriers were partly created by pressures placed by science dimensions.

Throughout this thesis, a number of patterns emerged when different types of activity were considered. Each research chapter identified a number of ways in which boundaries are created in different circumstances which also reveals a number of overarching conclusions. This allowed for the identification of commonalities and differences. Risk played a considerable role in the creation of boundaries and was acknowledged to differing extents in each chapter. In both chapters four and five there was an emphasis on the constraints posed by risk analysis and challenges posed by precautionary principle approaches utilised in the EU. Risk also emerged in the analysis of data for chapter six, albeit to a lesser extent. That is, it was acknowledged that risk influences decision making when it comes to adopting new technologies. It occurs at a personal level. An additional similarity between different practices was the perceived influence of operational differences. Both chapters four and five illustrated how this contributed to the creation of boundaries in a broad food security context, and in R&D. This however was not acknowledged to the same extent in the process of technology adoption, which emphasised the importance of knowledge exchange and focused on different social and political contexts. The influence of national differences on the creation and bridging of boundaries was also apparent throughout different practices. This was particularly prominent in chapter four which highlighted the influence that national differences have on the creation of boundaries. Evidence also arose in chapter six of this thesis that suggests that national differences may also shape the ways in which boundary work is utilised to overcome adoption challenges by facilitating knowledge exchange between those that develop technologies and those that use it.

Perhaps the main differences between different practices was the context in which barriers were identified. For R&D, this was predominantly in the own social and political contexts of the knowledge producer, with the identified challenges to interaction being at a developed country level. In the adoption of technology, participants identified challenges that they perceived those in developing worlds to consider. Linking into this, another difference between the practices of R&D and adoption was the politicisation of science and vice versa. While there was an emphasis on the politicisation of science as a contributor to the creation of boundaries in R&D, boundaries in adoption were perceived to be created by what Davidshofer et al., 2016 defined as a 'scientification of politics'. That is, barriers were established due to a lack of knowledge exchange, which coincides with conducting pure research, and being concerned about personal social and political contexts.

In specifically addressing the research questions of this thesis, this work has found that forms of knowledge being prioritised correspond with national differences (risk, uncertainty, regulatory frameworks and so forth), and different social and political contexts. In this respect it indicates the ways in which different forms of science and politics divide. Furthermore, using boundary work to explore this also shows that boundaries between various forms of science and politics transcend different types of practice. This is apparent in the commonalities identified in the previous paragraph. While this research presents some insight into the ways in which types of science and politics comes together in the context of adoption, it finds that this receives a lot less attention in comparison to the ways in which they divide. This lack of awareness may have an impact on achieving food security. Finally, it is apparent throughout the empirical chapters of this thesis that in each of these different practices 'science' and 'politics' have been interpreted differently by core food security actors engaged with. In a broad food security context, science and politics was referred to as differing scientific communities, and policy makers, practices, institutions and structures. When discussing R&D, key food security actors referred to science as scientific research, industry or those that create / develop technology. 'Politics' was identified as EU regulations/frameworks, government or those that govern / police technology. Finally, when considering adoption, science and politics were considered in terms of those that create / develop technology, and those that use it, as well as the ways in social, political and economic factors influence the implementation of different technologies. This indicates that priorities differ according to the different situations. However, despite science and politics being considered differently throughout different practices, this research has shown that similarities in how boundaries are created still exist.

Some potential implications arose from this research. Firstly, there does not appear to be a space for negotiation and interaction between different fields. This suggests that there is much more to be done to begin to achieve food security in its truest sense. As a researcher considering if and where this interaction occurs, my own experiences reflect this. With a PhD project that has connections to two different schools, it was apparent that this thesis does not situate itself in any one discipline. That is, this research did not fit into existing frames of research currently being undertaken in either school. For the School of Biological science, it contained 'too much politics', and for the school of History, Anthropology, Philosophy and Politics, the focus on technology made it 'too scientific'. It was difficult to find a space where this research can exist and be of interest to multiple different fields. This indicates that much more needs to be done to remedy this. Secondly, there is a tendency to either mislabel what constitutes as interdisciplinary research and / or have a very narrow understanding behind what constitutes as interdisciplinarity. From an academic context, many interdisciplinary institutions exist, however this is not interdisciplinary in its truest form. For example, while combining numerous elements of biological science in these institutions (such as biochemistry and ecology, for example), is indeed important, in a food security context we cannot truly consider this interdisciplinary. To address food security we need the development of institutions that incorporate a range of disciplines from a range of fields such as biological science, computer science / engineering, politics, psychology, geography anthropology and the list goes on. Only then will we be on track to addressing core concerns. More is needed to bring multiple fields together.

This research is of value in a number of ways. Firstly, the current body of literature on interaction between science, and politics when considering technology in the field of food security is small and slowly growing. To date there has not been much work on how these fields connect and affect each other. Additionally, there is little existing research that looks at interaction between these variables through the lens of co-production. Secondly, by considering the inter-relationships on technical and political practice, and how they shift, this work has reinforced the use of co-production and boundary work as conceptual tools to explore these types of relationships. It is both a useful and relevant method to be utilised for interdisciplinary research on food security. For example, this research identified both boundary objects, and organisations, that are utilised to bring communities together for the adoption of technology. However, it also allowed for the understanding that the identification of forms of boundary crossings are somewhat limited. Thirdly, this research has provided insight into interaction between forms of science and politics communities at a practical level. As such, it allows for the presentation of an agenda for initial thinking about how interaction may work better.

While this original research has identified differences in patterns between how different forms of science and politics comes together and divides, this is the first stage of a much longer research project beyond the scope of this thesis. As such avenues for further research can be identified. Further research would be beneficial to not only specifically explore the ways in which science and politics interact in a food security context, but also to understand the reasons behind why this is not prioritised as much as the ways in which boundaries are created. Understanding why there is an emphasis on the ways in which forms of science and politics divide as oppose to come together both at a practical level and also among academic disciplines is important as it may allow for the development of tailored solutions and recommendations to be made. It may be useful to explore why 'science' and 'politics' are interpreted differently when different types of practices are considered. For example, what does this mean? Does this level of understanding affect the total process of technology development as a tool for achieving food security? Risk emerged in all four research chapters in this thesis, and certainly warrants further research. Different risk frameworks highlighted important national differences in chapter four, and it was also shown to contribute to the creation of boundaries in both chapters five and six. As such, it may be of relevance to explore this further. While it is apparent from this research that risk frameworks contribute to the ways in which boundary work functions, it is not yet clear what influence this has food security and what this means for achieving it.

This thesis has highlighted national differences. It indicated that some differences exist between how boundaries are created. Chapter six of this thesis also showed that this may also shape the development of boundary objects and boundary organisations. However, there was insufficient data to understand this further. As such it would be beneficial to conduct further research that asks if different organisational factors and regulatory frameworks relating to food security shape how boundary work functions and if so how?

To conclude, the main take home messages of this thesis are as follows. The research conducted for this thesis has indicated a lack of knowledge surrounding the ways that various forms of science and politics come together to address food security. Food security practice emphasises the need for interaction, however there is little that explores this in the existing literature. While there is substantial practical evidence of progress being made, this research has identified a key area of concern: key informants from a broad range of food security actors are not aware of the ways in which this occurs. What's more, even when awareness is apparent like that observed for the adoption of technologies, the main focus is still on the challenges that interaction faces.

By exploring how this occurs in practice, this research has shown that the clear divides between science and politics literature presented in the literature review of this thesis also translates into practice. There is a gap between the objectives of food security (the need for technology, in particular) and the practice of food security actors.

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Appendices

Appendix A: Interview Schedule

Prior to interview: For ethics purposes I am required to obtain your consent for this interview. I would appreciate it if you could provide [written / verbal] consent that you agree with and understand the following statements [read statements from consent form].

[Begin audio recording at this stage]

Tell Participant: To give a brief overview again, this interview aims to understand more about the relationship between science, industry and government to see how they come together and divide for food security purposes. It is split into 3 sections that consider food security, the relationship between science, industry and politics and finally the importance of technology. It should take no longer than 45 minutes to an hour of your time.

[Opening Questions]:

To get started, could you tell me a bit about your specific role within your organisation?

Q1. When we talk about food security, what is your understanding/ your organisations understanding of this term?

Q2. Food security comprises of a number of different dimensions such as food safety and sustainability of food supply. Of these two, what would be your organisations main focus? [Probe: Are these related or separate issues for you?]

Q3. What role do you feel technologies play in achieving food security? [What technology do you feel is most important?]

Q4. What is your role within this area? And what do you perceive the role of others to be in relation to implementation?

Q5. In relation to food security, how important do you perceive the relationship between industry and government to be? Where do you think this relationship currently stands?

Q6. Where do you engage with science/politics within the frame of your work?

Q7. What are the barriers of working together with science/government? [Probe: different knowledge assumptions? Time? Different cultures?]

Q8. Does this have a particular impact on your work? How do you deal with this?

Q9. Who are the experts that you consult with the most? What is there role? [Probe: do you speak more to academia or industry? Is it a relative mix of the two?]

Q10. What are the useful aspects of experts to your work? In what aspects of your work are experts not useful for?

Q11. What are the challenges to introducing new technology to practice?

Q12. For your organisation, what is the process of getting new technology/knowledge or data to end users? [Probe: Who is the end user? are there any priorities? Are there any specific processes?]

Q13. What have been the most important recent developments within this area of emerging technology for food security? What drives these changes? [Only ask this question if the information hasn’t already came out in answers from other questions]

Appendix B: Participant information sheet

PARTICIPANT INFORMATION SHEET

Title of study: An examination of the role of technology in addressing food security

You are being invited to take part in a study. This document underlines why it is being done and what it will involve. Please take the time to read the following information and feel free to ask any questions if something is not clear or you would like more information. Thank you.

What is the purpose of this study?

As an interdisciplinary field, addressing and achieving food security requires a collaborative approach across many disciplinary and professional boundaries. This work looks at the relationships between science, industry and government to explore how they both divide and come together for food security purposes, particularly when considering the role of emerging technologies. Today food security is very much a scientific concern, with the need for existing and emerging technologies being acknowledged. As such the overarching aim of this work is to ascertain how food production technologies and food security politics relate. By exploring disciplinary, professional and institutional differences it is hoped that potential transformations for global food security can be put forward.

Who is running this study?

This study is being conducted by Kerry Wallace as the basis of an interdisciplinary PhD at Queens University Belfast, under the supervision of Dr. Mike Bourne (Politics, International Studies and Philosophy) and Dr. Katrina Campbell (Institute for Global Food Security). This study is funded by the Department of Employment and Learning (DEL).

What will the study involve for me?

This study will require you to undertake an interview that should last approximately one hour. This will occur in the most feasible method possible i.e. face-to-face or via skype, and will be audio recorded for transcription purposes and analysis only, this will not be used in any official outputs.

Do I have to take part?

No, your participation is voluntary. We have approached you about taking part in this study as your background and expertise fall into our predefined stakeholder categories for this research and we believe that you can make both an important and valuable contribution to this project. If you do not wish to participate, you do not have to do anything in response to this request. If you do decide to take part in the study and change your mind later, you are free to withdraw at any time with no reason. You can do this by informing the researcher directly. If you are participating in interviews, you are free to stop it at any time. Any recordings will be erased and the information you have provided will not be included in the study results. You may also refuse to answer any questions that you do not wish to answer during this interview.

Will information about me collected throughout the study be kept confidential?

Prior to the interview the researcher will ask you how you would like to be addressed in official outputs (i.e. the level of anonymity you would require.) Should you request full anonymity, all the information you provide to us will be kept confidential and only the researcher and her supervisors will have access to it. No personal details about you will be used in transcripts or research outputs and information about you, transcripts and recordings will be kept on a password protected folder on the researcher's computer. Information will not be released to any third parties and confidentiality will only be breached if there are supervening legal or ethical obligations.

What will happen to the results of this study?

Results from this study will be used in the researcher's thesis, for publications and at conference presentations/posters if applicable, however, if requested, you will not be identifiable. If you would like more information from the study on completion, please let the researcher know and arrangements can be made.

Who can I contact if I have any concerns or require any further information?

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Appendix C: Participant consent form

PARTICIPANT CONSENT FORM

The researcher will read the following statements to participants and gain verbal consent for each

1.	I have read and understood the information sheet for this project and have been given the opportunity to ask questions	☐
2.	I understand that I can withdraw at any time without reason and do not have to answer any questions I don't feel comfortable answering	☐
3.	I agree to the interview session being audio recorded	☐
5.	I understand that the results of this project/my words may be quoted in the researcher's thesis, publications, and other such research outputs.	☐
6.	I require the following level of anonymity for such citations:	
	1) I agree to be cited by name, role and organisation	☐
	2) I agree to be cited by role and organisation only	☐
	3) I agree to be cited as a government official/industry representative only	☐
	4) I agree to be cited as an anonymous key informant interview	☐

Name of Participant

Verbal consent obtained?

Date

Appendix D: Interview references

[1] – Interview with UK government body representative one (31/10/16)

[2] – Interview with UK government body representative two (13/12/16)

[3] – Interview with UK government body representative three (13/01/17)

[4] – Interview with UK government body representative four (22/03/17)

[5] – Interview with UK government body representative five (05/12/16)

[6] – Interview with UK government body representative five (18/11/16)

[7] – Interview with UK government body representative six (02/02/17)

[8] – Interview with US government body representative one (02/11/16)

[9] – Interview with US government body representative one (02/11/16)

[10] – Interview with US government body representative one (15/12/16)

[11] – Interview with US government body representative two (17/11/16)

[12] – Interview with US government body representative two (13/12/16)

[13] – Interview with US government body representative three (20/03/17)

[14] – Interview with US government body representative four (12/04/17)

[15] – Interview with an industry representative one (03/02/17)

[16] – Interview with an industry representative one (09/12/17)

[17] – Interview with an industry representative one (26/01/17)

[18] – Interview with an industry representative two (09/12/16)

[19] – Interview with an industry representative three (03/02/17)

[20] – Interview with an industry representative four (10/02/17)

[21] – Interview with a trade association representative one (16/02/17)

[22] – Interview with a trade association representative two (01/03/17)

[23] – Interview with a trade association representative three (08/02/17)

[24] – Interview with a trade association representative four (29/03/17)

[25] – Interview with a trade association representative five (28/03/17)

[26] – Interview with a research institute representative one (05/12/16)

[27] – Interview with a research institute representative two (07/11/16)

[28] – Interview with a research institute representative three (01/11/16)

[29] – Interview with a research institute representative four (19/10/16)

[30] – Interview with a research institute representative five (19/12/16)

[31] – Interview with a research institute representative six (18/04/17)

[32] – Interview with a research institute representative seven (24/03/17)

[33] – Interview with an international organisation representative one (23/11/16)

[34] – Interview with an international organisation representative one (09/12/16)

[35] – Interview with an international organisation representative two (29/11/16)

[36] – Interview with an international organisation representative two (08/12/16)

[37] – Interview with an international organisation representative three (08/12/16)

[38] – Interview with an international organisation representative three (16/01/17)

[39] – Interview with an international organisation representative four (19/01/17)

[40] – Interview with an NGO representative (19/01/17)

[41] – Interview with a CSO representative (15/03/17)

[42] – Interview with a farmer’s union representative (25/11/16)

[43] – Interview with a farmer’s union representative (01/12/16)

[44] – Interview with a farmer’s union representative one (13/12/16)

[45] – Interview with a funding body representative two (07/12/16)

[46] – Interview with a farmer’s union representative three (16/01/17)

[47] – Interview with an international regulator (17/02/17)