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The Regulatory Dilemma: An interdisciplinary perspective into how regulation can be used to impact innovation

by

Christopher M. Hughes

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ABSTRACT

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By Christopher M. Hughes

Innovation is an emergent property of a complex socioeconomic system. It is an evolutionary process that through the interactions of entities within their environment it gives rise to something new. This process of innovation continually disrupts the modus operandi, thus allowing the system to evolve over time. However, failure to anticipate the future states of the system poses significant systemic risk – as witnessed by the Financial Crisis of 2008. Therefore, policy-makers need sufficient and reliable knowledge as to how to steer the system towards better outcomes for society. Problematically, understanding this relationship can often be beyond the scope of a single discipline or area of research practice. Therefore, this thesis is organised around the idea as to how regulation can be used to impact innovation through an interdisciplinary perspective. Hence, the first paper systematically analyses the research area by conglomerating the fragmented literature that reside around this domain. This is in order to identify gaps, themes, relationships and deficiencies within the research stream. The second paper then looks towards agent-based modelling – a method for measuring complex systems – as a suitable way to answer the issues raised by the first manuscript. This was achieved by breaking up the agent-based literature

to analyse its effectiveness for understanding this relationship. From this the author systematically compared and contrasted the various design specifications of the agent-based models, thus providing a relevant framework to analyse how different policies can shape the market mechanism through various policy objectives. These findings are subsequently converged to frame the final paper, which the author calls the Regulatory Dilemma. This aims to measure the aggressiveness of a variety of policy-instruments to see what effect they have on the system via agent-based simulation. Hence, the research contributes to existing literature on how regulation shapes the innovation process; however, specifically facilitating the gap that analyses the stringency of two policy instruments that target towards both the inventor (i.e. through rewarding invention) and the imitator (i.e. penalising imitation). Consequently, this presents an interesting insight into how regulation can impact the dynamics of the system. It also seems to prove a useful tool to transcend borders set by standard analytical models and open up promising avenues for future policy design. More research plans to extend this model with greater adaption and realism for the pre-assessment as to the effectiveness of the proposed policies.

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Declaration of Authorship

I, Christopher Mark Hughes, declare that the thesis entitled and the work presented in the thesis are both my own, and have been generated by me as the result of my own original research. I confirm that:

• this work was done wholly or mainly while in candidature for a research degree at this University;

• where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;

• where I have consulted the published work of others, this is always clearly attributed;

• where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;

• I have acknowledged all main sources of help;

• where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;

• none of this work has been published before submission

• parts of this work have been published as: Hughes et al. 2014 and Hughes and Lawrence, 2014

Signed:...

Date:..

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Preface

This thesis is presented in the three paper format. The papers are written so that they can be read in isolation from one another. Whilst each paper is a self-contained manuscript they are all interlinked by a common theme. Therefore, the three papers provide a generic narrative for when this body of work is interpreted as a whole. In addition to the studies, this thesis starts with an introduction that provides a background of the research area and how the themes of the papers are structured in relation to the main body of work. Finally, this thesis ends with a conclusion that discusses the findings of each paper in a broader context, with a section that highlights the limitations and direction for future research. It is also worth to note that each study contains some additional material that does not contribute to the central flow of the argument, but complements the main theme of that paper.

Chapter 1

Introduction

1 Setting the Scene

Throughout history, humanity has developed solutions to respond to the opportunities and challenges presented by our environment. This creativity has made innumerable scientific discoveries. From language and stone tools to sophisticated genetic engineering and information technologies. It is argued to be an emergent property of a complex system, where agents interact with their environment and through these interactions it gives rise to something new. This process of innovation continually disrupts the modus operandi, thus evolving the system over time (Schumpeter, 1934; Campbell, 1960; Nelson and Winter, 1985; Kauffman et al., 2000; Goldberg, 2002; Olssen and Frey, 2002; Frenken and Nuvolari, 2004; Khanafiah and Situngkir, 2006; Baldwin et al., 2006; Hodgson, 2005; Arthur, 2009; Fleming and Szigety, 2006; Valverde et al., 2007; Ganco and Hoetker, 2009; Caminati and Stabile, 2010; Geisendorf, 2010; Simonton, 2010; Johnson, 2011, Vermeij and Leigh, 2011; Konig et al., 2011; Wagner, 2011; Sole et al., 2013; Gabora, 2013). Policy-makers within this context aim to steer the dynamics of the system by modifying the actors towards preferred outcomes for society. However, failure to anticipate the future states of the system poses significant systemic risk. Consequently, any policy recommendation that aims to influence the social properties of the system needs to be fully understood with reliable and systemic knowledge (Fagerberg et al., 2013).

The purpose of the thesis is therefore to enhance ones understanding into the relationship between innovation and regulation and the various structures and processes that it is dependent on. Consequently, the first paper aims to analyse the relationship by systematically conglomerating the fragmented literature that reside around this domain. The second paper then looks towards agent-based modelling (ABM) as a suitable method to unpack the issues raised in the first manuscript. Therefore, this deviates from the first manuscript to concentrate more on the design specifications of the ABMs to see how they were constructed and its suitability as a policy tool. These findings are subsequently converged to frame the final paper, which the author calls the Regulatory Dilemma. This aims to measure the aggressiveness of a variety of policy-instruments to see what effect they have on the system via agent-based simulation. Considering this, the next section will provide an overview of the main themes and issues of the research field. Hence, it will provide a basis to frame the relevant goals and objectives of each individual manuscript to see how they relate to one another when interpreted as a whole.

1.1 Innovation: Definition, Types and Features

Innovation is increasingly being recognised as an important social and economic phenomenon worthy of scientific study. It is often seen as critical for the development and competitiveness of firms, regions and whole nations (Blind, 2012a). Firms are concerned about their innovative capacity due to its perceived value for competitive advantage and economic profits (Zahra and Covin, 1994; Christensen, 1997; Christensen and Raynor, 2003). Similarly, policy-makers also care about its assumed social benefit for enhancing growth, welfare and employment (Maddison, 1991; Freeman, 1994). However, to recognise that it is desirable is not sufficient in itself. What is required is sufficient and reliable knowledge about how best to exploit its benefits to the full (Fagerberg et al., 2013). Therefore, before describing the various structures and processes and how this can be shaped by regulation, it is important to highlight what is meant by innovation.

Within the literature, there exists a wide variety of perspectives on this issue. Schumpeter (1934) provides an early definition to describe innovation as the (i) introduction of a new product or modification brought to an existing product; (ii) a process of innovation in an industry; (iii) the discovery of a new market; (iv) developing new sources of supply with raw materials; (v) and other changes in the organisation. This is in support with a more recent explanation that illustrates innovation to be the "effective application of processes and products to the organisation and designed to benefit it and its stakeholders" (Anderson and West, 1996). In spite of the fact that this encapsulates the essence of Schumpeters (1934) definition. It could be argued that it seems to neglect other forms of knowledge that may arise through entities other than the firm. Similarly, Keathley et al., (2013) suggests it is the "conversion of new concepts and knowledge into new products, services, or processes that deliver new customer value in the market". However, this line of reasoning also implies that the purpose of innovation is for economic gain. Whilst it could be argued that the majority of innovation is developed with this in mind, some of the most revolutionary technologies have been created for variety of other purposes.

A case in point is with the development of the internet. This was originally created through the Advanced Research Projects Agency (ARPA) – an agency of the US Department of the Defence. The purpose was to create a communication network so that individuals could communicate to one another via computers even if nodes in the network were removed. This decentralised structure meant that it was extremely resilient to attack. Consequently, it led to the emergence of an early packet switching network and the first to implement the protocol suite TCP/IP, both of which became the technical foundations of the internet (Lievrouw, 2006; Schneider et al., 2009; Coffman and Odlzco, 2002; Oppliger, 2001). Another innovation that embraced this technology came from academia, known as the World Wide Web. This was developed by Tim Berners-Lee at the European Organisation of Nuclear Research (CERN). Berners-Lee proposed an information space so that documents and other web resources could be accessed via the internet (W3C, 2004). Whilst it was originally developed to meet the demand for automatic information sharing between scientists in universities and institutions around the world, the innovation was released into the public sphere for free with an open licence (Giampietro, 2013).

Therefore, as suggested by many scholars of innovation it is the process of turning opportunity into something new and putting this into practice (e.g. Tidd et al., 2005; Freeman et al., 1982; Rothwell and Gardiner, 1985; Drucker, 1985; Porter, 1990); thus, innovation refers to the development, adaptation, imitation and adoption of knowledge that is new in a given circumstance (Katz, 2016). From this, there is a widespread array of the types of innovation that can emerge. These range from products and processes, as well as new business models, organisation structures and management practices (Ettlie and Reza, 1992). Similarly, there are also a number of ways to analyse the many forms of change (Norman and Verganti, 2014). For example, a largely adopted framework looks at the impact certain innovations have upon society. In this context, innovation is differentiated between disruptive ("or radical") and incremental (or "follow on") change, See Figure 1.1.

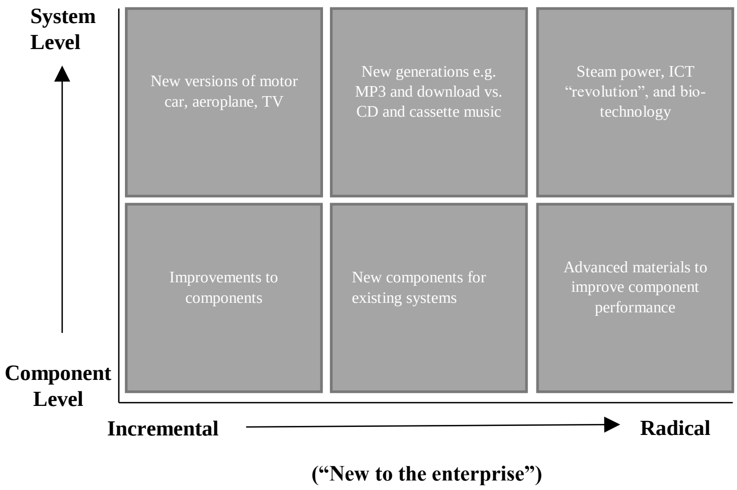


Figure 1.1: Dimensions of innovation.

As illustrated by Figure 1.1, whilst the majority of innovation builds on what has already been done before, which require modifications to existing functions and practices; there are some innovations that change the entire order of things, thus making the previous approaches obsolete (Koberg et al., 2003). This is known as disruptive innovation and they have a significant impact on society. However, it is important to recognise that not all innovations are disruptive even if they are considered revolutionary. A case in point is with the development of the automobiles in the late part of the 19th century. At first, these vehicles were seen as a luxury item due to their high cost. Consequently, it did not disrupt the market from horse-driven vehicles. It was only after the introduction of the Ford Model T car in 1908 – a vehicle regarded as the first affordable automotive – that it had a significant impact on the transportation industry (Christensen and Raynor, 2003).

Similarly, just as it can be useful to classify innovation based on the level of change, it is also useful to describe the various types of applications, with one example being product innovation. This can be illustrated as something that is new or an improvement with respect to its characteristics or intended uses (OECD, 2005). In this context, it can include improvements to technical specifications, components and materials, incorporated software, user friendliness or other functional characteristic's (OECD, 2009a). Whilst product innovation is seen to be one of the main drivers for economic growth, process innovation can play just an important role. For example, being able to produce something no one else can, or do it in ways that are better than anyone else is a powerful source of competitive advantage. A case in point is with Japanese dominance in a range of product markets in the late twentieth century. As through its total quality management and lean manufacturing, it led the country to dominate a whole range of sectors. Finally, being able to offer better services may also be considered a type of innovation. Whilst services may appear different due to their intangible nature, often a similar process of discovery to implementation is applied (Tidd et al., 2005).

In this context, it is important to differentiate innovation from invention. Whilst it can be easy to confuse the two. Inventing is just one part of a long process in bringing a good idea into widespread and effective use (OECD, 1993). A good example lies with Thomas Edison and the creation of the incandescent lightbulb. Whilst various designs existed at the time, very few had practical relevance in a world where there was no power to turn it on. Consequently, Edison and his team focused on developing not only a commercially viable electric lamp based on a carbon filament (Edison, 1880), but also an entire electricity generation and distribution infrastructure (Tidd et al., 2005). Therefore, by looking at how best to bring his product to market, they were able to identify factors that others simply overlooked. As a consequence electric lights became cheap, safe and convenient to use. Edison realized innovation is more than simply coming up with good ideas; it is the process of growing them into practical use.

Not only does this place emphasis on understanding what innovation is; but, also the relevant structures and processes that give rise to it. One of the first systematic attempts to describe the process of innovation was the work by Joseph Schumpeter in the first half of the twentieth century (Foxon, 2002). Whilst various authors described economic and technological change as part of exploiting new ideas before him (Lorenzi et al., 1912; Veblen, 1899; Cantillon according to Schumpeter, 1949). It was Schumpeter, which described innovation in the context of a socioeconomic system, where he differentiated the process between invention, innovation and diffusion. However, despite virtues in this simple representation (Foxon, 2003), much of modern theory has moved away from this linear model towards innovation as being an emergent property of a complex adaptive system (Kuhlman et al., 1999; Lemay and Sa, 2012; Dougherty and Dunne, 2011; Katz, 2000; Cooksey, 2011; Rose-Anderssen et al., 2005; McCarthy, 2005).

Therefore, innovation is argued to be part of a network of organisations within an economic system that are directly involved in the creation, diffusion and use of knowledge as well as the organisations responsible for the coordination and support of these processes (Dosi, 1988). In other words, actors – that is to say people, enterprises and institutions (Katz, 2016) - are all interlinked within a complex system (Freeman, 1987; Lundvall, 1992; Nelson, 1992, 1993) and through their repeated interactions it can give rise to something new. In turn, it continually disrupts the modus operandi thus evolving the system over time (Schumpeter, 1934; Campbell, 1960; Nelson and Winter, 1985; Kauffman et al., 2000; Goldberg, 2002; Olssen and Frey, 2002; Frenken and Nuvolari, 2004; Khanafiah and Situngkir, 2006; Baldwin et al., 2006; Hodgson, 2005; Arthur, 2009; Fleming and Szigety, 2006; Valverde et al., 2007; Ganco and Hoetker, 2009; Caminati and Stabile, 2010; Geisendorf, 2010; Simonton, 2010; Johnson, 2011, Vermeij and Leigh, 2011; Konig et al., 2011; Wagner, 2011; Sole et al., 2013; Gabora, 2013).

However, whilst this change is often seen as improving the system as a whole, it can also lead to situations whereby it induces negative impacts. Prominent cases can be found in the financial sector as well as in manufacturing, where actors' looking for short term gains invoke greater costs for society at a later stage, thus leading to a reduction in long-term welfare or economic growth (Fagerberg et al., 2013). Consequently, regulators can be seen to play an important role in trying to ensure that the system leads to preferred conditions for society. Whilst most would agree that regulation is needed in some shape or form (for example, guns being sold to children and the abolishment of slavery), there is often contention between the various types of policy-instruments and the extent in which they are applied.

1.2 Regulation: Objectives, Themes and Instruments

Regulation has existed for as long as individuals have tried to influence the private actions of agents: that is, forever (McLean, 2003). Like many political concepts, regulation is hard to define, not least because it means different things to different people. However, Levi-Faur (2011) defines it as "the ex-ante bureaucratic legislation of prescriptive rules and the monitoring and enforcement of these rules by social, business, and political actors on other social, business, and political actors". It is thus seen as a restrictive form of governance that imposes sanctions for non-compliance. Policy whilst seemingly similar tends to encompass a broader reach that guides our actions towards desired societal goals (Cochran and Malone, 1995). These objectives can be reactive in response to a current pressing problem. Similarly, it can also be proactive and created as a course of action designed to prevent a problem, such as government rebates for enhancing the adoption of energy efficient technologies. In other words, policy raises the important issues to fix a problem – present and future – whilst regulation is a means by which this can be achieved. However, despite the distinct differences between them. Within the literature, they are often viewed as a means for influencing individuals towards desired policy objectives. Therefore, to make the thesis tractable the author defines these forms of governance as a means to influence the behaviour of actors' part of a socioeconomic system towards better outcomes for society. In this context, there are wide ranges of instruments that can be applied by policy-makers to shape the dynamics of the market mechanism at various stages of this systemic process.

A typical precondition for regulation often lies in situations whereby the market forces alone do not lead to socially optimal results. This is known as “market failure” within economics and include cases of market power (and abuse thereof), public goods, externalities, and asymmetric or incomplete information (Pelkmans and Renda, 2014). However, fixing these failures is not the only precursor for regulation. For example, when the objective of policy integration departs from that of efficiency to provide more socially relevant objectives. A case in point is with the pressing need to tackle climate change. This challenge will not be solved if it is left to the market mechanism alone, such is the power of vested interests and the path dependent nature of the trajectories pursued over the years (Martin, 2012b). Therefore, regulators need to play a proactive role – not just in fixing market failures – but also for creating the right environment to address some of the global 21st century challenges (Fagerberg et al., 2013).

There are a wide variety of regulations that can be implemented to drive the system towards better outcomes for society. A report by the OECD (1997), introduced a three-fold taxonomy as to the heterogeneous policy-instruments that exist. First, economic policies try to provide suitable conditions within the marketplace. This can be achieved by increasing competition and reducing unemployment (eg Aghion et al, 2005; Barbosa and Faria, 2011). Secondly, there are social policies that aim to protect the environment and the safety and health of society at large. For example, policies that aim to reduce carbon emissions through encouraging technological development within certain areas (eg Pickman, 1998; Fernadez-Cornejo, 1998). Finally, there are administrative policies that try to govern the practical functioning of the public and private sectors; therefore, aiming to ensure companies play by a certain set of rules and conditions, such as intellectual property and copyright legislation (eg Abrams, 2009; Lerner, 2009).

Another useful classification is based on how various policy-instruments can be applied through various parts of the innovation process. For example, concerning the supply side there are policies that support entrepreneurs and new start-up companies, such as by providing firms with additional capital, preferential taxation and incubation hubs that offer services, such as training or office space (Rindova et al., 2009; Douham et al., 2013; Mason and Brown, 2013). Similarly, there are policies that aim to promote Research and Development (R&D). Often this is classified between direct and indirect government assistance: direct funding allocates money through grants and procurements, whereas indirect support is based on incentives like reducing tax from R&D related activities (Etan 1999; Gonzalez and Pazo, 2005; Becker and Hall, 2013). From the demand side of the market mechanism there can be policies targeted towards the consumer. These range from subsidies for enhancing adoption of particular innovations or taxing certain ones to reduce their use (Cantano and Silverberg, 2009; Ferro et al., 2010; Scwartz and Ernst, 2009). Furthermore, there can be policies aimed towards spreading awareness and educating individuals to influence their behaviour towards certain policy goals and objectives (Desmarchelier et al., 2013; Rixen and Weigand, 2014).

Therefore, regulation can be seen to play an integral part of the innovation process. According to Stewart (2010) indeed any changes to the regulatory framework can impact the system based on three dimensions: flexibility, stringency and information. Whilst not all regulations are affected by these variables, it does provide an interesting overview into the changes that can arise through policy-integration, See Figure 1.2.

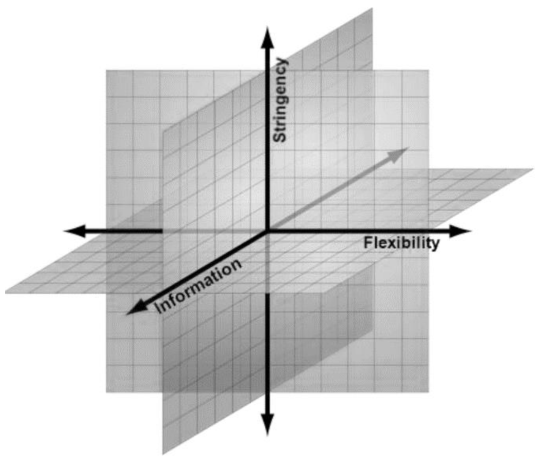


Figure 1.2: Key dimensions of regulation.

Flexibility describes the number of implementation paths firms have available for complying with the regulation. For example, there are some regulations that require strict compliance that have to be adhered to, such as with safety standards where innovations need to be created in a certain way. Conversely, a regulation could be considered more flexible if it tries to influence compliance as oppose to forcing it. In this context, firms can weigh up the regulatory incentives against market ones and thus decide to what extent to behave as required. A case in point is with tradeable permits. This is where emissions are capped and allocated to firms. Those companies that emit less than their assigned allocation can then trade permits with another company (Stavins, 2003).

The information dimension aims to analyse whether a policy-instrument causes more or less information within the market. Often this is by trying to improve the feedback mechanisms within the system. For example, consumers may not know about the quality of a product or service that they are purchasing. Therefore, regulation can help alleviate this by promoting more complete information. A case in point is with the preapproval of screening new drugs that acts as a certification to ensure the quality and efficacy of them (Tuncak, 2009). However, whilst this aims to enhance information within the market it can also introduce uncertainty (Braeutigam, 1981). In this example, pharmaceutical companies may be unsure whether the Food and Drug Administration (FDA) will approve a new drug. Consequently, this lack of information may have an adverse implication on R&D if they believe the risk for failure to be too high. In this context, the delay of the authorisation process can also play an important role (Vernon et al., 2009; Prieger, 2002; Golec et al., 2010).

The final dimension measures the degree of aggressiveness regarding the regulatory environment. This is where regulators may choose to tighten or loosen policies to enhance its desired effect. For example, heightening the stringency of a certain policy targeted towards encouraging new technological pathways into sustainable energy. However, often a trade-off emerges between the stringency of regulation and its impact. A case in point is with intellectual property and copyright legislation. This is because if policy makers penalise companies too aggressively for infringing copyright then firms will gain an incentive to create something new, but due to the reduction in imitation this may inadvertently reduce competition thereby weakening the economic pressure for future invention (Harrison, 2008; Vanderkerckhove, 2008). Conversely, if the protection is less stringent then it may entice competition, thus forcing companies to develop new ways of reducing cost or increasing revenue. However, if firms can copy new ideas without having to pay the upfront research costs it may reduce the reward for future invention, thus leading to a market failure (Reenan 2014; Czarnitzki and Kraft, 2012).

Each dimension arguably plays an important role in shaping the dynamics of the system. However, whilst it was previously argued that market failure was often the precursor for policy-integration, the government can also fail by integrating policies that inadvertently exacerbate the problem or create new ones (Orbach, 2013). For example awarding subsidies to firms may seem as a viable way to induce innovation. However, it may lead to situations whereby it protects inefficient firms form the forces of competition; thus, creating barriers for new companies to enter the market. Similarly, if the government protects organisations, it can also lead to situations that can encourage irresponsible risk taking – as witnessed with the Financial Crisis of 2008.

Therefore, any policy that is put forward needs to be critically evaluated so that policy-makers can anticipate any unexpected causalities that may arise through its integration (Fagerberg et al., 2013). A case in point is with the Stop Online Privacy Act. The act aimed to tackle online copyright infringement by proposing several policies, such as increased powers for blocking websites, preventing search engines linking to them and consumers becoming responsible for the content that they view (USPG, 2011). However, fears arose regarding the long-term implications should it be implemented. This is because the inherent nature of this particular social system is about using and sharing information. Consequently, by placing greater restrictions on the processes between the interacting agents it could inadvertently hinder innovation in the long-term. Not just on the internet, but also in other sectors and industries that are reliant on the health and stability of the web. Hence, failing to understand the impacts of changing the regulatory environment poses significant systemic risk across a wide range of sectors and industries. Policy-makers thus need sufficient and reliable evidence to steer the system towards better outcomes for society. Gaining such knowledge is one of the main aims of Innovation Studies. Therefore, the next section will aim to discuss the main issues and concerns with this research field and suggest suitable ways of moving forward.

1.3 Innovation Studies: An Emerging Agenda

Innovation studies is a growing field that is based on the assumption that science, technology and innovation is fundamental to economic and social prosperity (Fagerberg and Verspagen, 2009). However, to learn more about how society can benefit from innovation, one also needs to understand the innovation process and how various actors interact with broader social, institutional, and political factors (Fagerberg, 2013). This is one of the main purposes of IS, which started off largely as a “multi-disciplinary” specialism that operated within existing disciplines. Much of this early research was driven mainly from sociology and economics, with rare attempts to combine insights from different disciplinary frameworks (Fagerberg et al., 2013). Furthermore, when researchers from different backgrounds did encounter one another this often gave rise to fierce dispute (Martin, 2012a). This is often due to the range of different viewpoints, which can lead to disagreements as they are not always thought as compatible with one another (Hughes and Lawrence, 2014). However, over time it became more interdisciplinary as researchers began to link, blend and integrate various inputs from various different academic backgrounds (Klein, 2010; Martin, 2011).

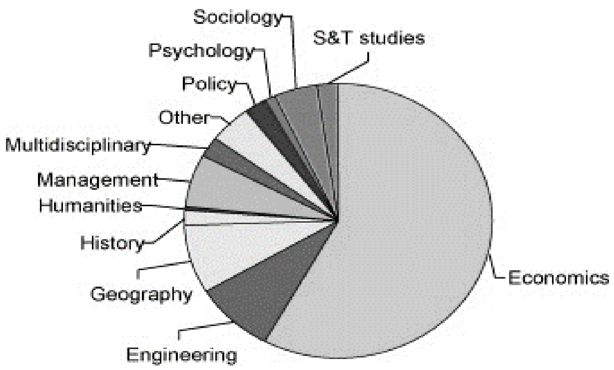


Figure 1.3: Educational background of Innovation Studies scholars.

As demonstrated by Fagerberg and Verspagen (2009) in Figure 1.3 there exists a wide range of different disciplinary backgrounds that now study innovation, whilst economics still remains the dominant discipline a variety of others have emerged – for example, management, engineering, and geography - each bringing their unique insights into the domain. These disciplines provide additional data, methods and conceptual frameworks to aid understanding of how different policies may impact innovation (Martin, 2016).

However, despite the discipline broadening considerably over the last few decades, there remains the notion as to whether it has expanded enough. This is because there is still little understanding regarding the different types of innovations that are being generated and the factors and policies that influence those (Faberberg et al., 2013). Whilst there has been improvement, progress has been infrequent. For example, the majority of papers analysing this relationship tend to omit regulation as part of the study itself. Therefore, these studies imply policy through recommendation as oppose to actually measuring it within their analysis (Fagerberg et al., 2013). Furthermore, a large part of our understanding has been historically influenced by reductionism (Mazzochi, 2008). This is based on the philosophy that complex phenomena can be broken up into simple components and analysed through linear mathematical models and equations. However, reducing everything to simple fundamental laws does not always imply the ability to start from those laws and reconstruct the same system (Anderson, 1972). In other words, emergent phenomena cannot always be described simply by reducing the properties to lower scales (an issue that will be later explored in more detail).

Therefore, not only does this raise concerns as to whether scholars are asking the right questions, but also whether they are being answered in the right way. For example, regulatory frameworks in the past have been driven largely by classical economics. Central to this ideology is an almost religious belief in efficient markets. This is where the market functions most effectively if everyone is allowed to pursue his or her self-interest in a free and open market. In other words, it is a self-correcting mechanism where competition and unrestrained selfishness is of benefit to the whole of society, thus government interference should be strictly limited (Sheil, 2000). Consequently, regulation under laissez-faire economics has been seen to play a largely restricted role in the functioning of markets, whereby policy-makers aim to ensure the macroeconomic climate is right for free-market capitalism – operating without let or hindrance – then getting out of the way (Martin, 2016). However, this philosophy undoubtedly contributed to the 2008 Financial Global Crisis (Fagerberg et al., 2013). For example, deregulation enabled financial institutions to dictate governmental policy and enabled wealth to be channelled into speculative investments, thus exacerbating volatility of share and housing markets. The combination of household debt due to excessive borrowing and unregulated speculative investment, led to the collapse of the subprime mortgage market. What followed was the bankruptcy of major financial institutions, which in turn crashed share markets around the world (Beder, 2009).

Consequently, just as the global financial crisis revealed the need to fundamentally rethink how financial systems are regulated, it has also made clear that pure economics was insufficient to analyse it. This is because in reality markets are not efficient; humans tend to be over focused in the short-term and blind in the long-term, and errors get amplified through social pressure and herding, which ultimately leads to collective irrationality, panic and crashes (Bouchard, 2009). Therefore, to think that the market could impose its own self-discipline is arguably illogical. For example, just as self-interest drives markets, self-interest also drives irresponsibility, inordinate risk taking and fraud (McCleskey, 2010). Therefore, relying on models based on these strong assumptions and untested axioms can have disastrous consequences for the global economy.

Whilst this philosophy might have been applicable back when economic and social structures were simpler. In today's globalised and interconnected world it is increasingly unsuitable (Bonabeau, 2002). For example, when Adam Smith wrote the *Wealth of Nations* he was referring to a completely different environment than the one we have today. The world is incommensurably more complex with many new actors and dynamics. Together, their power and authority have outstripped the power of nation-states and their interactions are becoming ever more complex (Mothe and Paquet, 1996). Therefore, not only does this increase systemic risk, but it also makes trying to understand and predict changes within these complex systems that much harder.

Considering this, it is extremely important to understand how policy - or lack thereof – may affect the system within these complex environments. As failure to do so can lead to disastrous consequences for society. Innovation studies is in a strong position to respond to these challenges. However, much more needs to be done. This is because in order to design effective policies, policy-makers need to understand the big picture, or more specifically the big moving picture as there is always a danger that today's research will reflect past trajectories rather than future challenges (Fagerberg et al., 2013). In this context, theories for understanding various aspects of how regulation impacts innovation should not be carved in stone, but rather evolve as a result of changes in society and our attempts to understand them. Therefore, the study of innovation needs to continually extend its broad interest across a wide range of fields. One discipline, which may inform innovation studies and policy-making, is that of complexity science.

1.4 Complexity Science: Embracing Diversity

The precise definition of "complexity science" is still the subject of large debate (Ladyman et al., 2011). However, it can be roughly characterised as the study of systems comprised of many parts where entities interact within an environment. Through these interactions, global behaviours arise that cannot be easily understood in terms of the interactions between the constitutional elements (Wolfram, 2002; Laughlin, 2005). These systems therefore exhibit so-called "emergent properties" that are difficult to describe from the underlying rules of the system (Rickles et al., 2007). However, instead of understanding how these systems aggregate together, much of the natural and social sciences have historically been more concerned with a reductionist approach (Mazzocchi, 2008). This is breaking things into smaller and smaller pieces so that they can be studied in isolation. Whilst this philosophy has been undoubtedly successful in explaining the world around us, the principles that have emerged through linear deduction are arguably insufficient for measuring these types of environments.

A case in point is when looking at an individual ant. By itself, its behaviour is far from mysterious. This is because there is a very small number of tasks that any ant has to do in within its lifespan. For example, depending on its caste it may defend against enemies, care for the queens' brood, tend to the upkeep of the nest, or forage for food (Flake, 1998). However, if you analyse how ants interact with one another then it can lead to some very interesting system dynamics. Seth and Cliff (2004) provide a good example when analysing the path laying and following behaviour of them. The authors illustrate that as ants forage for food they excrete a pheromone trail as they head back to the colony, which decays over time. This signals to the other ants the location of the food source, with ants typically preferring trails with stronger pheromone deposits. As more ants go to that location, as they return they may randomly deviate from the established trail, thus leaving new pheromone trails as they do. Therefore, the shortest path will always tend to have the freshest pheromone deposits, thus attracting the most traffic. This helps to reinforce these paths with the strongest concentration of pheromones. Hence, without any central synchronisation or control, colonies of foraging ants can quickly and reliably find the quickest path to the food source from the colony, and should that path cease to be navigable, then the colony will dynamically adjust to find a new one (Seth and Cliff, 2004).

The natural world is full of these types of environments, where on one level of analysis it can be described as having many interrelated components that interact in relatively simple ways; however, simultaneously, at another level of analysis exhibit some sort of collective coherent system behaviour. Maguire et al. (2006) provides a definition on describing complex systems as "a whole comprised of a large number of parts, each of which behaves according to some rule or force that relates it interactively to other parts". Maguire et al. (2006) goes on to say, "In responding in parallel to their own local contexts, the parts can, without explicit inter-part co-ordination or any one of them having a global view, cause the system as a whole to display emergent patterns at the global level – the emergence of orderly phenomena and properties of the whole that cannot be predicted from properties of parts", See Figure 1.4.

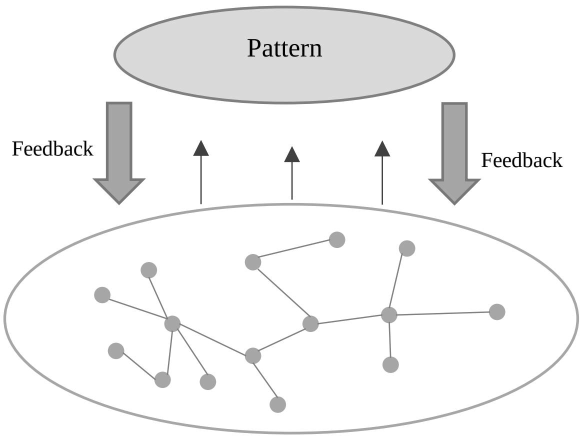


Figure 1.4: Demonstration of emergence within complex systems.

These types of environments are argued to dynamically evolve in non-linear ways (Katz, 2016). For example, whilst much of the physical world exhibit organisational structures where the properties of the whole are a simple aggregation of its parts (for example a swinging pendulum or Brownian motion in gas). Complex systems on the other hand – i.e. human societies - exhibit unpredictable features where any changes in the systems' configuration can have anything from a minor to a significant impact. A case in point is with strengthening the aggressiveness of a specific policy within a marketplace. This can cause little or no effect, or it might lead to a market collapse. Consequently, it is extremely difficult to make exact predictions into their future development. This is because the environment is constantly changing through the transmission of knowledge and materials between people, which in turn influences their behaviour in the future. The result is that it becomes impossible to analyse emergent patterns of behaviour by studying the individuals in isolation (Gilbert, 2008)

However, the reconstruction of the multi-level dynamics of complex systems has presented a major challenge for scientific research in the past. This is because the measuring of these types of systems have been limited by mathematical tractability, but over time these research methods are becoming more accessible due to the increasing power of computers (Bourgine and Johnson, 2006). According to the OECD (2009b) this has accelerated research into this discipline, enabling scientists to create large numbers of virtual system components and set them to interact with each other in simulated worlds. As by varying parameters of these simulations, researchers can explore the spectrum of collective behaviours, validate existing models, and compare the virtual systems with their real-world counterparts (OECD, 2009). One such method to analyse these types of environments is known as ABM - a relatively new approach to modelling complex problems (Macal and North, 2009). It is a type of computation modelling technique for simulating a conglomerate of decision-making entities and behaviour rules within a shared environment (Schilloa et al., 2000), which through an analysis of the interactions of agents it can provide valuable information about the dynamics of the real-world system being emulated.

1.5 Agent-Based Modelling: A computational approach

ABM is a form of computational simulation that is growing in its use across a variety of disciplines (North and Macal, 2005). It is an artificial system based on a collection of autonomous decision-making entities called agents existing between space and time (Holland and Miller, 1991). These agents can be identical of endowed with unique attributes (Bankes, 2002). Each agent makes decisions based on a set of pre-determined rules. In addition, they are often characterised by bounded rationality and are able to learn, adapt and reproduce (Bonabeau, 2002). These models also place special emphasis on the interactions with other agents in order to assess their effects on the system as a whole. In this context, a main feature of the ABMs is the repetitive competitive interactions between the agents that evolve over time. The aggregation of these individual behaviours produces system level outcomes (Epstein and Axtell, 1996; Axelrod, 1997), thus constituting a "bottom-up" complex system (Richards, 2000; Epstein, 2007), See Figure 1.5.

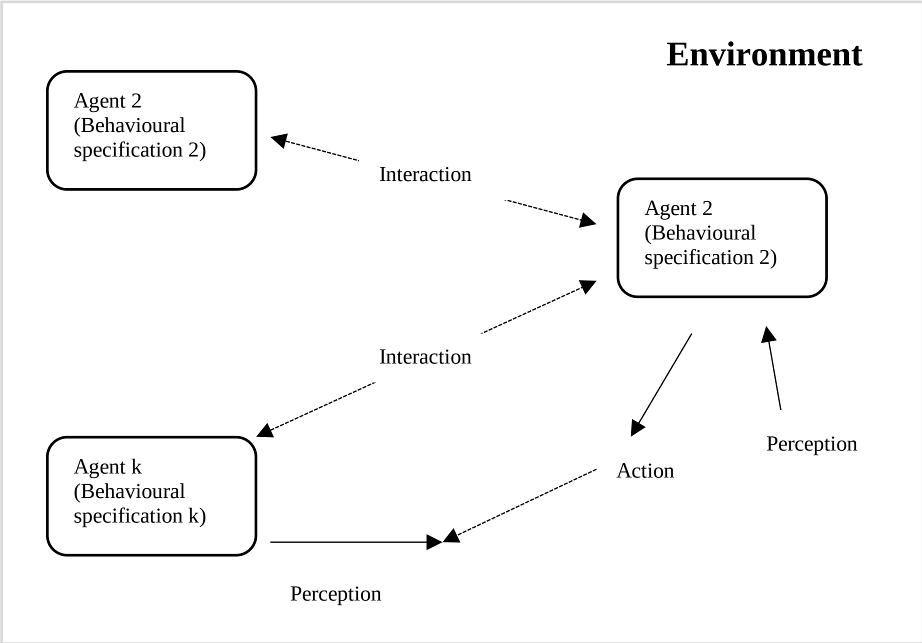


Figure 1.5: A simple illustration of the interaction processes between agents and their environment (Bandini et al., 2009).

The term "agent" is generally said to be a model component that can make independent decisions and change its behaviour in response to its experiences (Bonabeau, 2002). This is supported by Wooldridge and Jennings (1995) that illustrated several primary characteristics: (i) *Autonomous*: where agents operate without the direct intervention of others and has some kind of control over its actions and internal state; (ii) *Social*: the agent can interact with other agents using agent-communication language; (iii) *Reactive*: it perceives its environment and responds to changes that occur in it; (iv) *Proactive*: in that the agent is able to exhibit goal-directed behaviour. Therefore, it is considered to be an autonomous part of an environment, which senses it and then reacts upon it, over time, in pursuit of its own agenda, which effects what it senses in the future (Franklin and Graesser, 1997).

The environment in which these agents' interact is said to be a virtual space. This may be an entirely neutral medium with little or no effect on the agents (Gilbert, 2008), or it can fundamentally change the way the system behaves (Tesfatsion 2002, Laughlin 2005, Schelling 2006). Typically, ABMs tend to operate within a space that forms some sort of physical feature, such as a city, region or country (Cederman, 1997). Alternatively, it can be something more abstract like a knowledge space representing technological progress (Brabazon et al., 2012; Desmarhelier et al., 2013). In addition, it is possible to have no spatial representation at all but link the agents through a network. Agents' relationships are thus determined by how they are linked to one another (Scott, 2000). Various network structures in this context can be applied. These range from random or fully connected networks to small-world or scale-free topologies, to 1 or 2-dimensional lattices (Watts and Strogatz 1998, Strogatz 2001, Watts, 1999), See Figure 1.6.

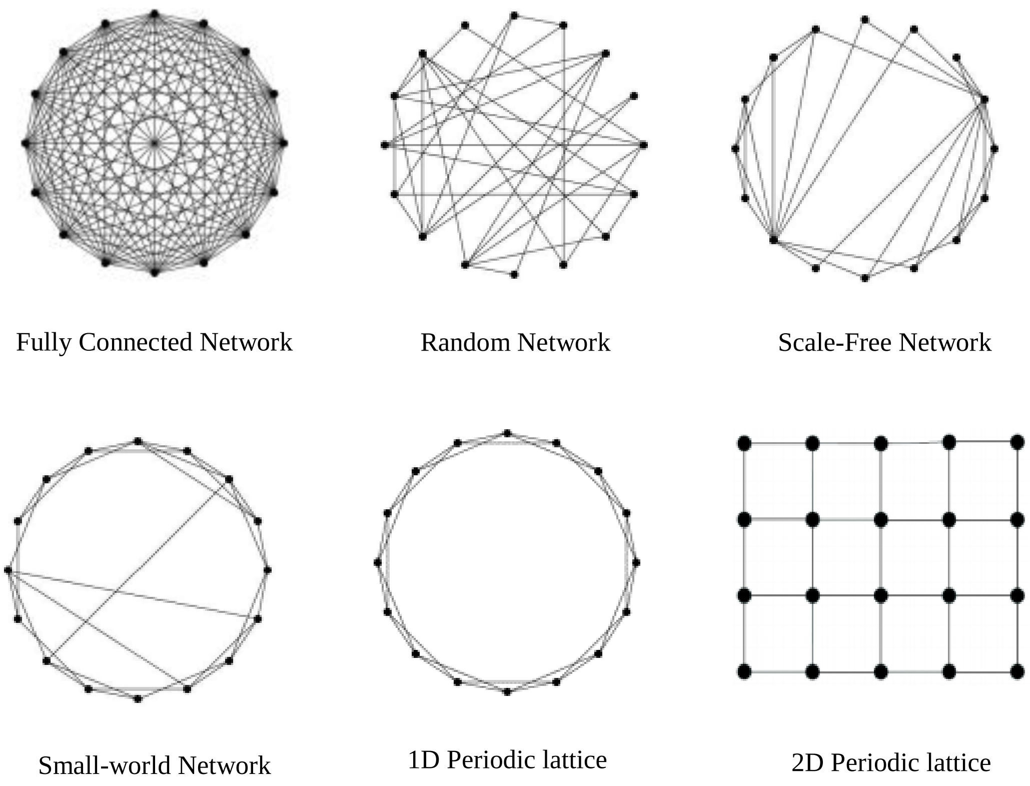


Figure 1.6: Example of various network topologies.

These agents' then interact within their environment over time. These mechanisms either involve the direct exchange of information between agents or an indirect relationship. This is realised based on the agents' perception as to the effects of another agent or a group of agents' action (Bandini et al., 2009). Various decision-making methodologies can be applied within this context. These range from simple thresholds to more complex algorithms. After agents have interacted with one another, the agent's record this information to inform their decisions and future behaviour. Therefore, through these interactions – direct or indirect – this gives rise to overall group behaviour over time. The benefits of this is that the collective behaviour can be very different from the behaviour of the individual agents. In some instances, this can even be highly unintuitive and difficult to explain (Langton 1990, Wolfram 2002, Laughlin 2005, Schelling 2006).

Therefore, ABM is seen to be a powerful simulation methodology that seems suitable to capture the complex dynamics within a system. According to Bonabeau (2002) there are three main benefits of this approach over other modelling techniques. These are: (i) it is possible to capture emergent phenomena. This emergent phenomenon can have properties that are decoupled from the properties of the single entities; (ii) it provides a natural description of a system. For example, the system can be composed of behavioural entities, which are arguably the most natural and closest match to reality (iii) they are flexible. This flexibility comes in different dimensions, such as more agents can be included; similarly, their behaviour, degree of rationality, ability to learn and evolve can also be modified. Due to these benefits, ABM applications have been growing across a variety of domains. These range from logistical optimisation (Weyns et al., 2006) to biological systems (Bandini et al., 2006), to modelling the engagement of forces on the battlefield (Moffat e al, 2006) or at sea (Hill et al 2006). Similarly, this growth has also been apparent within the social sciences (Gilbert, 2008). Applications in this context, vary from sociology (Bianchi and Squazzoni, 2015), to economics (Naciri and Tkiouat, 2016), and organisation theory (Miller, 2015) to political science (Marchi and Page, 2014).

The reason for this uptake in the social sciences is arguably due to the ability of being able to model highly heterogeneous populations, where agents have different characteristics and behaviour. This is said to enhance the potential for creating an artificial society that allows the growth of endogenous social structures (Lansing, 2002). For example, one of the first published ABMs in the social sciences was Schelling's Model of Segregation (Schelling 1969). The purpose was to try to explain why racial segregation was so difficult for policy-makers to combat. This was achieved by creating a system populated by households that belong to one of two types of racial groups. A global parameter dictated the preferential percentage of the same group that each household wanted to live next to. Therefore, households were able to move to an empty cell if they were uncomfortable living near many people of the opposite racial type. The findings found that even with a relatively low preference for the same racial type, the environment can become highly segregated, See Figure 1.7.

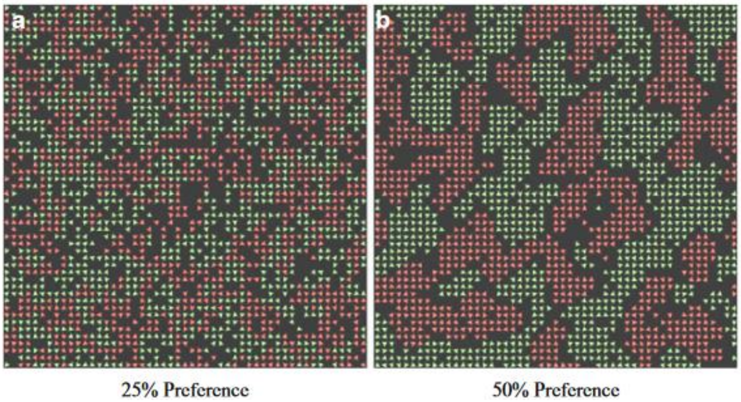


Figure 1.7: An example of an ABM of segregation based on work by Schelling (1969). Figures show the percentage of similar racial type that each household wants to live next too.

As demonstrated by Figure 1.7, when the preference rating of wanting to live next to someone of the same racial group is only 50%, the system led to clear segregation. Therefore, it provided interesting insights into the dynamics of human racial segregation where clear distinctive patterns of spatial segregation emerge even if individuals are only weakly segregationist.

Another popular model was introduced by Epstein and Axtell (1966), known widely as the Sugarscape model. This aimed to study the emergence of complicated social structures that emerge through society. Similar to Schelling's model, agents move on a lattice and follow simple rules. The environment originally provided sugar – a resource that the agents need to consume in order to survive. Thus agent's search for this resource within its local environment, eat and consume it. Based on each agents' random metabolic rate these agents will die if they run out of it. Similarly, they are also endowed with various levels of vision. Once the simulation is run the interaction of these agents leads to an interesting pattern of migration.

This is where the surviving agents move towards the richest zones of the landscape, in order to ensure the survival of the population, See Figure 1.8.

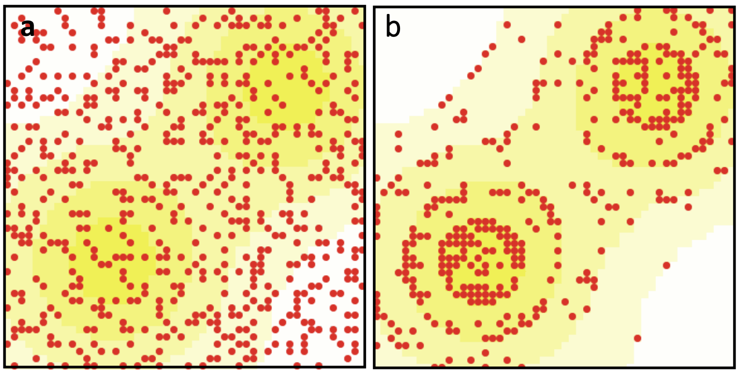


Figure 1.8: Agents of the Sugarscape model at the beginning of the simulation and after 50 time-steps.

Therefore, this model demonstrates interesting insights into the prevalence of inequality as an emergent characteristic of many economies, even very simple ones (Epstein and Axtell, 1966). It has since been adapted towards a variety of different scenarios i.e. wealth distribution, disease propagation and sexual reproduction. Consequently, by extending the complex behaviour within the model it is able to explain and be used as a tool to address many social challenges. Hence, ABMs are seen as not only being able to demonstrate useful collective phenomena emerged from the local interaction of autonomous and heterogeneous agents, but it is also possible to extend the analysis to gain greater depths of knowledge regarding the inherent forces that drive a system and what influences the characteristics of it. In this context, these models can be seen as a useful computational laboratory (Twomey and Cadman, 2002), where a variety of artificial scenarios can be explored to assist and guide decision-making (Hanusch and Pyka, 2007).

In this context, ABM is seen as a useful method for policy assessment. This is because despite conventional research methods used in traditional policy analysis (eg. statistical analysis, economic models and linear programming) being useful for identifying relevant factors and patterns at a certain point in time in a given context (Ferro et al., 2010). Policy-makers need substantial knowledge through a variety of other methods in order to aid decision-making. A case in point is with the BASS technological diffusion model. This is an aggregate model that provides an empirical generalisation based on differential equation formulation to explain how new products spread throughout society (Zhang and Vorbeychik, 2016). However, despite being useful for describing the process by which this happens, they do not explicitly model agents at the micro level. These aggregate models are thus constrained to a set of theoretical issues. For example, one cannot ask “what if” type questions for probing alternative scenarios and policy-instruments to see what effect they have on the innovation process (Ferro et al., 2010).

Consequently, ABMs are seen to overcome these limitations due to their flexibility for measuring a variety of policy-settings. From this perspective, they can be used to accelerate creation of scenarios, allow rapid changes in parameters, and provide a test bed for concepts and strategies (Hermawan et al., 2017). In turn, they can provide invaluable insights into the dynamics of the system. This is because in the context of the BASS model, the atomic level is not the social system as a whole but rather individual consumers and organisations, each with differing behaviours where their interactions can be modelled with multiple and constant interactions between the spheres of research, innovation, production, diffusion and consumption (Schwarz and Ernst, 2009). Consequently, within each part of this process lies the opportunity for regulation to try to shape those dynamics towards preferred objectives for society. Considering this, the next section aims to expand on these issues, but in the context of its relevance based on the authors’ position on innovation in society. This is achieved by discussing the theoretical and methodological justifications for why the ABM approach was implemented and its suitability as a policy tool.

2 Theoretical and Methodological Justifications

Innovation is an emergent property of a complex socioeconomic system where agents – such as people, enterprises and institutions – interact within a market mechanism and through these repeated interactions it gives rise to something new. This process of innovation continually disrupts the modus operandi, thus allowing the system to evolve over time. In this context, innovation is not seen as an end in itself, but rather a means for achieving constant transformation. This heterodox perspective has arisen largely due to the wariness regarding the limitations of classical economics. As in the past complex phenomena has been broken up into simple components and analysed through linear mathematical models and equations. Human behaviour has thus been comparable to the physical laws of motion, where it is viewed as both regular, predictable and largely deterministic. However, the search for unchanging truths, as in Physics, is not seen as appropriate for studying social phenomena as complex as innovation (Fagerberg et al., 2013). Therefore, whilst this reductionist position might have been acceptable back when economic and social structures were simpler. In todays globalised and interconnected world it is increasingly unsuitable. This is because the world is incommensurably more complex with many new actors and dynamics; and so, applying methods used in traditional policy analysis are likely to fail when applied to environments that are counterintuitive, non-linear and irreversible (Arndt, 2006).

This calls for new methods and approaches to challenge the orthodox position from mainstream economics and design new ways for measuring innovation and the various structures and processes that drive it. Innovation studies is arguably in a strong position to respond to these challenges. However, whilst an array of heterodox approaches have emerged – such as the system of innovation concept and evolutionary economics - that aim to offer richer theories for understanding the uncertainties of the real economy and it's diversified functioning – much more needs to be done. This is because applying philosophies that fail to provide sufficient understanding into the dynamics of complex socioeconomic systems could lead to disastrous consequences for our society. For example, due to the unpredictable features exhibited within these types of environments, any policy change within the systems' configuration can have anything from a minor or insignificant impact to something major like a market collapse. Therefore, new theoretical and methodological approaches should not be carved in stone but rather evolve because of changes in society and our attempts to understand them. Therefore, the author looks towards Complexity Science. This is said to challenge the reductionist position that is at the heart of conventional science (Morin, 2006; Marion, 1999). It is the scientific study of complex systems, which are environments composed of many parts that interact to produce global behaviours that cannot be easily understood in terms of the interactions between their constitutional elements (Wolfram, 2002; Laughlin, 2005). These systems, therefore, exhibit so-called "emergent properties" that are difficult to describe from the underlying rules of the system (Rickles et al., 2007).

Problematically, in the past the reconstruction of capturing the multi-level dynamics of complex systems has been out of reach from scientific investigation. However, major advances in computational technologies have catalysed complexity research, enabling scientists to create large numbers of virtual system components and set them to interact with each other in simulated worlds (OECD, 2009b). For example, System Dynamics (SD), Network Analysis (NA) and Agent-based modelling (ABM) have all emerged as a method for identifying the complex mechanisms of what drives a system and the key characteristics of what influences it. However, whilst NA and ABM are suitable for describing how individual actors in a system interact with one another when compared to SD. NA is often constrained by its ability to model the dynamic processes of agents within multiple levels of analysis (Luke and Stamatakis, 2013). SD on the other hand, despite suitable for capturing non-linear dynamics of complex systems, fails to represent the micro-level of interacting agents through space and time. This aggregated form of analysis is therefore limited to a set of theoretical issues. For example, one cannot ask "what if" type questions for probing alternative scenarios and policy-instruments to see what effect they have on the innovation process.

With this in mind, agent-based modelling was chosen. This is a computational methodology for simulating a collection of autonomous and heterogeneous agents.

Each agent individually assesses its situation and makes decisions based upon a given set of rules. Through these interactions, it can generate the emergence of coherent system behaviours. In this context, even simple ABMs can provide valuable insights into the dynamics of a real-world system that it aims to emulate. According to Bonabeau (2002), there are three main benefits of this approach over other modelling techniques. These are: (i) it is possible to capture emergent phenomena. This emergent phenomenon can have properties that are decoupled from the properties of the single entities; (ii) it provides a natural description of a system. For example, the system can be composed of behavioural entities, which are arguably the most natural and closest match to reality (iii) they are flexible. This flexibility comes in many dimensions, such as the amount of agents and their degree of rationality; similarly, how they learn and evolve can also be tuned. In this context, it theoretically enables one to construct a socioeconomic system where agents can interact within an artificial environment. In turn, this provides a useful computational laboratory (Twomey and Cadman, 2002), where different policy-instruments can be integrated to explore a variety of different scenarios to assist and guide decision-making (Hanusch and Pyka, 2007).

Overall, the continuing existence of incorporating new disciplines and constantly developing and conglomerating knowledge allows society to respond to the challenges presented by the 21st Century. Therefore, by reaching out to different disciplines that deal with issues of common interest the author hopes to advance knowledge by merging disciplines to solve a unique problem. This is achieved by embracing two schools of thought to enhance ones understanding into how regulation impacts innovation and address issues that might not have been possible had it not been addressed in this way. The next section highlights how the interdisciplinary approach is implemented. Similarly, the relevant scope and contributions of each study, before highlighting the structure of the thesis at the end.

2.1 Research Summary

The thesis is organised around the idea of how regulation can be used to impact innovation through an interdisciplinary perspective. This is because understanding this relationship could be considered beyond the scope of a single discipline or area of research practice. Therefore, one needs to avoid falling prey to disciplinary sclerosis and instead respond to the new challenges encountered by decision makers within government (Fagerberg and Martin, 2013). The interdisciplinary approach thus enables the author to synthesise "information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialised knowledge" (National Academies of Science, 2005). Hence, Paper one aims to scope out the domain area into how regulation impacts innovation. This is achieved by identifying gaps, themes, relationships and deficiencies within the research stream. The second paper will then look towards ABM - a method often used to measure complex systems - as a suitable approach to answer some of these issues. The findings are subsequently converged to frame the final paper, which measures the aggressiveness of a variety of policy-instruments and how they shape system dynamics using this methodological approach. Considering this, the next section aims to illustrate the scope and contributions of each study, before highlighting the structure of the thesis to provide a greater understanding into how they relate to each other for when the thesis is interpreted as a whole.

2.2 Scope and Contributions

The primary aim of the research in this thesis is to analyse the relationship between regulation and innovation. Similarly, the various processes and structures that drives it. This is an extremely important topic as policy-makers need sufficient and reliable knowledge to inform policy and practice towards better outcomes for society (Fagerberg et al., 2013). Currently, there are very few studies review this literature in a rigorous and systematic manner. Hence, one knows a lot about the variety of regulations applied in the analysis, but very little is understood regarding the type of innovation that is involved (See Blind 2012a; Stewart 2010; Pelkmans and Renda, 2014). With this in mind, the first paper aims to scope out the domain through a systematic review. Therefore, contributing towards the ongoing development into our understanding of how regulation can influence innovation. This is argued to be extremely important for policy making as a particular type of regulation that effects one type of innovation may have the converse effect on another. Similarly, other observations may emerge when comparing this relationship against different sectors, methodologies or the level of analysis. Therefore, the scope of the study was broadened to consider these factors over a period of twenty-five years. From the synthesis of the relevant material, several frameworks were developed to provide a holistic understanding into the domain. By doing so, the research aims to contribute towards theory development by highlighting the major debates and issues around key subject areas (Tranfield et al., 2003). Similarly, the author also provides theoretical insights to guide scholars on how to advance the research field.

The second manuscript then looks towards ABM as a policy tool to unpack the issues raised by the first manuscript. This is achieved by systematically reviewing papers that analysed a variety of policy-instruments to see how they shaped the dynamics of socioeconomic systems. Of note, it is not within the scope of the study to consider other methods used to capture this complexity. Similarly, studies were also restricted to ones that explicitly looked at policy within these types of environments. In this context, whilst previous reviews have addressed related aspects of this research field, none, to the authors' knowledge, have put regulation at the forefront of their analysis with emphasis on how they were developed (See Kiesling et al. 2013; Zhang and Vorbeychikk; Zsifovits, 2013). This study, therefore, aims to facilitate this gap by deviating from the first manuscript to concentrate more on the design specifications of the ABMs to see how they were constructed and whether it is suitable as a policy tool. In turn, this provides a useful and informative guide for scholars and modelling practitioners into how to design socioeconomic systems for policy evaluation. Similarly, it provides insights into the long-term causalities of future policy integration, thus arguably overcoming the limitations with conventional research methods used in traditional policy analysis (Ferro et al., 2010).

The final paper then aims to merge the theoretical perspectives from papers one and two. The purpose of this study is to build an ABM that facilitates the gap of analysing the stringency of two policy instruments. One is targeted towards the inventor (i.e. through rewarding invention), whereas the other looks at penalising the imitator (i.e. penalising imitation). Previous research around this topic has focused mainly on the demand side of the market-mechanism, where innovation is often assumed to have its own market potential. Whilst this may be reasonable in some cases, more often than not firms face intense competition from other products or new ones released into the market. With this in mind, the ABM was constructed to concentrate more on the supply-side of the innovation process where competition dynamics has been largely overlooked within the agent-based literature (See Eppstein et al. 2011; Zhang and Nuttell 2011; Cantona and Silverberg, 2009). Therefore, by facilitating this gap this methodological innovation aims to provide policy-makers and analysts with a useful and informative tool to aid decision making that can be adapted to understand a variety of policy issues and concerns. Similarly, from a research perspective this model has plenty of opportunities to advance our theoretical understanding into various research streams, such as extending the model towards different sectors and technological specific areas. Finally, the analyses of the aforementioned policy-instruments also contributes to our theoretical understanding into some of the complex issues and debates raised in the first manuscript.

This section has highlighted the scope and contributions of the thesis. The next part aims to expand on what has been discussed and provide a greater explanation into the structure of the thesis and why the aforementioned studies were chosen. Whilst each manuscript is presented with its own abstract. The author will discuss the papers with more emphasis on their commonalities and how they relate to each other for when this body of literature is interpreted as a whole. Therefore, despite these papers providing extensive theoretical and domain insights. For the purpose of structuring the thesis only the relevant objectives and findings will be discussed.

2.3 Structure of Thesis

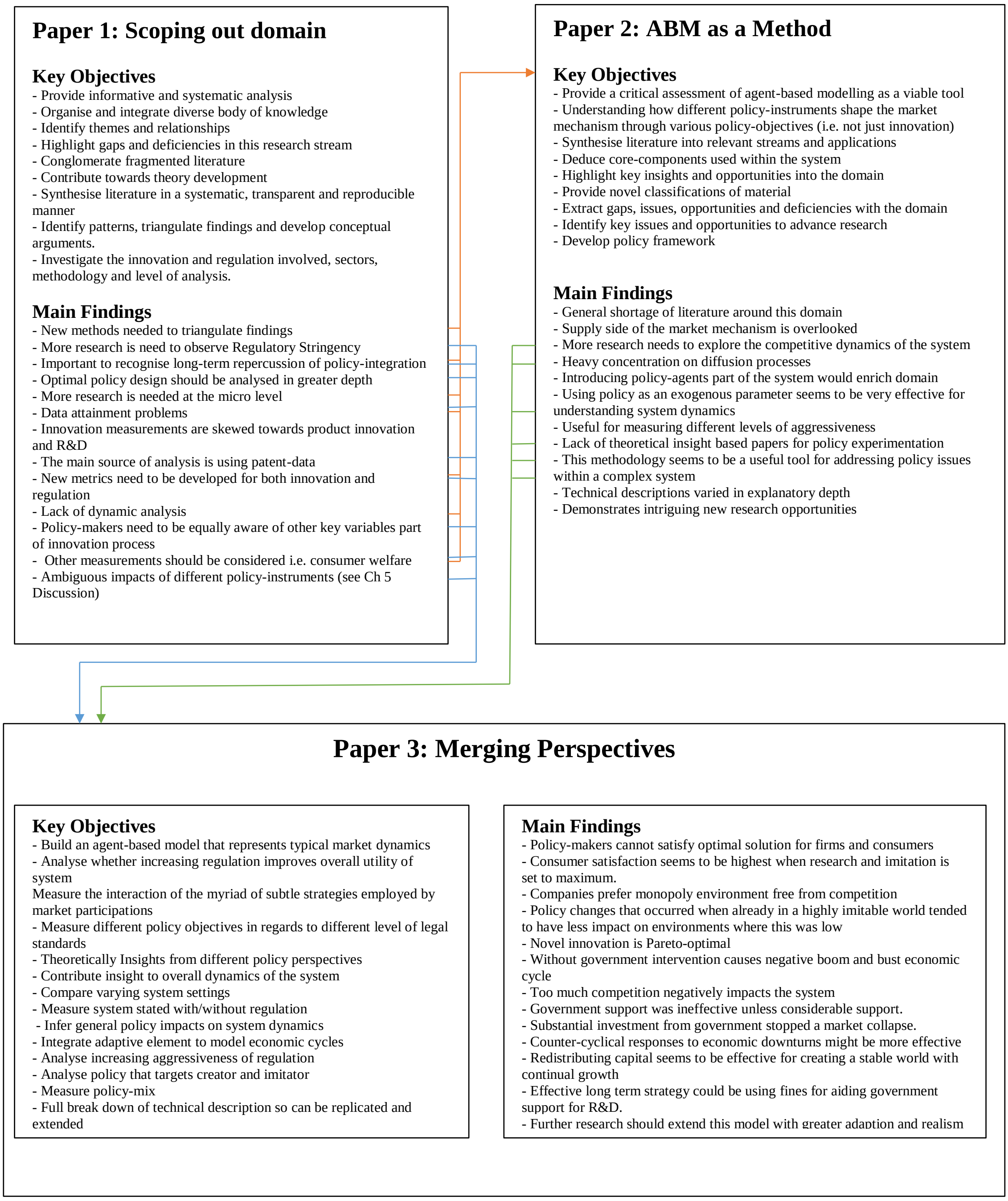


Figure 1.9: Structure of Three Paper Format.

2.4 Overview into the structure of the thesis

The first study analyses how different regulations have been used to impact different types of innovation. This is because the studies that analyse this relationship have contributed in parts to different pieces to the overall puzzle. Therefore, it was hard to construct a complete picture. Consequently, due to the fragmented view of the domain the author decided to conglomerate the studies to provide holistic insights into the research area. Therefore, the author aims to inform policy and practice through a systematic approach (Thorpe et al., 2005; Tranfield et al., 2003). This provided the boundary conditions for selection; for example, due to the general applicability of the domain it was considered important to have a stringent selection criterion. In this context, the material was analysed if the papers measured both: “innovation” and “regulation”. These studies were then categorised using a mixed-research synthesis. This is where the author integrated the results from both qualitative and quantitative studies (Sandelowski, 2006). The quantitative studies enabled to gain more reliable and objective explanations through descriptive and causal insight. Qualitative papers were then then able to provide greater explanation into the cause-and-effect relationships. Of note, a lot of studies implied policy as oppose to actually measuring it. Similarly, others studies analysed this relationship at different parts of the innovation process. Therefore, despite not being primary measures for our analysis, the authors discussed these briefly at the end.

Through the analysis of the synthesised material, the authors identified emergent themes and gaps to contribute towards theory development. The research found several interesting insights that helped framed the other two papers. For example, a theme emerged within the first paper called Regulatory Stringency, which was applied to different industries and sectors. This aims to measure the aggressiveness of different regulations and its impact on innovation output. However, due to the limited research around this subject there were ambiguities concerning the results. Similarly, a lot of the studies analysed this relationship using Patent data. Despite the obvious advantages of this being free and easily accessible, patents are an imperfect measure. This is because they tend to restrict studies to consider inventions only, as opposed to innovation. The reliance on this data was found to be because of data attainment problems. Therefore, it was argued that new methods and tools should be developed for measuring both regulation and innovation. Not only to triangulate findings, but due to the distribution of the analysed studies was skewed towards Product Innovation and Research and Development. In addition, it was also found that understanding optimal policy design would greatly enrich this domain at all stages of the innovation process. Not just when measuring innovation but other policy-objectives such as, growth, system stability and consumer welfare.

From this analysis, the author looked towards Complexity Science to help unpack the issues raised by the first manuscript. In particular, the author analysed ABM to see if it is a viable method for measuring this relationship. The author synthesised the ABM literature around this area in order to provide insights into how different policy-instruments can be used to help shape the market mechanism through various policy-objectives. Therefore, this deviated from the first manuscript to concentrate more on the design specifications of the ABMs to evaluate how they were constructed and whether it is suitable as a policy tool. Interestingly, only recently was there sufficient literature for viable synthesis on this subject. Therefore, this could be an explanation as to why no other reviews have yet addressed this gap.

The synthesised literature was broken up into relevant streams and applications. It was found that there was a lack of conceptual models that provided generic theoretical insights. This was because the majority of the literature was skewed towards providing policy forecasts targeted towards a specific domain. Furthermore, the author compared and contrasted the various design specifications of the models. This was to deduce the core-components and their relationships within the system design. The author found that there was a heavy concentration of research on agent-based diffusion models. Therefore, the supply-side of the market mechanism was often overlooked. In particular, understanding the competitive dynamics of the system. Similarly, these features of the design specifications were then used as a basis to analyse how different policy-instruments shaped those dynamics. It emerged that ABM seems to be an effective tool for understanding policy integration at all stages of the innovation process. In particularly, Regulatory Stringency as identified by manuscript one. This is because it is possible to measure different levels of aggressiveness through an exogenous parameter that can be applied at all stages of the innovation process.

Taking into considerations the contributions of both papers one and two. The authors converge these findings into a new study, which is framed as the Regulatory Dilemma. The purpose of this study is to build an ABM that facilitates the gap of analysing the stringency of two policy instruments that target towards both the inventor (i.e. through rewarding invention) and the imitator (i.e. penalising imitation). Similarly, by building upon existing agent-based simulation techniques, this theoretically derived model aims to represent typical market dynamics. However, it has a particular emphasis towards the supply-side of the market mechanism where the competitive dynamics within the innovation process can be observed.

The first part of the analysis measured different artificial environments based on fixed research and imitation strategies. This was to identify in which theoretical 'worlds' companies and consumers prefer to live. An adaptive element was then introduced in the absence of policy intervention to identify the system state(s) society would end up with. Regulation is then incorporated at different levels of aggressiveness to see if it can improve the system towards preferred policy-objectives. The findings gave interesting insights into the dynamics of the system. For example, when examining government support for R&D it seemed to be able to change the system from a market collapse. This implied that the current pro-cyclical approach adopted by most EU-27 member states in terms of financial crisis may not be the best long-term strategy. In summary, this approach helped us learn what to expect and what not to expect from these policy instruments. Thus, seems to prove to be a useful tool to transcend borders set by standard analytical models and open up promising avenues for future policy design.

Overall, this thesis provides an interdisciplinary perspective into understanding how different policy-instruments can shape the dynamics of the system at various stages of the innovation process. Through two systematic reviews, the author converges the findings to create and solve a novel problem that might have been overlooked had it not been by this approach. From this, there are many new opportunities to advance this research into various streams and contexts. The next section is the first manuscript of the thesis that will analyse the direct relationship between innovation and regulation.

Chapter 2

How Does Regulation Impact Innovation? A Systematic Review

Abstract

This paper is an intended contribution towards the ongoing evolution of how different regulations can impact different types of innovation. The author organises and integrates a diverse body of empirical literature to enrich our understanding around this domain. So far, this research area has been examined from different angles that have all contributed towards different pieces to the overall puzzle. However, due to the fragmented depiction of the domain it is hard to construct a complete picture. Therefore, the author aims to provide a holistic understanding of this research area. This is extremely important as a particular type of regulation that effects one type of innovation may have the converse effect on another. Similar phenomena could also be observed when analysing the scientific method of enquiry or the unit of observation. Consequently, as this area of the research remains opaque, the author aims to address this gap. This is achieved by synthesising the literature in order to identify themes and relationships to highlight the gaps and deficiencies in this research stream, before suggesting future research directions. From the analysis, the author concludes that regulation does impact innovation. However, the views are mixed as to the consequential impacts. Similarly, it is found that among the quantitative papers - due to data attainability problems - many papers have skewed their analysis towards product innovation and R&D; subsequently, sectors such as services have been neglected. In addition, among the qualitative papers there are very few empirical

investigations. This is somewhat surprising considering the complexity involved when analysing the relationship between regulation and innovation. Finally, it is argued that in order to develop this research area further new metrics need to be developed to study both regulation and innovation.

1 Introduction

Innovation is often seen as the critical dimension of economic change (Schumpeter, 1942; Arrow, 1962; Uzawa 1965). It is arguably the conversion of knowledge and ideas into a benefit for the economy and society. This may be a new or improved product, process or service released into the marketplace. It can be seen as a dynamic process where actors are all interlinked within a complex innovation system (Freeman, 1987; Lundvall, 1992; Nelson, 1992). Policy-makers within this context may try to oversee this process and regulate the behaviour of actors within the system (OECD, 1997). Government intervention, therefore, can often play a pivotal role in influencing the innovation activities of individuals, industries and whole economies (Blind, 2012a). Thus, understanding how the breadth and type of regulation will impact different types of innovation can be essential for long-term economic stability and growth.

The topic of how regulation impacts innovation has been examined from different angles. For example, there are policy papers that look at government involvement in stimulating research and development (R&D) (Gonzalez and Pazo, 2008; Almus and Czarnitzki, 2003; Hud and Hussinger, 2014). Similarly, there are policy papers that look at regulation and the impact it has on producing sustainable technologies (Dyerson and Pilkington; Nameroff et al., 2004; Pickman, 1998). In addition, there are studies that look at protecting innovation from imitation (Abrams, 2009; Thompson and Rushing, 1996; Varsakelis, 2001). However, despite these papers contributing different pieces to the overall puzzle, it is hard to construct a complete picture as to how regulation can be used to impact innovation. This is because introducing or changing innovation-related policies is dependent on a variety of interconnected factors that can cause unintended impacts on the type of innovation. This makes anticipating and predicting the effects of policy integration extremely problematic.

Consequently, when informing policy and practice, it is useful to provide a holistic understanding of this research area.

Currently, very few papers review the literature in a rigorous and systematic manner. Blind (2012a) carried out a comprehensive review on how regulation affects innovation with regulation and sectors as the focal point for discussion. The literature was classified based on policies that affected market conditions, the safety and soundness of institutions, and social welfare and the environment. This was similar to Stewart's (2010) multi-industry review that considered the impact of different regimes on innovation in the private sector within the United States. Stewart (2010) categorised policies in a similar manner to Blind (2012a), although innovation was categorised based on how it had an impact on market dynamics, such as generating new markets or improving existing ones through spurring incremental improvements. Stewart (2010) found that policies that are flexible or increase information exchange tended to induce innovation.

This was supported by Pelkmans and Renda (2014) review on how regulation impacted innovation within the European Union. These authors found that regulation that is more restrictive hampers innovation, whereas policies that are more flexible are better for stimulating innovation. Similarly, the lower the compliance and red tape burdens the greater the positive effect. However, Stewart (2010) also argued that gradual changes to regulation resulted in more incremental improvements to existing technologies. In comparison to Blind (2012a), Stewart (2010) also deduced that regulations such as market entry and antitrust policies that aim to change the underpinning dynamics of an existing market have a negative effect on innovation, whereas Blind (2012a) found results that are more ambivalent. Both agreed, however, that regulation targeted towards enhancing social welfare spurred more environmental products.

Ambec et al. (2013) who reviewed environmental regulation between the years 1991 and 2011 support these conclusions. This was achieved by analysing conflicting evidence and alternative theories on the impact of environmental regulation on innovation. They found that environmental regulation seems to induce innovation;

however, the empirical evidence as to whether this enhances firms' performance is mixed, with more recent studies providing more supportive results. This was similar to Gonzales' (2009) environmental review in which the author looked at key determinants of technological change. Despite regulation being looked at in part with other explanatory variables, Gonzales found that at least in the long run (supported by Blind , 2012a), environmental regulation has a positive impact on innovation both in terms of performance and innovation output.

Although these reviews provide valuable overviews of the domain area, the studies seem to have skewed their analysis towards the regulatory side. Hence, one understands much about the variety of regulations applied in the analysis, but very little is understood about the type of innovation that is involved. Therefore, it could be argued that a particular type of regulation that affects one type of innovation may have the converse effect on another. Additionally, similar phenomena could be observed when analysing the scientific method of enquiry or the unit of observation. Consequently, as this area of the research remains opaque the author aims to address this gap through the investigation of the innovation and regulation involved, sectors, methodology and its subsequent level of analysis. This is then synthesised and scrutinised in order to identify themes and relationships around this domain.

The purpose of this paper is to provide a rich and in-depth analysis of how regulation impacts innovation. It is achieved by systematically investigating 55 key studies, with an additional 60 papers selected outside of our primary enquiry method. The literature is then analysed and the author identifies patterns, triangulate findings and develop conceptual arguments. Furthermore, the author also highlights the gaps and deficiencies in this research stream and suggest future research directions. In doing so, aim to complement existing reviews by overcoming the limitations of previous studies. This is based on a systematic framework (Fink, 1998, Thorpe et al., 2005 and Tranfield et al., 2003) and is arguably a different methodological approach to the reviews within this domain. This is because the author aims to synthesise existing research in a systematic, transparent and reproducible manner (Tranfield et al., 2003). Due to the knowledge being systematically managed, this paper also aims to provide adequate evidence to inform policy and practice (Thorpe et al., 2005; Tranfield et al., 2003).

The rest of the paper is organised as follows. The next section explains the methodology used to conduct the literature review, including the selection criteria and boundaries of this review. The literature is then broken up by methodology, with additional papers analysed at the end. The analysis is then all merged together where the author discusses the research findings before concluding.

2 Methodology

The aim of the review is to structure the research field on how regulation impacts innovation. The purpose is to identify emergent themes and illustrate the most important gaps, thus contributing towards theory development (Tranfield et al., 2003). A mixed-research synthesis is adopted where the author integrates the results from both qualitative and quantitative studies in a shared domain of empirical research (Sandelowski, 2006). The purpose is to enrich ones understanding of the domain. This is because papers have looked at different parts of the research area.

The DelphiS database was chosen as the key resource for the review as it contains a comprehensive range of databases relevant to management and economics; for example, key journal sources such as Web of Science Core Collection, Scopus, EconLit, Emerald, JSTOR and ScienceDirect. Papers were then identified using the search terms shown in Table 2.1.

Search Term 1 AND	Search Term 2 AND	Search Term 3
Regulation OR Polic(y/ys/ies)	Impacts OR Shapes OR Influences	Innovation

Table 2.1: Search terms used for identifying papers using the DelphiS database.

The keywords provided the boundary conditions for this review. The first keyword was the regulatory parameter to find material that analysed government intervention. In this context, “policy” was included with “regulation” in the initial search. This was because they were sometimes used interchangeably within the literature. The second keyword selected was “innovation”. Given the plurality of meanings embedded in this term the author employed a general selection requirement that assessed whether it was examined based on the authors’ definition on innovation (See Introduction). Finally, as the purpose of the research was to analyse the relationship between “regulation” and “innovation” and how they impacted one another, comparative words were also included in the search. For example, terms such as “influence” and “shapes”. Each keyword cloud was searched using the “AND” Boolean expression, whereas the synonymous words of the keywords were searched using the “OR” Boolean expression. This enabled to conglomerate a rich source of material to answer the research objectives.

The initial search obtained 8,122 peer-reviewed papers. The search terms were subsequently restricted to just the title, keywords and abstract. This reduced the literature to 844 studies. Several other strategies were also employed within the selection process, such as back and forth citations (82 studies) and expert opinions regarding the domain (69 studies). The abstracts of these papers were then analysed based on the following selection criteria: (i) to what extent the paper addresses regulation (ii) to what extent the paper analyses innovation; and (iii) to what extent these variables were looked at together. Studies were then removed if they were considered irrelevant based on this criterion. This reduced the count to 103 studies. A further 12 policy papers were found to be relevant. Duplicates were taken out from the selection criteria. Overall, the search led to 115 studies (See Figure 2.1).

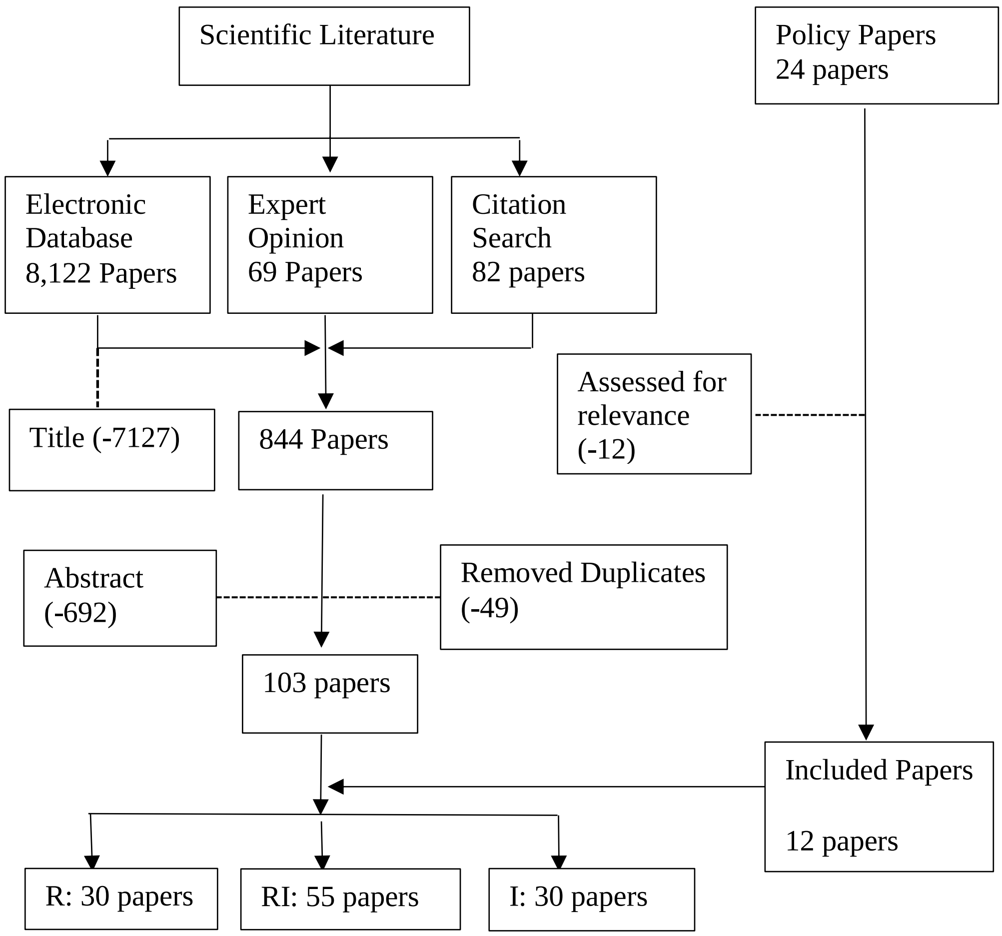


Figure 2.1: Breakdown of the literature search.

These studies were then classified by relevance to answering the research question. This was similar to Klewitz and Hansen's (2014) relevance criteria in which they grouped literature according to how applicable it was to their research field (See Table 2.2).

	Relevance	Regulation/Innovation	Amount
RI	High	Regulation and Innovation	55
R	Low	Regulation	30
I	Low	Innovation	30

Table 2.2: Relevance criteria for categorising papers.

The relevance of each paper was subsequently determined by our primary measures of 'innovation' and 'regulation'. Category I papers were ones that measured innovation but neglected the regulation side. For example, they were papers that implied looking at regulation as oppose to measuring it, such as increasing competition and its effect on innovation output. Similarly, Category R based papers focused specifically on the regulation side but from different parts of the innovation process, such as productivity or diffusion. Finally, Category RI papers analysed both innovation and regulation together. These were subsequently the focus for this review. Category R and I papers are briefly analysed at the end.

Description	Amount
Quantitative	31
>> Descriptive	10
>> Econometric	21
Qualitative	24
>> Discussion	21
>> Interviews	1
>> Case Studies	2

Table 2.3: Breakdown of the methods applied within the studies.

There were 31 quantitative studies and 24 qualitative papers. Of the quantitative studies, 21 were econometric, in comparison to 10 descriptive papers. There was surprisingly little empirical research among the qualitative papers, with the majority of studies focusing on critical discussion and framing conceptual arguments. The next section will highlight the findings of the research papers, categorised by methodology, where the author critically analyses the quantitative papers to gain a more reliable and objective explanation of the research area. The qualitative papers will then be analysed in order to provide a better explanation of the cause and effect relationships of how regulation impacts innovation. The final stage of the analysis will then analyse additional papers that were considered slightly outside the domain area.

3 Quantitative Research

Both descriptive and econometric studies were grouped by their regulation and innovation measurements. Regulation measurements were determined by identifying emergent themes within the papers, whereas innovation measurements were categorised based on the type of innovation that was used in the studies. The overall majority of the innovation measurements seemed to be skewed towards product innovation and research and development, as opposed to other types such as process, service and strategy innovation. This could be why the author found ‘innovation’ used as an all-encompassing definition of innovation among other reviews (See Figure 2.2).

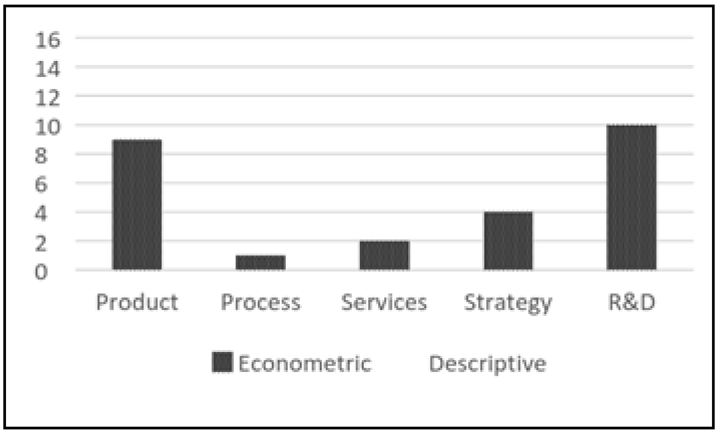


Figure 2.2: Relative distribution of innovation measurements; Y-axis = paper count; X-axis = type of innovation.

The innovation measurements were incorporated with the regulation themes (See Table 2.4). A total of seven were identified: *Environmental, Stringency, Protecting Invention, Safety, Government Support, Institutional and Uncertainty/Delays*. Table 2.4 below illustrates the relative distribution of the studies for scoping out the domain.

Regulatory Themes	**Products**		**Process**		**Services**		**Strategy**		**R&D**	
Environmental	*D(2);E(5)*	*7*	*D(0);E(0)*	*0*	*D(0);E(1)*	*1*	*D(0);E(1)*	*1*	*D(1);E(2)*	*3*
Stringency	*D(3);E(2)*	*5*	*D(0);E(1)*	*1*	*D(0);E(1)*	*1*	*D(0);E(2)*	*2*	*D(1);E(1)*	*2*
Protecting Invention	*D(4);E(3)*	*7*	*D(0);E(1)*	*1*	*D(0);E(0)*	*0*	*D(0);E(0)*	*0*	*D(1);E(2)*	*3*
Safety	*D(1);E(0)*	*1*	*D(0);E(0)*	*0*	*D(0);E(0)*	*0*	*D(0);E(0)*	*0*	*D(0);E(0)*	*0*
Government Support	*D(0);E(1)*	*1*	*D(0);E(0)*	*0*	*D(0);E(0)*	*0*	*D(0);E(0)*	*0*	*D(2);E(4)*	*6*
Institutional	*D(0);E(1)*	*1*	*D(0);E(0)*	*0*	*D(0);E(0)*	*0*	*D(0);E(1)*	*1*	*D(0);E(0)*	*0*
Uncertainty/Delays	*D(0);E(0)*	*0*	*D(0);E(0)*	*0*	*D(0);E(1)*	*1*	*D(0);E(0)*	*0*	*D(0);E(2)*	*2*

Table 2.4: Relative distribution of quantitative papers. D= Descriptive E=Econometric.

The first two themes analysed were centred on *Environmental Regulation* and *Regulatory Stringency*. The papers on *Environmental Regulation* covered pollution control such as reducing chemicals or undesirable materials; similarly, conservation management to maintain the health of eco-systems. *Regulatory Stringency* studies, however, focused on different levels of aggressiveness regarding the regulatory environment within a particular marketplace. For example, how strong the regulation is for encouraging new technological pathways toward sustainable technologies. The third theme was studies concerned with *Protecting Invention*. These studies mainly looked at intellectual property rights aimed at protecting inventors from individuals imitating their creations, such as literary and artistic work, designs, symbols, names and images used in commerce. Consequently, many of these papers were heavily focused on product innovation and R&D. The fourth identified theme was *Uncertainty/Delays*, which is largely concerned with the threat of new policies or delays to changes in new/existing ones. Interestingly, the main innovation measurements used to study this theme were strategy innovation and R&D. The fifth theme was *Government Support*. There were two main types of support for inducing innovation. These were direct and indirect financial assistance. Direct funding allocates money through grants and procurement whereas indirect support is through R&D tax incentives, such as deducting tax from R&D related activities. Direct subsidies tend to target specific projects with higher expected social returns, with the intention of raising the marginal rate of R&D (David et al., 2009). The final themes were *Safety Regulation*, *Institutional Regulation* and *Uncertainty/Regulatory Delays*. *Safety Regulation* is concerned with policies or rules that are put in place to ensure that something is safe and not dangerous for those that may consume it either directly or indirectly; for example, the huge uptake of drones poses a risk to the public and other aircraft. Therefore, there needs to be operating guidelines so as to reduce negative externalities. *Institutional Regulation*, on the other hand, involves policies that include the corporation, social networks and cultural rules. Private and public interests can sometimes take conflicting positions so policy makers must make regulation balanced to ensure efficient and fair allocation of resources. Finally, *Uncertainty/Regulatory Delays* highlight possible legislative enactments and subsequent introduction times for their integration.

3.1 Descriptive Studies Overview

The majority of the studies in this category were policy papers, which focused on Protecting Invention and Regulatory Stringency. In addition, the innovation measurements were all related to Product Innovation and R&D. In terms of the level of analysis, the studies tended to be analysed at the firm or regional level (See Table 2.5).

Theme	LOA	Innovation	Regulation	Author
Protecting Invention	Firm	Product	Intellectual Property	Bessen, 2011
Protecting Invention	Firm	Product	Intellectual Property	Haley and Haley, 2012
Regulatory Stringency/ Environmental Regulation	Firm	Product	Intellectual Property	Dyerson and Pilkington, 2006
Regulatory Stringency/ Environmental Regulation	Industrial/ Regional	Products/ R&D	Intellectual Property	Nameroff et al., 2004
Government Support for R&D	Regional	R&D	Tax Incentives/ Subsidies	OECD, 2010
Protecting Invention	Regional	R&D/Product	Intellectual Property	ICC, 2005
Government Support for R&D	Regional/Firm	R&D	Public Funded Research	National Audit Office, 2013
Regulatory Stringency/Standards Regulation	Firm/ Industry/ Regional	Product	Patents	Tuncak, 2009
Protecting Invention	Industry/ Individual	Product	Patents	Hunt and Bessen, 2004

Table 2.5: Descriptive statistics. LOA = level of analysis.

The majority of descriptive papers highlighted the fact that regulation impacts innovation, such as environmental regulation forcing technological change towards more sustainable innovations. Nameroff et al. (2004) highlighted the increasing trend of environmental regulation by analysing green chemistry patents. The authors identified that universities and the government sector seem to pay attention to green chemistry. Just as patent law changes proliferated the development of environmental technologies, one can witness a similar impact within India's pharmaceutical industry. For example, Haley and Haley (2012) compared both process-patent regimes and changes leading to newer product-process regimes. Furthermore, due to the regulatory reforms of strengthening and improving the product patent system, Indian pharmaceutical companies changed their decision-making processes by moving from process to product research. However, the authors highlighted that this might have hurt domestic innovation in the process, raising the notion of more research concerning optimal social returns regarding product-patent regimes (Haley and Haley, 2012).

Tuncak (2009), when looking at chemical laws, found that increasing regulatory stringency would help increase innovation of chemical patents and thus help to ensure a safer marketplace by ensuring that legitimately scrutinised products are released onto the market. This is supported by the ICC (2005), which found evidence to suggest that increasing protection would ultimately benefit society. This is because a system that protects the inventor is crucial for innovation. For example, within the pharmaceutical industry, the proliferation of counterfeit drugs (apart from the obvious risk to harming consumers) will mean legitimate companies have less revenue to reinvest to bring new products onto the market. In that sense, imitation of existing products is perceived as a negative drain on the economy as it is taking away money from innovators. This in turn reduces the incentive to invest in products. However, if regulation becomes too stringent and penalises an imitative company, it can also slow down the rate of technological diffusion. Bessen and Hunt (2004) highlight how litigation rates for penalising imitation have been increased and more than doubled during the 1990s. This, it is argued, poses a substantial risk to genuine innovators that try to improve on existing products as they may be fearful of the risks. Regarding the strength of the regulatory environment, Dyersen and Pilkington (2006) found that there is a significant need for market protection for disruptive innovation and that a limiting factor of success in regulation occurs when radical technology is demanded.

Finally, the descriptive studies also highlighted spurring innovation by rewarding invention through government support for R&D. According to OECD (2010), there are several rationales for supporting business R&D. For example, helping firms overcome the riskiness of investment that can stifle R&D, contributing to the overall national competitiveness whilst maintaining jobs, especially in times of crisis. Therefore, it is seen as crucial for the growth of economies in the long-term. This is supported by the National Audit Office (2013), which found that the total annual cost to government of providing R&D tax relief has increased from 89 million in 2000-2001 to 1.1 billion in 2010 and 2011. However, UK business spending on R&D is concentrated in a small number of very large firms, with 28 per cent of total UK business spending on undertaking R&D in 2011 occurring in the pharmaceutical sector. Additionally, no UK company is featured on the Thomas Reuters 2012 list of 'top 100 global innovators', despite spending around 0.16 per cent of GDP on combined direct and indirect funding.

3.2 Econometric Studies Overview

In the previous section, descriptive statistics helped to explain how regulation impacts innovation. However, they do not illustrate cause and effect relationships. For example, one can gain an understanding of the increase in government support for research and development but one does not understand how effective it is at stimulating innovation. Neither does it highlight whether this can have the converse effect over time. Therefore, it is important to understand this relationship through econometrics. This section aims to support the descriptive studies by analysing the relationships of 21 econometrics with 39 statistical correlations between the regulation and innovation measurements (See Table 2.6).

Regulatory Theme	**Innovation**	**Author**	**+/-**
Regulatory Stringency			
>>Heighten	Products	Blind, 2012b	+
	R&D/Strategy – Adaption with high R&D	Canin-De Francia, 2005	+
	Strategy – Adaption close to TechFrontier	Amable, et al., 2010	+
>> Reduce Regulation	Service – CEI Filings	Prieger, 2002	+
>> No Regulation	Service – CEI Filings	Prieger, 2002	+
>> Labour Market Regulation	Product/Process	Barbosa and Faria, 2011	-
>> Product Market Regulation	Product/Process	Barbosa and Faria, 2011	-
Environmental Regulation			
>> General	Products	Pickman, 1998	+
	Services	Ford et al., 2014	+
	Products	Ford et al.,, 2014	+
	Research and Development	Fernadez-Cornejo, 1998	+
>> Incremental	Products – Incremental	Fernadez-Cornejo, 1998	+
>> Novel	Products – Novel	Fernadez-Cornejo, 1998	-
	Products - Novel	Ford et al., 2014	+
>> Less Toxicity	Products – Less Toxicity	Fernadez-Cornejo, 1998	+
>> Foreign Regulation	Strategy	Popp, 2006	-
>> Domestic Regulation	Products	Popp, 2006	+
>>Force Tech Change	Products	Pickman, 1998	+
>> Short Term effects	R&D	Viscusi and Moore, 1993	+
>> Long Term effects	R&D	Viscusi and Moore, 1993	-
Protecting Invention			
>>TRIPS	Product	Abrams, 2009	+
	Product/Process	Barbosa and Faria, 2011	-
>> Tightening IP	R&D Infrastructure	Thompson and Rushing, 1996	+
	R&D	Varsakelis, 2001	+
	Product	Lerner, 2009	-
Government Support for R&D			
>> Crowding Out	R&D	Gonzalez and Pazo, 2008	-
>>Additionality	R&D	Almus and Czarnitzki, 2003	+
	R&D/Products	Czarnitzki and Licht, 2005	+
	R&D	Hud and Hussinger, 2014	+
>>Economic Downturn	R&D	Hud and Hussinger, 2014	+
Uncertainty/Delays			
>> Regulatory Delay	Service – CEI Filings	Prieger, 2002	-
>> Reducing Delay	R&D - Investment	Vernon et al., 2009	+
>> Increasing Delay	R&D - Investment	Vernon et al., 2009	-
>> Threats of New Regulation	R&D	Golec et al., 2010	-
Institutional Policy			
>> Pay-off incentives	Products – Patents	Baldini, 2010	+
>> Tolerating Failure	Strategy	Ederer and Manso, 2013	+
>> Threats of termination	Strategy	Ederer and Manso, 2013	-
>> Golden Parachutes	Strategy	Ederer and Manso, 2013	-

Table 2.6: Summary of the inferential statistics.

The peer-reviewed studies suggest that regulation influences innovation; however, the results are mixed as to whether it has an overall positive or negative effect. For example, Blind (2012b) found that increasing regulation stringency enhanced product innovation. However, Barbosa and Faria (2011), who studied product innovation, found significant negative results. This is supported by Prieger (2002) who also found a significant negative correlation when analysing service innovation of CEI filings.

In terms of heightening the aggressiveness of the regulatory environment, Canin-De Francia (2005) suggest that it positively influences firms' strategies. They found a positive correlation, with firms that have higher R&D budgets better at adapting to new regulations. Amable et al. (2009) supports this especially if firms are closer to the technological frontier.

Interestingly, the majority of literature on regulatory stringency seemed to suggest negative results, where innovation had a converse impact when tightening the aggressiveness of the regulatory environment. However, this was arguably because the literature focuses more on economic regulation, where regulatory compliance is often seen as a compliance burden. In terms of environmental regulation, however, the results are mainly positive. This is mainly to do with forcing innovators down certain technological trajectories, as opposed to enhancing innovation output per se. For example, Pickman (1998) found a significant positive relationship between environmental regulation and product innovation, where it forced firms to invest in sustainable developments; however, innovation output did not decline because of the change in regulation.

Furthermore, Ollinger and Fernadez-Cornejo (1998), at the industry level, found a significantly positive relationship when filing new pesticide registrations. However, they did not increase the number of innovations in the market; rather the ones that were introduced had less toxicity, with novel technologies having a significant negative affect. Ford et al. (2014), on the other hand, found the converse affect within the oil and gas sector. They found a significant relationship of novel technologies being introduced in response to new legislation, but a non-significant relationship of incremental innovation being introduced.

In terms of strategy innovation, Popp (2006), when analysing pollution control technologies, also found that increasing regulatory stringency resulted in more domestic environmental patents; however, firms did not respond to regulatory changes abroad. Similarly, it did not necessarily reduce innovation output overall. On the other hand, Viscusi and Moore (1993), who carried out a firm-level analysis, found that environmental regulation increased R&D spending in the short term; however, in the long-term this eventually decreased negatively.

Thompson and Rushing (1996) analysed the intellectual property system through a simultaneous equation model. Their study involved 55 developed and developing countries over three periods of five-year intervals. They found that intellectual property rights had a significant effect on growth in more advanced countries, whereas the effect was insignificant in developing ones. This was due to the R&D infrastructure, where firms were able to exploit the system to their advantage. Similarly, Varsakelis (2009) found a statistical significance in terms of the strength of the patent system, where stricter regulation results in more R&D investment. This is supported by Abrams (2009) who attempted to answer an empirical question regarding how to find the right balance between accessibility and the incentives to innovate. This was done through analysis of the TRIPS agreement, which is an international agreement pertaining to trade-related aspects of intellectual property administered by the World Trade Organisation which issues standards for many forms of intellectual property. Through the analysis, they found increased innovation was the response to the TRIPS legislation, where patent term extension with both patent counts and citation-weighted counts increased.

Notwithstanding, Barbosa and Faria (2011) raised doubts with respect to strengthening the intellectual property system as a means to stimulate innovation, as they found a negative association between intellectual property protection and innovation intensity at the industry level. This is supported by Lerner (2009), who found statistical evidence that patents have little impact on innovation, arguing that public efforts to support the funding of technological innovation have largely failed.

Another way to stimulate innovation is, rather than penalising imitation, to encourage innovation through government subsidies for research and development. Gonzalez and Pazo (2008) analysed the effects of public R&D support on private R&D investment within Spanish manufacturing firms. They found a statistical significance that indicated an absence of ‘crowding out’, either full or partial, between public and private spending. Significantly, they also found that some small firms within low technological sectors might not have engaged in R&D activities had there been no support.

Almus and Czarnitzki (2003) examined the effects of public R&D policy schemes but in the context of firms located in Eastern Germany. The main aim was to identify whether R&D activities increased or whether they were simply replaced with privately financed R&D. Through their analysis, they found a significant increase of additionality of 4 percentage points. This is supported by Czarnitzki and Licht (2005), who looked at both Western and Eastern Germany using firm-level data. They found a positive significant relationship of additionality in public R&D grants and R&D expenditures, as well as patent applications, with input additionality having a greater affect in Eastern Germany. In terms of R&D and government support in the economic crisis, Hud and Hussinger (2014) conducted a treatment effects analysis, finding a significant correlation between R&D subsidies and increased R&D spending among subsidised SMEs in Germany during the crisis years.

Within the context of measuring the duration of new drug approvals by the FDA, Vernon et al. (2009) found that at the firm-level, approval delays are correlated to R&D spending. Similarly, increasing approval durations was found to result in a reduction of R&D spending and increasing regulation enhanced it. This is supported by Prieger (2002), who found regulatory delay was significantly negatively correlated to CEI filings and waivers, which suggests that it is not beneficial to service innovation. Additionally, Golec et al. (2010), in regards to regulatory uncertainty when threats of new policies are suggested, found that at the industry level there is a positive correlation between the threats and R&D reduction in response to this uncertainty.

In regards to institutional regulation, Baldini (2010), at the individual level, analysed the pay-offs for the inventor or department and found that changing pay-off mechanisms will directly correlate to patent rates, whereby increasing percentages to the individual or department will result in increased patents. Similarly, having a commitment from the organisation to exploit inventions is also positively correlated to new product innovation. Similarly, Ederer and Manso (2013) looked at whether pay-for performance is detrimental to innovation. They found that facilitating a suitable payment scheme that tolerates failure and rewards long-term success will result in an increase in innovation, and similarly, golden parachutes also help to change strategy that results in innovation.

4 Qualitative Research

The quantitative papers used systematic empirical investigation regarding how regulation impacts innovation using statistical, mathematical or computation techniques at different levels of analysis. However, they failed to provide rich in-depth analysis of those relationships. Therefore, through the analyses of 24 qualitative studies, these papers help to capture the inherent complexities and ambiguities that the findings from the quantitative papers uncovered (See Table 2.7).

Theme	Industry	Reference	Method
General	Multi-National	Pelkmans and Renda, 2014	Case Studies
Regulatory Stringency/ Environmental Regulation	Industry	Porter and Linde, 1995	Critical Discussion
Regulatory Stringency/ Environmental Regulation	Regional	Gonzales, 2009	Critical Discussion
Environmental Regulation	Industry	Leitner et al., 2010	Interview 13 experts
Environmental Regulation	Industry	Gerard and Lave, 2005	Critical Discussion
Safety and Standards	n/a	Todt and Lujan, 2014	Critical Discussion
Safety and Standards	Industry	Reeves ,2003	Critical Discussion
Safety and Standards	Industry	Eisenberg 2007	Critical Discussion
Safety and Standards	Industry	Katz 2008	Critical Discussion
Protecting Inventor	n/a	Bessen and Meurer 2008	Critical Discussion
Protecting Inventor	Individual	Himma, 2013	Critical Discussion
Protecting Inventor	Regional	Maskus, 2000	Critical Discussion
Protecting Inventor	Industry	Barton, 2002	Critical Discussion
Protecting Inventor	Industry	Guell and Fischbaum, 1995	Critical Discussion
Protecting Inventor	n/a	Anton et al., 2006	Critical Discussion
Protecting Inventor	n/a	Treece, 1968	Critical Discussion
Protecting Inventor	n/a	Hughes, 1988	Critical Discussion
Protecting Inventor	n/a	Stiglitz, 2008	Critical Discussion
Protecting Inventor/ Competition	Industry	Lemley, 2011	Critical Discussion
Protecting Inventor/ Competition/ Safety and Standards	Regional	Drahos and Maher 2004	Critical Discussion
Competition	Firm	Manne and Wright 2010	Case Studies
Government Support	Regional	Klette, T.J et al., 2000	Critical Discussion
Government Support	Firm	David, P. A. et al., 2000	Critical Discussion
Government Support	Regional	Hall, B.H., and J. Van Reenen, 2000	Critical Discussion

Table 2.7: Qualitative assessment of papers.

4.1 Qualitative Studies Overview

Similar themes emerged within the qualitative papers that were in line with the quantitative papers. However, there were surprisingly few empirical investigations, such as those involving case studies and interview methodologies, being adopted. The majority of the papers were critical discussions of the area. This is somewhat surprising, as understanding how regulation impacts innovation seems to be multi-faceted, ambiguous and complex. Therefore, it is arguably well suited for qualitative investigation.

Firstly, the author analyses the protecting the inventor theme through intellectual property legislation. In the first instance, there are obvious moral justifications for the use of intellectual property, whereby creators have the moral right to receive the fruits of their labour (Himma, 2013). However, there are also several arguments for tightening legislation from a systemic perspective. This is because legislation can proliferate innovation through the reward of creativity, which in turn attracts investment, promotes trade, enables technological transfer, creates new jobs and improves consumer welfare. Despite the positives of a stringent intellectual property regime, however, there are several weaknesses (Teece, 1986; Hughes, 1988; Posner, 2005; Stiglitz, 2008). Granting monopoly is not deemed as socially desirable. This is because firms will have less incentive to invest in new ideas, as they will be able to maximise payoff on their own inventions without competitive pressures requiring them to differentiate themselves (Guell and Fischbaum, 1995). Similarly, according to Barton (2002), it slows down the rate of technological diffusion. For example, the current patent policy on genes, such as polymorphisms, gene products and express sequence tags, enables companies to prohibit others from entering the market, and in turn fix prices at unreasonably high levels. Furthermore, even if the monopolists benefit from economies of scale, they have little incentive to concentrate on reducing costs compared to in a more competitive marketplace. Thus, intellectual property can be seen to have a converse affect as it creates market distortions that in turn negatively affect efficiency and reduces innovation. Furthermore, if the patent is strict, firms can live in fear of litigation, which will slow inventing and the diffusion of new technologies. In a weaker patent system, it is likely that the probability of successful lawsuits would be overturned (Anton et al., 2006).

Another approach to encouraging innovation is government support for R&D. However, there are mixed conclusions as to its effectiveness. According to Klette et al. (2000), clarification is extremely important, as all OECD countries spend significant amounts of money in order to stimulate the activity of firms. Previously it was mentioned that there are two types of financial support for R&D: direct and indirect financial assistance. Direct subsidies tend to target specific projects with higher expected social returns, with the intention of raising the marginal rate of R&D. However, they are prone to policy failure as policy makers as opposed to the market mechanism decide investment. Similarly, it is common to award firms with repeated success or large firms as they are considered less of a risk. Indirect tax credits are supposed to alleviate many of these issues. They allow the private economic agents of the system to decide what type of project they apply to (Hall and van Reenen, 2000). Therefore, they are considered neutral in terms of the content of R&D activity being supported, allowing access to all types of firms within the economy. However, there is some debate as to whether indirect tax credits are merely a substitute of public funding over private funding, and so they do not increase R&D rates. Similarly, there are no clear indications that they are successful in influencing corporate research and development strategies, rather they reward those firms which already undertake R&D investments.

In regards to environmental regulation, Porter and Linde (1995) analysed how regulation impacts on innovation by providing anecdotal examples of how regulation has induced innovation. They coined the term ‘Porter hypothesis’, illustrating that regulation may enhance the competitiveness of the regulated industry. This is for reasons such as an increase in ‘resource efficiency’ of production or by increasing the quality of products. A case in point is the chemical industry where regulations can lead to significant cost savings for affected companies. In support of this, Leitner et al. (2010) reviewed how current policy instruments drive environmental regulation using grounded theory. They created a model through interviewing 13 experts in order to encapsulate the dynamic interactions of innovation and regulation. The model highlighted several diffusion pathways that are triggered through regulation, competition and technology. This was so that policy makers could design smarter regulations that incentivised rather than forced organisations to comply with regulations.

With reference to safety and standards, there were more qualitative papers in this theme than in the quantitative theme. For example, Davis and Abraham (2013), at the industry level, produced a framework to interrogate how well pharmaceutical innovation and regulation are performing in terms of improving health. They found that more demanding regulatory intervention is required. Katz (2007) and Eisenberg (2007) provided an overview of the Food and Drug Administration regulation challenging the central arguments of how regulation impacts innovation. Their results show that regulation that aims to promote information asymmetry can promote innovation through increasing the returns of innovations that become successful. In other words, regulation can play a valuable service to industry by preventing it from becoming saturated with ‘lemons’ and so actually enhancing the value of new drugs and encouraging innovation within the pharmaceutical sector.

5 Overview of Additional Papers

Previously the author discussed how the literature was categorised by its relevance to how regulation impacts innovation, with the highly pertinent papers being the focus for this review. However, the literature is also accompanied with other measurable variables that may impact the innovation process. Policies within this context are integrated at each stage in an attempt to improve and stabilise the system; for example, policies that start with the entrepreneur for the development and optimisation of inventions, aiding and enhancing production and distribution for the eventual consumption of commodities and services (See Figure 2.3). It is noteworthy that there is much empirical literature that already exists surrounding how regulations impact these variables. However, within our analysis the author only discusses the ones identified by our search criteria.

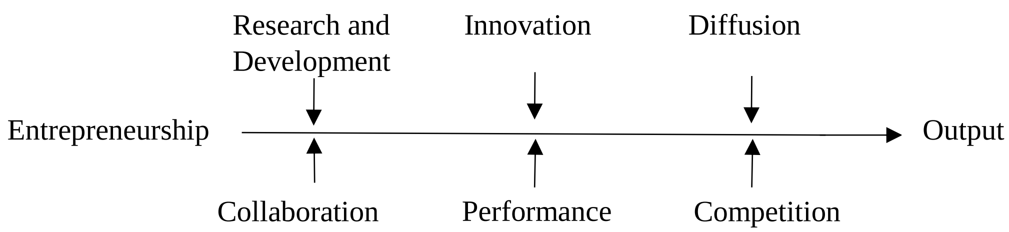


Figure 2.3: An illustration of other measurements used to look at how regulation impacts innovation.

The literature on regulatory inducing impacts seems to start with the entrepreneur, whereby entrepreneurs attempt to bring about new economic, social, institutional and cultural environments through the actions of individuals or groups (Rindova et al., 2009). For example, Norback et al., (2014) analysed entrepreneurial policies and their impact on existing incumbents. The authors found that international market integration leads to more pro-entrepreneurial policies. This is largely because liberalisation mitigates the protection on domestic firms. Similarly, Mason and Brown (2013) focused on turning new start-up companies into high growth firms (HGVs). The authors illustrate that traditional forms of support are inefficient due to the limited funds that are available. Therefore, policy makers must develop metrics to help optimise decision making with greater emphasis on the entrepreneurial actors, resource providers and connectors within the ecosystem.

Arguably, ensuring efficient levels of R&D is just as essential as entrepreneurship for the stability of an innovation system. For example, it is widely accepted that R&D enhances productivity levels and so enhances consumer welfare (Geroski, 1991). This is because even if R&D is undertaken by a relatively small fraction of firms, evidence suggests that firms benefit from the use of that innovation, which has positive implications for the economy as a whole. However, designing efficient R&D policy schemes is extremely difficult due to the scope and ability of governmental support. Similarly, there are many financial constraints, which differ across the various types of firm, financial markets in different countries and research projects.

One way of encouraging R&D is through enhancing collaboration with firms. Brodley (1990) analysed the National Co-operative Research Act (NRCA) in 1984 that encouraged joint research ventures. This policy granted special treatment under the antitrust laws to allow joint research and development ventures (Wright, 1986). It was found that the policy successfully encouraged 29 new collaborative partnerships a year, as opposed to seven before its enactment. However, Brodley (1990) warned that over time cooperative research might reduce competition and delay research progress due to free-riding behaviour. Therefore, regulation needs to be aware of unexpected causalities when introducing new policies into the environment, not just over the short term but also taking into account the long term.

Hart and Ahuja (1996), who analysed environmental regulation and efficiency in regards to pollution abatement and emission reduction, observed similar findings. The research suggested regulation had a positive impact on improving overall levels of productivity; however, this was only realised after one to two years. Similarly, companies that produced the highest emissions stood the most to gain from the enactment. As to whether increasing the stringency of environmental policy enhanced performance, Lanoie et al. (2008) found that it led to modest long term gains in productivity. Hart and Ahuja (1996) support this, finding that there were outcomes that are more positive in years three and four. In addition, they found that this impact was more important in industries already exposed to high competition. This is because competition ensures that the higher producing firms increase their market share at the expense of those less productive (Hopenhayn, 1992). Furthermore, Geroski (1991), who looked at how competition influenced the exit/entry dynamics. They found that it forces the exit of low efficient producers and raises the bar should new potential entrants want to enter the market.

The same was observed when measuring innovation output. Aghion et al. (2005) found that the number of firms in the market had an inverted relationship with the amount of products released to the market. This is because it discouraged firms that were already behind in technological progress from innovating; conversely, it encouraged neck-and-neck firms to strive for continual technological development. Canon de Francia (2007) support these findings, illustrating that technological knowledge prepares a firm to adapt to a greater demand. Therefore, with the introduction of new policies, it is argued that the best firms are the ones closer to the technological frontier, as they are better at gaining competitive advantage through adaption.

As to how competition can enhance the diffusion of innovation, Bohlin (2010) suggests that it accelerates the adoption process; for example, it was discovered that inter-firm competition was the key determinant for increasing mobile telecommunication technology diffusion speed. This is supported by Gruber (2011), who found that it accelerated the adoption process within broadband networks; however, it was also discovered that this enhancing effect dissipated after three to four years. Gruber and Yates (2011), on the other hand, looked at broadband diffusion but from a global perspective. They illustrated how a digital divide exists, as within technologically developed countries broadband diffusion was better if there were higher levels of investment, effective government practices at the national level and higher levels of education. However, within developing countries the main drivers for diffusion were competition coupled with investment. They concluded that optimising diffusion requires different stages of regulation depending on a nation's level of technological development.

With each of the variables discussed, trying to strike a balance in relation to how aggressive regulation should be so that consumer welfare is optimised is extremely problematic. For example, from a systemic perspective, if there is strong regulatory protection within the innovation process, it gives incentives to the generation of new knowledge, although this can reduce competition such that firms may have less economic need to innovate. This in turn can reduce the speed that new technologies spread among enterprises (Harrison, 2008; Vandekerckhove and De Bond, 2008), which may lead to less variety and higher prices for the consumer (Hughes et al., 2014). On the other hand, it is argued that weak regulatory protection entices competition that puts more pressure on the need to develop ways for reducing cost or increasing revenue. However, this can lead to invention spillovers, where firms copy the new idea without having to pay the research costs. Consequently, as firms can easily imitate it can mitigate the reward for future invention, leading to a systemic failure where consumer welfare is severely harmed (Hall and Reenan, 2011; Czarnitzki and Kraft, 2012). Therefore, policy makers need to strike a balance between the two at each stage of the innovation process in order to find what maximises social welfare. Similarly, researchers need to test different policy instruments. For example, Shavell and Tpersele (2001) looked at intellectual property and other reward systems, where innovators were paid directly by the government (mitigating monopoly rights) once a new product was discovered. This was subsequently integrated straight into the public domain. The author concludes that intellectual property does not possess fundamental social advantage over other reward systems and that optional reward systems can be superior in some instances. Similarly, Chaudhuri et al. (2006) highlighted some of the problems with intellectual property and consumer welfare, finding that pharmaceutical protection from international world treaties can significantly increase prices for medicines, which can have an adverse effect on social welfare.

6 Discussion

This review is organised around the idea that regulation influences innovation. Here, the author has presented a rather heterogeneous picture of the existing research, both regarding the variety of regulation and regarding the type of innovation involved. From the analysis, one can conclude that regulation does impact innovation. However, the views are mixed as to the consequential impacts. This section, therefore, aims to merge the methodological findings from both the quantitative and qualitative studies before drawing domain insights at the end.

The results of the quantitative analysis suggest that when integrating new policies it can induce strategy innovation, especially if firms are closer to the technological frontier. However, despite regulation inducing R&D spending it often results in lower rates of process or product innovation. One explanation for this negative relationship could be that the econometric literature focuses more on economic regulation, where regulatory compliance is often see as a compliance burden. Interestingly, the converse is observed when analysing environmental regulation. Through analysing the qualitative based papers this was found to be because these types of policies force innovators down different technological pathways, which in turn leads to the development of new process or product innovation. In turn, this can enhance the overall competitiveness of the regulated industry for reasons such as “resource efficiency” in production or by increasing the quality of existing products. However, it is still largely contested as to whether this results in an increase in innovation output as opposed to just firm performance.

In regards to analysing Government Support for R&D, whilst the majority of the quantitative papers found a positive correlation with it enhancing R&D budgets and product innovation. The qualitative studies depicts a more ambivalent picture. For example, it was found that direct financial assistance could be prone to policy failure. This is because policy-makers as oppose to the market mechanism decide who is awarded with the additional capital. Therefore, it often rewards firms with repeated success or larger ones as they are considered less risk. However, by awarding grants to market leaders it can lead to perpetual dominance with existing firms. In turn, this distortion can then lead to reduced competition and the monopolisation of markets, which will inevitably slow down the rate of innovation. Whilst indirect support for R&D aims to alleviate some of these limitations by allowing the economic agents of the system decide as oppose to policy-makers. There are no conclusive indications that they are successful in influencing corporate R&D strategies and instead just reward firms that already undertake R&D investments. In this context, it is argued that more research needs to explore this relationship.

When analysing the protecting the inventor theme, the results from the quantitative based papers were inconclusive. One explanation could be the limitations with measuring the stringency of regulation via conventional proxies. A case in point is when reviewing the qualitative studies. It was found that dependent on the strength of the legislation it could lead to inverse results. For example, in regards to intellectual property and copyright regulation. Too stringent will mean firms would get the economic inventive to innovate; however, this can reduce competition that innovations depend on. Similarly, this would reduce the pressure on existing incumbents to want to create. On the other hand, weak regulatory protection may heighten competition, but if firms can easily imitate other companies' innovations without having to invest in R&D then companies will lose the economic incentive to develop new products or services. This results in a trade-off between the stringency of regulation and its subsequent impact on innovation. Therefore, not only should this relationship be explored further, but also new innovative solutions are needed to measure it.

Similar relationships were identified at different stages of the innovation process. For example, earlier the author stated how the quantitative based papers illustrated how economic regulation tended to have a negative impact on innovation output. However, through analysing the indirect papers there is evidence to suggest that the stringency of regulation may create similar inverse affects at different parts of the innovative process. A case in point is with policies that induce competition. This is because by keeping a high number of firms competing in the marketplace, it puts pressure on companies to develop strategy and business models that best facilitate innovation activity. However, too much competition may discourage laggard firms from innovating, and instead just encourage neck and neck firms to develop. In this context, firms closer to the technological frontier seem to be better at gaining competitive advantage as they have better competences for adapting to the new regulation.

The analysis also suggests it is important to recognise the long-term repercussions of policy integration. For example, when analysing the quantitative based papers in regards to environmental regulation the results found that may take a few years before the benefits are realised. According to the qualitative based papers, this is because firms need time to adapt to the new regulatory environment before it becomes advantageous. Similarly, other quantitative studies have shown that regulatory effects can dissipate after a few years. Therefore, more longitudinal research across different sectors is needed in order to highlight any differences between the long and short-term effects of policy integration. It is also noteworthy within the econometric studies that earlier studies found slightly more negative impacts, whereas investigations that are more recent revealed more positive implications. This is especially prevalent in relation to environmental regulation.

The amount of time that policy makers give companies to comply with proposed regulation was also found to be essential for stimulating innovation. However, timing itself is a double-edged sword. Too little time might discourage innovation by creating an unsustainable increase of compliance burdens. Too much time might hamper innovation due to a lack of pressure on firms to meet the requirements. Consequently, the optimal timing should be determined independently and should always be considered when integrating new policies. Similarly, there is also sufficient evidence to suggest that policy uncertainty will delay investment and innovation decisions. However, companies tend to delay or reduce innovation activities if there is high uncertainty and so more research needs to be done in this area.

As for the domain itself, the literature is quite fragmented, covering a wide range of different sectors and industries. However, it varies in depth, quality and focus; for example, the majority of studies look at environmental regulation and intellectual policy in relation to innovation, with very few analysing other areas of regulation, especially at the individual level. More research needs to be done at the industrial level aswell so that one can draw more definitive conclusions to make sectoral comparisons of the econometric studies. This is because it is important to understand the inferential relationships of how regulation impacts innovation due to sectoral differences.

Similarly, the majority of studies seem skewed towards product producing sectors, such as the automobile, manufacturing and pharmaceutical industries, and so service industries such as healthcare and financial services are neglected. This is arguably due to data attainment problems, where the current innovation measurements are largely skewed towards product innovation and R&D. This could be an explanation as to why 'innovation' was used as an all-encompassing definition when referring to the variety of each. In addition, the main source of analysis tends to be patent data. Despite the obvious advantages of it being free and easily accessible, patents are an imperfect measure. This is because they tend to restrict studies to considering inventions only, as opposed to innovation. Therefore, new metrics for both innovation and regulation are needed to advance this research area - not only to triangulate findings but also because the distribution of the studies reviewed is skewed. For example, despite an equal distribution between the quantitative and qualitative papers, there is very little empirical investigation among the qualitative studies. This is surprising due to the relationship between regulation and innovation being extremely complex, reciprocal and multi-faceted, with a myriad of factors influencing innovation decisions and outputs. Therefore, it seems evident that qualitative empirical investigations would be very well suited at trying to capture this complexity.

In summary, both the qualitative and quantitative studies have offered interesting insights into how regulation impacts innovation. Whilst the quantitative papers provided a more objective explanation into the research area. The qualitative studies helped expand on these issues to offer richer discussions into the cause and effect relationships. Whilst commonalities were found that reinforced these theoretical findings, interesting differences also emerged. For example, when analysing the protecting the inventor theme and government support for R&D. Consequently, not only do these insights provide a holistic understanding into the domain to guide policy-making, but it also highlights the gaps in the research stream to inform scholars on how to advance the research field.

7 Conclusion

The growing amount of work around this domain prompted this review. The aim was to provide an informative and systematic analysis of the literature to scholars who have an interest in this domain. The research covered a period of 25 years and the author critically evaluated the literature to gain insights into how regulation impacts innovation. The research area was found to be fragmented, comprising of a large number of studies examining the impact of particular pieces of regulation on specific types of innovation within certain sectors and at different levels of analysis. Despite all contributing towards different sections of the overall puzzle, previous reviews had failed to provide a complete picture as to how different policies can impact different types of innovation. Therefore, through a rigorous and systematic analysis the author has shed light on this debate with the aid of pre-existing literature to understand this complex relationship.

The findings from the study suggest that future research should aim to extend the domain with greater analysis towards a variety of different sectors and industries. Similarly, as the majority of the literature was skewed towards product producing sectors, a lot of innovation remains hidden from scientific investigation. One explanation as to why the distribution of the studies is skewed could lie with data attainment problems, where conventional indicators fail to provide sufficient processes to capture less technological and R&D intensive innovations. Considering this, the next generation of research is to find new ways of measuring how different policy-instruments can impact different types of innovation – not only to triangulate existing findings – but also to provide greater depths of knowledge regarding the type of innovation that is involved.

In addition, despite innovation being the focus of this review, policy makers need to be equally aware of other key variables that are part of the innovation process. Similarly, the knock-on effects that they can have throughout this process. This is because should one fail then the whole system can collapse. In this context, understanding optimal policy design and how they can impact different stages of this systemic process would also greatly aid this domain. Not just when measuring innovation but other policy-objectives, such as growth, system stability and consumer welfare. As by regulators placing innovation at the forefront of their policy analysis, whilst taking a holistic perspective towards problem solving, it will help us reach innovative potential.

Chapter 3

Analysing the effectiveness of agent-based simulation as a method for understanding how policy shapes system dynamics

Abstract

Agent-based modelling is developing into an important tool for policy and decision-making and has increasingly been used to study the diffusion of innovation. The purpose of this paper is to analyse the methods effectiveness as a viable tool for measuring how policy can be used to shape system dynamics. This was achieved by synthesising agent-based literature that looked at how different policies can be applied to the market mechanism through various policy objectives. This material was then broken up into relevant streams and applications to provide an in-depth overview of the domain area. From this, the author systematically compared and contrasted the various design specifications of the agent-based models. Despite the relative newness of agent-based modelling, it seems to be a useful method for addressing policy issues within this research area. The analysis highlighted several key opportunities and insights into the domain. Firstly, the majority of the literature was focused towards data driven models tailored towards a specific domain. Consequently, there appeared to be a lack of models that provided generic theoretical insights into policy evaluation.

This was somewhat surprising due to limitations with attaining reliable datasets and its usefulness as a tool for speculative thought experiments. Secondly, with the conceptual design of the agent-based models, the supply side of the market mechanism was often overlooked. This was especially prevalent in regards to understanding the competitive dynamics of the system. Another key finding was that the majority of the studies used policy as an exogenous parameter for the comparison of different system states as oppose to including policy agents as part of the model itself. Consequently, it is argued that the domain would be enriched with the inclusion of regulators as part of the system design. This is because it enables to ask different questions that may be considered out of reach from the former approach.

1 Introduction

Innovation and the diffusion of technologies emerges from the inter-relationships between social, technological and economic factors. However, due to the complexity of the interactions among the features involved and the intrinsic uncertainty in technological and social developments, it inserts analytical difficulties into understanding the aggregate dynamics of behaviour (Epstein and Axtell, 1996; Pyka et al., 2004; Windrum et al., 2007; Moss, 2008; Dawid and Fagiolo, 2008; Faber and Frenken, 2009; Verspagen, 2009). Consequently, agent-based modelling (ABMs) is seen as a suitable method to capture this complexity. This is because it can simulate the explicit behaviours and interactions of autonomous and heterogeneous agents that generate the emergence of coherent system behaviours.

Theoretically, it is possible for one to construct a social system where agents such as firms and consumers can interact within an artificial environment. It is through these repeated interactions among the entities of the system that can lead to interesting macro-level dynamics. In this context, regulation can be used to help steer the system towards different policy objectives throughout this process. These range from incubation policies that try to increase the rate of new start-up companies (Garibay, 2015), regulations that aim to reduce CO_2 emissions by setting emissions standards on production (Zhang et al., 2011), to policies that aim to increase the adoption rate of a specific technology (Schwarz and Ernst, 2009).

There have been several reviews that have looked at ABM from the point of view of the market-mechanism. For example, Dawid (2006) looks at innovation diffusion of ABMs in a computational economics context. Garcia (2005) describes potential uses of ABM in market research associated with innovations, exploring the benefits and challenges of modelling complex dynamical systems. Similarly, Zsifovits (2013) analyses ABM for simulating eco-innovation diffusion concerning green mobility, focusing on the diffusion of electric vehicles. Perhaps the most related to the authors' research are papers by Zhang and Vorbeychik (2016) and Kiesling et al. (2012). Zhang and Vorbeychik (2016) analyse diffusion models towards empirical grounded models. These are practical applications of ABMs to provide forecasts, decision support and policy analyses for specific applications based on empirical data. Kiesling et al. (2012) also analyses the diffusion of technologies on the consumer adoption perspective. Despite regulation being discussed in short, it is intertwined with applications at the end, and so, similar to Zhang and Vorbeychik (2016), the study neglects the depth and variety of policy-based papers.

Despite the aforementioned reviews addressing related aspects of the domain area, none, to the authors' knowledge, has put regulation at the forefront of their analysis. Similarly, it was found that these studies skewed their analysis towards the demand side of the market mechanism. Therefore, this paper aims to complement existing reviews by making the following contributions. Firstly, the author provides a systematic review of how different policy instruments can be used to shape system dynamics. In particular, the author offers a novel classification of the market mechanism to see where policy is integrated at each stage of the process. Secondly, as this review is updated and comprehensive, the analysed material supersedes previous reviews around this domain. For example, one explanation as to why regulation has been largely omitted could be that only recently has there been a sufficient large body of literature on this topic for viable synthesis. Finally, the author provides a critical assessment of ABM as a viable methodology, whereby the author assesses the gaps and deficiencies in this research stream and offer suitable directions for future research.

The purpose of this paper is therefore to provide a rich and in-depth analysis as to the effectiveness of ABM is for analysing how different policy instruments can shape the dynamics of the system within a market mechanism. The next section discusses why the ABM approach was implemented. This is followed by the methodology and the relevant selection criteria of the reviewed literature in section three. Section four will then provide an overview and background into ABM. Section five will then classify the studies by their relevant orientation and application. Following from that, section six will then analyse the design specifications of the reviewed materials, with section seven integrating those key features to see how different policy-instruments can shape the dynamics of the system through various policy objectives. Section eight will then critically discuss those findings from the reviewed material, before concluding at the end in section nine.

2 Why Agent-based modelling?

Innovation is an emergent property of a complex socioeconomic system, where agents - such as – firms and consumers - interact within a market mechanism and through these repeated interactions the system evolves over time. Various policy-instruments within this context aim to shape the dynamics of the system towards preferred objectives for society. Traditionally, understanding this relationship has been driven by reductionism. This is based on the philosophy that complex phenomena can be broken up into simple components and analysed through linear mathematical models and equations. However, whilst this philosophy might have been applicable back when economic and social structures were simpler. In today's globalised and interconnected world, it is increasingly unsuitable. This is because the world is incommensurably more complex with many new actors and dynamics. Consequently, applying conventional research approaches used in traditional policy analysis – i.e. statistical analysis, economic models and linear programming – are likely to fail when applied to environments that are counterintuitive, non-linear and irreversible (Arndt, 2006).

Problematically in the past, the reconstruction of multi-level dynamics in complex systems has been limited by mathematical tractability. However, due to the increasing power of computers, it has enabled new ways to explore this complexity (Bougine and Johnson, 2006). For example, System Dynamics (SD), Network Analysis (NA) and Agent-based modelling (ABM) have all emerged as a method for identifying the complex mechanisms of what drives a system and the key characteristics of what influences it. Whilst there are some overlaps into how they approach complexity, each of these methods study systems in different ways.

System Property	SD	NA	ABM
Model Breadth	•		
Feedback Loops	•		•
Dynamic Systems in real time	•		•
Interactions of individual actors		•	•
Interactions between multiple levels	•		•
Complex relational structures		•	
Heterogeneous actors		•	•

Table 3.1: Primary Strengths of each method
(See Luke and Stamatakis (2013) for an in-depth overview).

As demonstrated by Table 3.1, whilst NA and ABM are suitable for describing how individual actors in a system interact with one another when compared to SD. NA is often constrained by its ability to model the dynamic processes of agents within multiple levels of analysis (Luke and Stamatakis, 2013). Similarly, as the method is often grounded in data it is thus limited in its capacity to analyse any emergent effects that arise through the interactions of agents. SD on the other hand, despite suitable for capturing non-linear dynamics of complex systems fails to represent agents at the micro-level. This aggregated form of analysis is therefore limited in its capacity to model heterogeneity and social structure - an important drawback for understanding the dynamics of complex socioeconomic systems. This is because individual interdependence and communications are among the most significant aspects when innovation plays a central role (Valente, 2005; Rogers, 2010).

ABM alleviates many of these concerns. It is a 'bottom-up' methodology that examines how individual elements of a system behave as a function of individual properties, their environment, and their interactions with one another (Luke and Stamakis, 2013). According to Bonabeau (2002), there are three main benefits for this approach over other modelling approaches. These are: (i) it is possible to capture emergent phenomena. This emergence can have properties that are decoupled from the properties of single entities; (ii) it provides a natural description of a system, such as giving agents behavioural attributes, which are arguably a closer match to reality (iii) they are flexible. This flexibility comes in many different dimensions, such as the amount of agents and their level of rationality; similarly, how these agents interact and learn within a shared environment. In this context, it is possible to model a variety of social systems that comprise of agents – such as firms and consumers – and analyse how they interact and learn. In turn, this provides a useful computational laboratory (Twomey and Cadman, 2002), where a variety of policy scenarios can be explored to assist and guide decision making for policy-makers (Hanusch and Pyka, 2007).

In conclusion, as the world gets increasingly more interconnected and sophisticated so too does the way we need to approach these types of environments. This is because complex phenomena cannot always be described simply by reducing the properties to lower scales. Whilst new methodologies have emerged that aim to measure this complexity, ABM was chosen due to its ability to capture the non-linear dynamics of agents as they evolve through space and time. Consequently, this methodology can be built to provide valuable information about the real-world system being emulated. Considering this, the next section aims to discuss the methodology and the relevant selection criteria of the reviewed literature.

3 Methodology

The aim of this review is to analyse the effectiveness of ABM as a method to understand how policy can shape the systemic properties of the market mechanism. Therefore, the author will structure the research field by classifying the material around this domain, which is then synthesised into relevant streams and applications. This provides the theoretical background that enables the author to explore the technical sections within the reviewed studies. Consequently, this is broken up into emergent features that the author uses for incorporating it into a policy framework as illustrated in the final section.

The Delphi-S database has been chosen as the key resource for the review. This is because it contains a comprehensive range of database relevant to our field. For example, key journal sources such as Web of Science Core Collection, Scopus, EconLit, Emerald, JSTOR and Science Direct. Papers have been identified using the search terms shown in Table 3.2.

Search Term 1 AND	Search Term 2 AND	Search Term 3
Regulation OR Polic(y/ys/ies)	Innovation	Agent-based ABM Multi-agent

Table 3.2: Search terms used for identifying papers using the DelphiS database.

The keywords provided the boundary conditions for this review. The first keyword was the policy parameter to find material that analysed government intervention. In this context, “regulation” was included with “policy” in the initial search. This was because they are sometimes used interchangeably within the literature. The other keyword chosen was “innovation”. Given the plurality of meanings embedded in this term, the author employed a general selection requirement that assessed whether innovation was being modelled within a socioeconomic system. The final keyword searched for material that tried to model this perspective using ABM. Due to the variety of terminologies used to refer to this methodology, synonymous words were also applied, such as Multi-agent, ABM and Agent-based. Each keyword cloud was searched using the "AND" Boolean expression, whereas the synonymous words of the keywords were searched using the "OR" Boolean expression. This enabled to conglomerate a rich source of material to answer the research objectives.

The initial search resulted in 1278 peer-reviewed papers. The search terms were subsequently restricted to just the title, keywords and abstract. Several other strategies were utilised within the selection process, such as back and forth citations (53 studies) and expert opinions regarding the domain (12 studies). The studies were then analysed based on the following selection criteria: (i) does the paper adopt an agent-based approach (ii) is innovation modelled within a socioeconomic system and (iii) is policy applied within the analysis. Studies were then removed if they were considered irrelevant based on this criterion. This resulted in 29 studies. In addition, when reviewing these papers additional literature was found, which led to 41 papers.

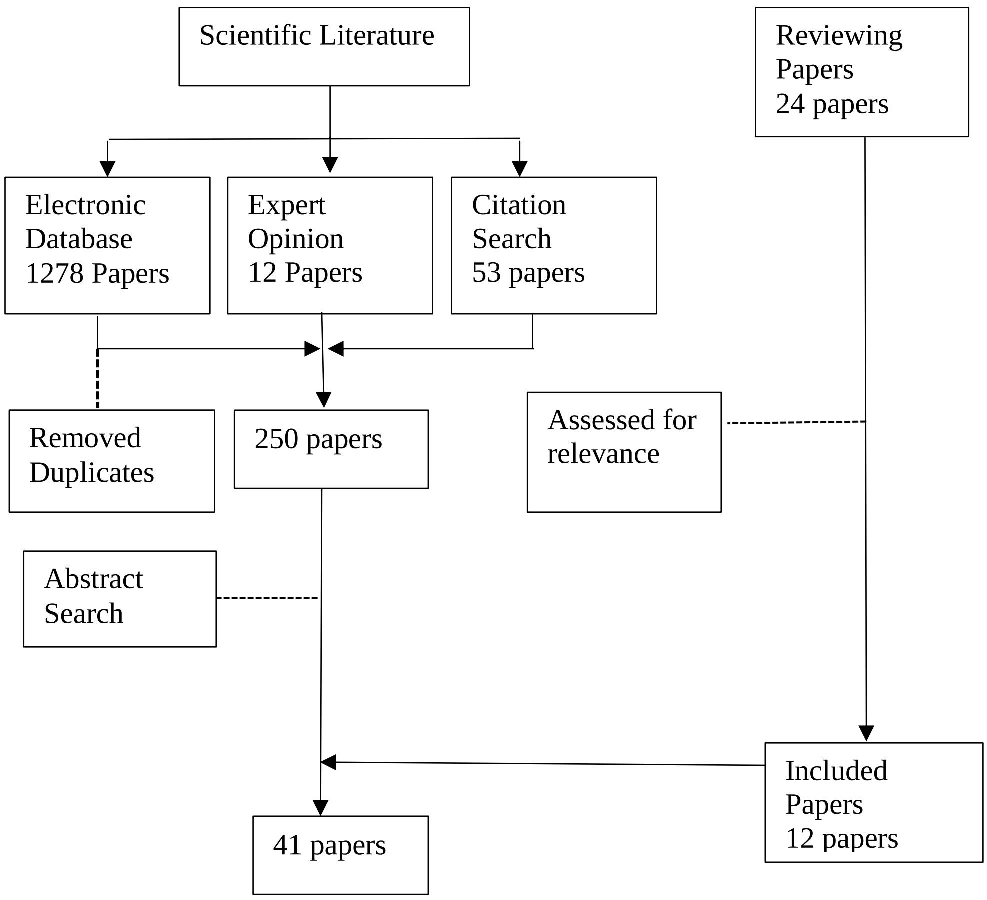


Figure 3.1: Breakdown of the literature search.

4 Background and overview of agent-based modelling

In ABM, a system is modelled as a collection of autonomous decision-making entities called agents. Each agent can be identical or endowed with unique attributes determined by a set of predetermined rules (Bankes, 2002). The repetitive interactions between these agents are a key feature of ABM, which relies on the power of computers to explore the dynamics that is considered out of the reach of pure mathematical methods (Bonabeau, 2002; Axelrod, 1997; Epstein and Axtell, 1996). Similarly, based on experience and available information within their environment it subsequently determines how these agents interact and learn. Therefore, by analysing these interactions it is possible to observe and study the emergence of coherent system behaviours (Ziegler et al., 2005).

One explanation as to why this ‘bottom-up’ methodology has gained traction in recent years lies in the ability to model complex emergent phenomena. Its key assumption is based on complex adaptive system theory (Holland, 1995, 1998; Wang et al., 2005). This assumes that social phenomena emerge from local interactions of agents where the sum can be greater than the sum of the parts (Jennings and Campos, 1997). In other words, the outcomes of the simulation cannot be tied back directly to the encoded agent behavioural rules and profiles (Adamatti et al., 2014). Therefore, macro-phenomena are generated by the behaviours of individual actors that are part of the system (Schilloa et al., 2000). It is through these repeated interactions that can constitute a bottom-up complex system (Richards, 2000; Epstein, 2007). In that sense, simulations are able to contribute to scientific discussions via analysis of emergent effects (Conte et al., 2007).

It is argued that this bottom-up perspective overcomes many of the limitations of traditional methodological techniques. For example, if one looks at typical diffusion models on innovation and how this spreads within society. Mathematical models built on very few structural influences would usually measure it. A case in point is the BASS model (Bass, 1969). It is an aggregate model that provides an empirical generalisation based on differential equation formulation (Zhang, 2016). Despite being useful for describing the process of how new products are adopted amongst a population, these models do not explicitly model heterogeneity and the complex dynamics of their processes. They are therefore limited to a set of theoretical issues. In other words, one cannot ask ‘what if’ scenarios, such as the diffusion impacts of new monetary grants and subsidies (Rixen and Weigand, 2014) or how different information policies aid the adoption of specific technologies (Desmarchelier et al., 2013).

Considering this, ABM is seen to provide a rich means for analysing the dynamics of social systems that traditional modelling approaches cannot easily capture. This is because the atomic level is not the system as a whole but rather individual consumers and organisations, each with differing behaviours where their interactions can be modelled with multiple and constant interactions between the spheres of research, innovation, production, diffusion and consumption (Schwarz and Ernst, 2009). Consequently, within each part of this process lies the opportunity for regulation to try to shape these dynamics. From this perspective, it can be argued that ABM constitutes a good candidate methodology, since “agents are a natural and powerful ontology for many social problems” (Bankes, 2002). In addition, aided by its flexibility, policy makers can build alternative regulatory scenarios and instruments to see what effect they have on the system (Ferro et al., 2010).

Critics of ABM, however, argue that human beings are irrational, make subjective choices and have complex psychology. Therefore, these factors are said to be difficult to quantify, calibrate and sometimes justify (Bonabeau, 2002). Similarly, it is argued that if ABMs are not empirically grounded with real data then they are merely “toy models” that do not reflect the real world (Garcia and Jager, 2011). In addition, they can sometimes be modelled with so many parameters that the results can easily fit the data and so they are nothing more than computer games (Rand and Rust, 2011). However, whilst it is important to recognise that they may not always reflect real-world phenomena, the same could be argued of any modelling technique. It is therefore the responsibility of the researcher to provide enough burden of proof to ensure the model corresponds to reality. As for whether the results can fit any dataset, this cannot be true if the model’s inputs, processes and outputs are illustrated to be valid through similar real-world observations. Similarly, it is important to note that it is possible to fit almost any data using regression if one is free to choose the functional form. However, once it has been selected and the dependent and independent variables have been chosen, there are rigorous methods that determine if the model fits the data; and this is the same with ABM (Rand and Rust, 2011).

Related to this, North and Macal (2007) illustrates that an ABM is a "toy" until it undergoes verification and validation. Verification is the process by which the model is implemented and how it corresponds to the system design, whereas validation is the process by which the implemented model represents the real world. Both provide the possibility of falsifying the model, which is extremely important in order to ensure the model is robust and as accurate as possible. Grimm and Railsback (2005) state that it is impossible to fully validate and verify a model, but the same is true of all models. For example, the BASS model of innovation diffusion has been able to replicate many real-world scenarios, but it has still not been fully validated. This is because there are many other innovations that are still to be tested. Nevertheless, dependent on the conceptualisation analysed based on verification and validation, the model outputs must be interpreted appropriately. Epstein (2008) summarises that ABM can be applied to infer prediction, explanation and education; and, due to the varying degrees of accuracy and completeness in the model inputs this will inevitably impact on the output that subsequently determines the inferences, such as whether they are used for qualitative insights or accurate quantitative forecasting (Castle and Crooks, 2006).

Overall, ABM provides an opportunity for researchers to study the changes of a social system from various dynamic aspects and long-run outcomes. Even though ABMs are still in their infancy, they have already demonstrated intriguing new research opportunities by facilitating a transition from an aggregate-level to an individual-level perspective (Kiesling et al., 2012). Therefore, it is not surprising that their application has been growing at a rapid rate (Bonabeau, 2002). According to Gagliardi et al. (2014), ABMs are increasingly used to study the economy (Arthur et al., 2006), supply-chain analyses (Swaminathan et al., 1998), regional development (Kalkan and Uyalrra, 2011) and the diffusion of innovation (Cantona and Silverberg. 2009). Applying them as a tool for learning how policy can shape the market mechanism is also a growing trend. However, only recently has there been a sufficient large body of literature on this topic for viable synthesis. The next section will analyse and give an in-depth overview of the reviewed studies.

5 Organising agent-based literature: An overview

The analysis of the synthesised literature illustrates a general shortage of research around this domain. Of the known studies, the author identifies 41 papers. The yearly distribution of these papers has been steadily increasing from 1997 up until the present day. This steady rate of growth could be a possible explanation for why no reviews have specifically looked at how policy shapes the system dynamics in the context of the market mechanism. In addition, the majority of the journals are focused on environmental policy, with over half of the synthesised material being focused on sustainability issues. Similarly, technological diffusion has been another primary focus and often models represent the demand side of the market mechanism.

Papers regarding the adoption of ABM can be broken up into two main streams: theoretical (8 studies) and practical based papers (33 studies). Theoretical based papers could be considered a high abstract representation of the real world system that it aims to emulate. On the other hand, practical based papers tend to be more empirically grounded, thus often integrating a greater depth and variety of data to try to create increased realism in relation to an applied domain. Several themes of the practical based papers emerged: ‘technological’, ‘sectoral’ and ‘geographic’. Technological systems focus on a specific technological field in terms of the structures and processes that support or hamper its diffusion. Therefore, many of these ABMs are focused on technological transitions. This is especially the case with alternatives to fossil vehicle technologies, such as plug-in hybrid electric vehicles and low-emission cars. Similarly, due to the environmental focus with these technologies, the system outputs can be coupled with not just adoption rates and market share of specific innovations but also emission rates, which are used as a comparison of different policy scenarios (See Table 3.3).

Application Domain	Author
Alternative Fuel Vehicles	Sullivan et al., 2009; Epstein et al., 2011; Schwoon, 2006; van der Vooren and Brouillat, 2015; Sullivan et al., 2009; Epstein et al., 2011; Zhang et al., 2011; Vliet et al., 2010; Huetink et al., 2010; Kohler et al., 2010
Heating Systems	Sopha et al., 2011; Sopha et al., 2013; Faber et al., 2010
Smart Metering	Rixen and Weigand, 2014; Zhang and Nuttell, 2011
Recycle Products	Brouillat and Oltra, 2012
Water Saving Technologies	Schwarz and Ernst, 2008
Low-Emission Vehicles	van der Vooran and Alkemade, 2012
Energy Technologies	Lee et al., 2014

Table 3.3: Technological agent-based systems.

These technological frameworks are often intertwined with sectoral system characteristics. Sectoral systems can be defined as models in which agents are represented within a particular industry with linked product goods. For example, Zhang and Nuttell (2011) analysed the effectiveness of BERR's 2008-2010 regulatory reform for promoting smart metering diffusion. This was achieved by developing an ABM with six electricity supplier agents that represented six major competitors in the U.K. electricity market, with the initial market share of each electricity supplier agent being the same as its counterpart's market share in the UK electricity market. In addition, Herrmann and Savin (2017) integrated "electricity consumers", where demand did not change over time. Similarly, they were integrated with different income levels based on empirical data, where a small percentage had a preference rating for renewable energy. Malerba et al. (2001) created another sectoral ABM, where the authors applied a history-friendly model in relation to the computer industry. This is a calibration strategy where one aims to replicate the industrial evolution, integrating detailed consideration regarding the key characteristics of the industry. Based on this assertion, the model aims to reproduce the main facts in the historical development of the industry. From this, it provides a platform to ask 'what if' policy scenarios (See Table 3.4) for a complete list of sectoral systems.

Application Domain	**Author**
Defence Sector	Blom, 2014
Agriculture	Gagliardi et al., 2014; Berger, 2001; Kauffman et al., 2009
Service	Desmarchelier et al., 2013
Energy	Herrmann and Savin, 2017
	Zhang and Nuttell, 2011; Lee et al., 2014
Cross-Industry	Heshmati and Lenz-Cesar, 2014
Computer Industry	Malerba, 2001
Automotive Sector	Vooren and Broillet, 2015; Zhang et al., 2011; Schwoon, 2006.
Chemical	Arfaoui et al., 2013

Table 3.4: Sectoral agent-based systems.

As demonstrated, sectoral systems are a viable means for determining key specifications for model calibration. Another important element is how these agents interact within this space. For example, there are various interaction topologies that aid diffusion processes. These range from simple abstract concepts to real-world networks (see section 6 for a descriptive analysis). However, whilst most models are less concerned with methods for initialising the simulation with empirical data, several studies have integrated social space using geographic datasets. In this context, geographic systems are used to represent the real world using spatial data of a particular region or country. For example, Adepetu (2016) used anonymised household data of home and work zip codes to map the San-Francisco area, including vehicle specifications and income levels of the residents in each surveyed household. Similarly, Schwarz and Ernst (2008) integrated an application area, which was a quadratic section of southern Germany, modelling household distributions. Individuals were calibrated using survey data (See Table 3.5).

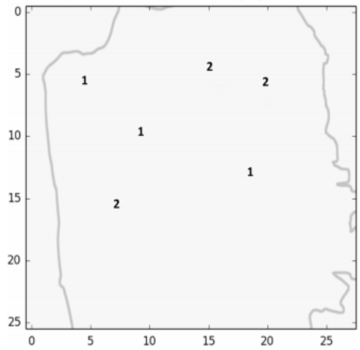
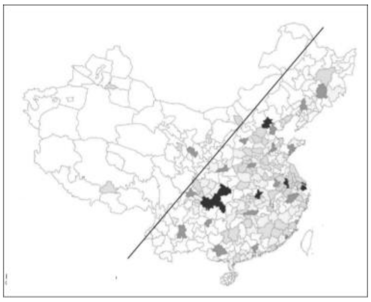
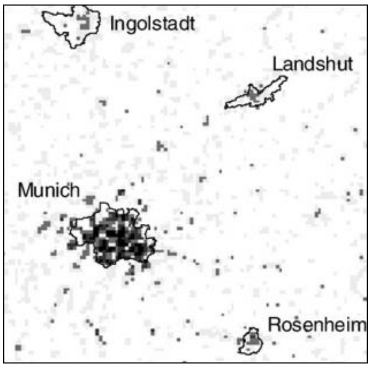
Application Domain	Author	Data	Visual Example
San-Francisco	Adepetu, 2016	Spatial distribution of charging station locations based on real-world location. The scale on both axes is km.	
China	Gaoxiang et al., 2012	The distribution of the population during the simulation. The grayscale represents population within provinces of China.	
Southern Germany	Schwarz and Ernst, 2008	Illustrates the number of households per km2 as one basic datum of the diffusion model. The grayscale represents household concentration.	
Norway	Sopha, 2011 Sopha, 2013	This demonstrates population of agents within the municipalities of Norway. The grayscale represents household concentration. Similarly, the authors visualise those that use electric heating, demonstrated by the dots.	

Table 3.5: Geographic agent-based systems.

Outside of the application-based models that are built around a specific domain, lie more abstract designs that tend to analyse policy within a generic framework. In this context, they may try to explain and understand policy effects by integrating critically bounding assumptions, but are less data driven in their construction. Therefore, they aim to provide policy insights as speculative thought experiments (Paolo et al., 2000), thus are more concerned with qualitative inferences rather than quantitative predictions.

Domain	**Author**
Intellectual Property	Antonelli and Ferraris, 2011
Innovation Niche	Lopolito and Taylor, 2013
Generic Innovation	Ferro et al., 2010
Intellectual Property	Kwon and Motohashi, 2014
Intellectual Property	Brabazon et al., 2012
Incubation	Garabay et al., 2015
Workforce	Dawid, 2016
Diffusion	Cantono and Silverberg, 2009

Table 3.6: Theoretical agent-based systems.

As demonstrated by Table 3.6, there is a relative shortage of studies that analysed the market-mechanism at a highly abstract level. This was somewhat surprising due to the problems with getting accurate and reliable data. Nonetheless, these studies have been able to provide interesting insights into the market mechanism. Similarly, how different policies can be used to shape the dynamics of the system. For example, Antonelli and Ferraris (2011) introduced an ABM to study the process of the generation of new technological diffusion. This was explored through different intellectual property regimes and architectural configuration based upon abstract regional structures where the knowledge interactions take place. Similarly, Lopilito and Taylor (2013) investigated the dynamics characterising the interactions in a network of firms, and assessed the impact of how policy actions relate to actors' expectations. Their research highlights that an information campaign is more effective for encouraging diffusion than a policy of subsidies.

In summary, this section has given a brief overview of the synthesised literature and the author has classified the literature by orientation and application. The aforementioned studies provide interesting policy insights. However, there are emergent similarities and differences in their conceptualisation. The next step is to analyse the ABM design sections of the reviewed studies and classify them into emergent components.

6 Agent-based system designs

This section aims to provide an overview of the design and construction principles of the ABM systems. Each paper share a common set of assumptions that reflect their modelling philosophy. However, before preceding it is useful to introduce the general building blocks and basic structure of the reviewed papers (see Table 3.7).

Building Blocks	Description
Bottom up Philosophy	Aggregate properties emerge as an outcome of the micro-dynamics of individual agents.
Heterogeneity	Agents can be heterogeneous. These range from a variety of behaviour rules, competencies, rationalities and so forth.
The evolving complex system	Agents are encompassed within a complex system that evolves through time (Kirman, 1998).
Non-linearity	The interactions that occur amongst the agents are inherently non-linear, with feedback loops existing at both micro and macro levels.
Direct interactions	Agents directly interact with one another. These decisions are based on adaptive expectations from the current and past choices that have been made.
Bounded Rationality	One can assign local and partial principles of rationality. Generally, agents are often assumed to behave as bounded rational entities with adaptive expectations.
Endogenous and continual originality	Social systems are inherently non-static. Therefore, there is ongoing introduction to originality in the economic system and the generation of new patterns, which they themselves create change for the learning agents.
Learning	Agents engage in continual learning through the dynamical changing environment. This is due to the introduction of novelty and new emergent patterns of behaviour; similarly, also the complexity of the interactions between the agents.
True Dynamics	Due to adaptive expectations the model is characterised by non-reversible dynamics where the system evolves in a path dependent manner.
Market mechanism	Agents partake within a market mechanism. For example, the products produced by company agents are then purchased by consumers. (See Section 6.1).

Table 3.7: Building blocks of agent-based systems.

The building blocks that the ABMs are framed on – or part of a subset of – tend to follow an underpinning structural design. This basic framework is an iterative process whereby agents – such as firms and consumers – interact within their environment based on a set of pre-determined rules. Consequently, through the agents repeated interactions the system dynamically evolves towards a variety of states based on the system settings (See Figure 3.2).

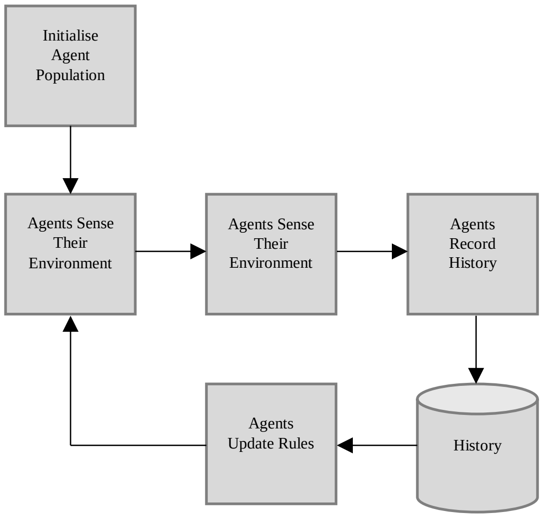


Figure 3.2: Basic structure of the agent-based system.

As demonstrated by the framework. A typical ABM starts with initialising a population of entities. This can belong to a number of different sets. The agents are endowed with a finite number of micro-variables and a range of micro and macro parameters. Whilst variables are susceptible to change, the parameters are fixed throughout the duration of a specific time horizon. Once the simulation starts, agents are chosen to update their micro-economic variables. In turn, it is often modified by the agents' available information based on their current and past state. This is then updated through the interaction of other agents within their localised environment. Various decision-making methodologies can be applied within this context. These range from simple thresholds to algorithms that are more complex. After agents have interacted with one another, the updated micro-economic variables are then recorded within the agent's history for the next step iteration. This history record of the changes to the micro-variables is then aggregated to macro information that is relevant for scientific investigation.

6.1 Design Specifications of the Market Mechanism

The previous section highlighted the building blocks and basic structure of the ABM systems. This provided a general overview so that the author can elaborate how the reviewed studies have applied these features to the market mechanism. For example, main functions, interaction structures and agents involved. This provides a platform to see how policy has been used to shape the systems dynamics towards optimal policy objectives.

The market mechanism is a system where buyers, sellers, and other agents come together and interact to trade in goods and services operating within a social space. Hence, the two primary agents modelled within these systems are ‘firm’ and ‘consumer’ agents. Additional agents are also included within the reviewed studies, such as workers (Dawid, 2008; Antonelli and Ferraris, 2011; Malerba, 2001), households (Scwartz and Erns, 2009; Heshmati and Lenz-Cesar, 2014; Faber et al., 2010), shareholders (Antonelli and Ferraris, 2011), public institutions (Hermann and Savin, 2017), and policy-makers (Zhang and Nuttell, 2011; Zhang et al., 2011; van der Vooren and Alkemade, 2012; Cantano and Silverberg, 2009; Lolipito, 2011). However, only several studies include policy makers and other regulatory agents as part of their system design. This is somewhat surprising due to the regulatory orientation of the reviewed studies. Instead, different policy scenarios are often used for comparison against different system outputs within a fixed time horizon (see section 7.0 for details).

Company agents often represent the supply side of the market-mechanism; the purpose is usually to provide goods and services to be adopted by consumers. The majority of these firms are product-producing ones. However, Dawid (2016) included several firm agents to act as a local market platform for the exchange of goods. These manufacturing firms often use money as a proxy for maximising profit through various learning and decision processes. These decisions vary from simple probabilities to more sophisticated processes that utilise evolutionary concepts, such as genetic algorithms where agents adapt towards optimal states (e.g. Brabazon et al., 2012; Deschmarchelier et al., 2013).

In terms of production, companies select their products to be sold in the marketplace. These products have an associated cost in order to produce them. This can be at a fixed cost (i.e. procurement of necessary resources) and variable costs (i.e. dependent on the volume produced). For example, Wang et al 2015 reduced the variable cost as a means of improving technological competence, thus reflecting improvements in process innovation. Similarly in regards to deciding how much to produce, Garabay et al (2015) enabled firms to anticipate demand by previous sales, adjusting price dependent on how well they are doing in the market. In addition, Antonelli and Ferraris (2011) endowed agents with the ability to learn better ways to perform their production cycles through acquiring technological competence. At each time cycle, firms accrue cumulative technological knowledge, which could be transformed into innovations once a threshold is reached. The more successful the agents become, the greater the motivation for them to innovate. Production levels can also be increased by moving around a social space to reach more favourable zones for production.

Similar spatial processes have been applied to research and development (R&D). For example, Wang et al. (2013) gave firm agents the ability to move locations to better built-up areas with different knowledge worker concentration. Blom (2014), on the other hand, programmed firm agents to modify their research strategy, such that if the product that the company sells on the market does not meet expectations the firm can adapt its behaviour, for example, by finding an external partner for cooperation. As to how studies allocate budgets for R&D and how new technologies are discovered. Epstein et al. (2011) applied a stochastic mechanism to see whether a product has been ‘invented. This probability is based on the amount of budget in their R&D department. Zhang and Nuttell (2011), on the other hand, allowed the modification of budgets through experience, thereby learning through failure. Similarly, Malerba (2001) distributed random R&D budgets, where firms can develop technological improvements in both cost and performance. If the money allocated to research runs out before it becomes a marketable product, it simply fails. However, if the product succeeds then the funds from the revenues can be reinvested back into research.

Just as firms make R&D and production decisions, companies can also make strategic ones based on entering a market. For example, Gaoxing et al. (2012) applied a basic probability threshold for deciding whether to acquire a replicative or innovative technology in a product portfolio. Desmarchelier (2013) applied the Herindahl-Hirshman index for their calculations. This is a commonly accepted measure for assessing market concentration, which calculates the size of the firm in relation to the industry. Therefore, the closer the market is to a monopoly the more likely that a firm will imitate that technology. Entrepreneurial decisions have also been considered for market entry, but there are surprisingly few studies on this. For example, Heshmati and Lenz-Cesar (2014) enabled new spin-off companies from the parent organisation, similar to Desmarchelier et al. (2013), although in the latter case if firms go bankrupt they are immediately replaced by a new firm. In addition, Garabay et al. (2015) enabled new firms to reproduce based on a mutation probability, where the child agent receives a percentage of its money and resources. Furthermore, firms go insolvent based on a fitness score, determined by the sum of a firm’s wealth, resources and product quantity. If this score drops below zero it is removed from the simulation.

Due to the majority of firms being product-producing companies, it is not surprising that the main innovation modelled is product innovation, which is often represented within a technological space. For example, several studies have adapted the Kauffman NK-search heuristic model (Kauffman and Levin, 1987; Kauffman, 1993, 1995) as a product design landscape (Brabazon et al., 2012; Desmarhelier et al., 2013). The origins of the model lie in adaptive evolution, where firms search for dominant designs based on a range of incremental and disruptive technologies for selection (see Frenken and Windrum, 2000; Frenken, 2001; and Fleming and Sorenson, 2001). Additionally, Kwon and Motohashi (2014) modelled technological components with a 2D patent matrix. The row represents the technological group of an agent’s existing patented technology, whereas the column corresponds to the novelty of this technology. This is measured as the product’s technological competitiveness. Similarly, Garabay et al. (2015) built a technological space represented by a network structure, where the resources flow similar to how energy does in a food web. Hermann and Savin (2017), on the other hand, modelled a fixed amount of inventions where improvements to these can be made only in terms of quality and cost. This is similar to the work by Malerba

(2001) and van der Vooran and Alkemade (2012), where only a fixed number of technologies have been modelled. For example, van der Vooran and Alkemade (2012) modelled four vehicle technologies: PHEV, ICEV, HFCV and BEV, where several characteristics can be improved. These are: 1) functionality, including the driving range and refuelling time of the vehicle; 2) performance, including acceleration and top speed of the vehicle; 3) fuel consumption; and 4) emissions.

These technological spaces are often intertwined with a social space, which brings us to the demand side of the market mechanism. Similar to the supply side, a number of deterministic and stochastic threshold approaches have been applied for adoption. These vary in complexity; for example, from simple decision rules, such as cost minimisation and reservation prices, to sophisticated psychological models calibrated through interviews and surveys (see Schwoon, 2006; Kauffman, 2009). In terms of simple decision rules, Faber et al. (2010) applied cost minimisation for analysing domestic micro-cogeneration adoption amongst heterogeneous consumers. At each time step, a consumer considers purchasing a new heating unit based on a three-step algorithm. For example, if a new unit is needed the consumer will scan the market based on technological awareness. This awareness is created based on the level of marketing, the market-share of the product and the bandwagon effect. From there, a consumer will purchase the cheapest technology. Cantona and Silverberg (2009), on the other hand, created a conceptually different but structurally similar model. Consumers have varying reservation prices and some agents are willing to pay more for goods that are perceived to be green. The agents then adopt once any of their neighbours have and the price falls below their individual reservation price.

Perhaps the most sophisticated consumer agent based designs are those calibrated based on social theory. In this context, agent adoption decisions are determined by psychological rules, as opposed to perfect rationality. For example, Ajzens' theory of planned behaviour (TPB) is a commonly applied theoretical foundation for modelling consumer agents' behaviour in practical based papers. It suggests that attitudes, perceived behavioural control and intentions are predictors of behaviour. For example, Kauffman et al. (2009) used TPB to analyse the diffusion of organic farming practices, where agents adopt when their intention exceeds an empirically derived threshold.

Similarly, Zhang and Nuttel (2011) modelled consumers on TPB, where consumer agents' attitudes are expressed as a function of electricity prices and individual price sensitivity. Their subjective norm toward choosing an option is influenced by word of mouth and the agent's individual motivation to comply. Perceived behaviour control is influenced by a range of environmental factors, such as infrastructure and service availability. By combining these factors, consumers' adoption decisions are framed as a function of attitude, subjective norms and perceived behaviour control toward choosing an option. Another commonly used social psychological framework is known as the Consumat approach (Jager et al., 2000). In this framework, consumer agents switch between various cognitive strategies, such as comparison, repetition, imitation, and deliberation. For example, Schwoon (2006) analysed possible diffusion path fuel cell vehicles. Depending on the consumer's level of need satisfaction and uncertainty the consumer follows one of these strategies. For example, in the context of buying a new car the author assumes that need satisfaction is very low and therefore rule out repetition and imitation. Deliberating consumers are certain in their decision-making. They evaluate all the cars available in the market and therefore act fully rationally. Uncertain consumers, however, evaluate only the expected utility they would get from buying the brand again that they are currently driving. Therefore, they reduce their decisions based directly on their perceived environment; i.e. they do social comparisons.

As demonstrated, adoption decisions can also be characterised by their social influence, such as through the awareness of innovation (Faber et al., 2010), word of mouth (Zhang and Nuttell, 2011) or considering a share of adopters in the agent's neighbourhood (Cantona and Silverberg, 2009). In this context, interaction topologies aid the diffusion process. These can be abstract concepts (i.e. complete graphs and randomly generated networks) or real-world networks (i.e. small-world and scale free). Similarly, a wide range of lattice-based topologies is also popular within the reviewed studies. These boundaries can be integrated using empirical data (Adepetu, 2016; Gaoxing et al., 2012; Schwarz and Ernst, 2008; Sopha, 2011) or more theoretically derived (Berger, 2001; Sullivan, 2009; Epstein et al., 2009). For example, Zhang and Nuttell (2011) created a virtual community where residential electricity consumer agents are randomly populated in cells and consumer agents are able to receive and exert influence through interaction with their closest neighbours, with the inclusion of a random interaction parameter to reflect different social dynamics of the real world. Similarly, Epstein et al. (2011) looked at the diffusion of PHEV by developing a virtual environment constructed with the principle of homophily. Agents are located within a spatial radius, uniformly distributed between 0 and 5km by similar salary and age. This framework aimed to model the spread of social influence within neighbourhoods and socioeconomic classes. The approach generated fat-tailed distributions reminiscent of real social networks. An agent analyses the vehicles owned within a geographic neighbourhood and social network to assess the proportion of PHEVs for comparison to the agent's threshold. This adoption threshold varies from different susceptibilities through social and media influences and behaviour switch attitudes and behaviours for changing technology.

To summarise, this section has demonstrated the main components of the market mechanism and how agents can interact within their environment. This iterative process is then observed through a variety of outputs such as innovation rates (Gaoziang et al., 2012), performance (Desmarchelier et al., 2013; Garabay et al., 2015), market concentration (Adepetu, 2016; Gagliardi et al., 2014), productivity (Antonelli and Ferraris, 2011), adoption rates (Rixen and Weigand, 2014), pollution emissions (van der Vooren and Brouillat, 2015; Arfaoui et al., 2013; Desmarchelier et al., 2013), GDP (Garabay et al., 2015), consumer welfare (Kwon and Motohashi 2014), and so forth. However, whilst it could be deemed desirable to integrate as many of the aforementioned features to try to ensure that these inferences are interpreted accurately. The next section aims to critically evaluate issues that may arise regarding how much of these assumptions can be integrated into the model to ensure sound and robust results.

6.2 Model Selection and Validation

The previous section highlighted how different studies have developed their ABM systems. This was achieved by identifying the core-components that have been applied within the reviewed studies. However, when deciding the assumptions of the market-mechanism one often faces a trade-off between descriptive accuracy and explanatory power (Goldstone and Janssen, 2005). This is because the more assumptions that are included into the model, the higher the risk that it cannot be solved analytically. Within this context, there are two modelling philosophies. One argues that there should be a minimal amount of variables and mechanisms that are included within the system design. Whilst the other argues, that modellers should include as many components that reflect the real world as possible and then remove features that do not add to the general quality of the model (Moss and Edmonds, 2005). This is because despite simple and abstract models being more tractable, they can run the risk of missing important aspects of reality. Nonetheless, despite the adopted strategy, the extent to which an agent-based system can represent the real world should play a pivotal role for designing systems. This implies that some sort of validation is needed to ensure that the model produces valid and robust results such that they can serve as a basis for policy-making (Berger et al., 2001). In light of this, the author highlights a typical procedure of the validation process.

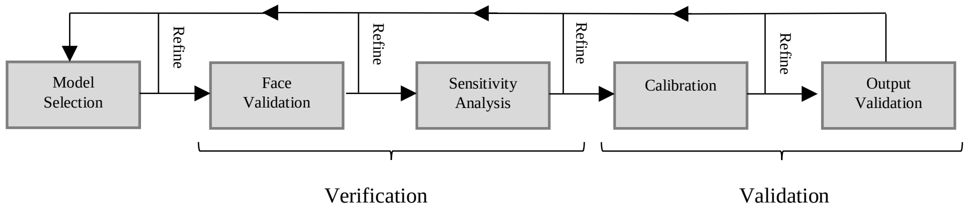


Figure 3.3: Generic Validation Process.

As demonstrated by Figure 3.3, once the theoretical framework has been established the model goes through a series of refinements. The first stage aims to verify the conceptual model. This is achieved by analysing how well the implementation corresponds to the conceptual design. In other words, ensuring the model behaves as it should (Crooks et al., 2007); for example, checking code and algorithms and analysing whether the parameters and features of the model are correctly represented. From this, sensitivity analysis can be applied to assess the relevant inputs and how they impact system behaviours. This is important as it identifies the significant parameters that may affect the system results (Carley, 1996; Crooks et al., 2007; Troitzsch, 2004). For example, Herrmann and Savin (2017) analysed how sensitive the inputs were on the diffusion of two competing technologies. They found that the model was sensitive to changes concerning costs and efficiency of these technologies. However, as the consumers' decision to adopt was based on those features, this was considered reasonable as it was backed by empirical evidence.

Once the model has been sufficiently verified, the next stage aims to ensure that the model gives an accurate representation of the real system. Therefore, calibrating the model until its accuracy is judged acceptable. In other words, so that the model has the right behaviour for the right reasons (Klugl, 2008). For example, Heshmati and Lenz-Cesar (2014) went through a search and refinement process, observing the changes in parameter values and comparing the virtual results with empirical observations. Similarly, another approach is a technique known as the history-friendly method. This is a calibration strategy that aims to replicate the industrial evolution based on historical data, thus integrating detailed consideration regarding the key characteristics of the industry (See Gagliardi et al., 2014; Herrmann and Savin 2017; Malerba et al., 2001)

Despite the varying procedures in validation, the main goal is often to restrict the size of free parameters (Fagiolo and Roventini, 2017). This is because the dimensions of the model can be so numerous that they can generate any result. Similarly, the causal relations between these assumptions become increasingly difficult to study (Windrum et al., 2007). In this context, models focused towards assumptions that are more refined are arguably more accurate than models based on stylised facts. For example, data issues arise such as availability, bias, and quality that in turn impacts interpreting the results for when counter factual policy analysis is applied. Hence, to provide meaningful inferences, one must consider assumptions that are not always the most descriptively accurate. Nonetheless, once validated to an acceptable level it provides a viable framework to investigate “what-if” type scenarios. This approach allows one to consider a variety of policy options that can be used for scientific investigation. This is the purpose of the next section whereby the author aims to elaborate on how policy has been used to shape system dynamics at various stages of the market mechanism.

7 How policy can be integrated within the market-mechanism

The previous section analysed the fundamental parts of the ABMs by systematically analysing the system design sections of the reviewed material. This was achieved by breaking up the literature into components that have been modelled within the market-mechanism. These features are then integrated with varying policy-instruments to see how they have shaped the dynamics of the agent-based systems. Here the author presents the framework that the author aims to extend and adapt as the domain evolves over time (see Table 3.8).

Core-components	**Regulation**	**Authors**
Entrepreneurship	Incubation Policy	Garibay, 2015
	Additional Capital/Resources	Garibay, 2015
	Preferential Taxation	Wang et al., 2013
	Market Exploration	Malerba et al., 2001
	Post Entry Phase Support	Malerba et al., 2001
	Additional Capital/Resources	Malerba et al., 2001
Competition	Deregulation	Rixen and Weigand, 2014
	Deregulation	Blom, 2014
	Deregulation	Berger, 2001
	Anti-trust	Malerba et al., 2001
	Competitive/Monopoly Roll-out	Zhang and Nuttell, 2011
R&D	Public R&D	Blom et al., 2014
	Public R&D	Hermann and Savin, 2017
	R&D Subsidies	Hermann and Savin, 2017
	Feed-in Tariff	Hermann and Savin, 2017
	R&D Subsidy	Brouilett and Oltra, 2012
Invention	Authorisation	Arfaoui et al., 2013
	Intellectual Property: Expiration	Antonelli and Ferraris, 2011
	Intellectual Property: Expiration	Brabazon, 2013
	Intellectual Property: Breadth	Brabazon, 2013
	Intellectual Property: Enforceability	Brabazon, 2013
	NPE’s: Limiting Damage	Kwon and Motohashi, 2014
	NPE’s: Injunction Rate	Kwon and Motohashi, 2014
	NPE’s: Litigation Costs	Kwon and Motohashi, 2014
Production/Operation	Penalise (Polluter Pays Principle)	Desmarchelier et al., 2013
	Tax discount	Wang et al., 2013
	Subsidies	Zhang and Nuttell, 2011
	Training	Dawid, 2016
	Standards	Zhang et al., 2010
	Market Price	Sopha et al., 2011; 2013
	Norms	Brouilett and Oltra, 2012
	Tax	Brouilett and Oltra, 2012
	Standards	Vooren and Brouilett, 2015
	Standards	Zhang et al., 2011
	Tax	Schwoon, 2006
Complementary Assets	Service Station Subsides	Adepetu et al., 2016
	Infrastructure Build-up Programs	Schwoon, 2006
	Infrastructure (tech specific)	van der Vooran and Alkemade, 2012

Core-components	Regulation	Authors
Adoption and Diffusion	Rebates	Epstein et al., 2011
	Monetary Grants	Rixen and Weigand, 2014
	Subsidies	Faber et al., 2010
	Subsidies	Scwartz and Ernst, 2009
	Subsidies	Cantano and Silverberg, 2009
	Adoption Group Subsidies	Ferro et al., 2010
	Subsidies (Installation)	Sopha et al., 2013
	Subsidies (Installation)	Hemann and Savin, 2017
	Sales Tax	Vooren and Bruilett, 2015
	Rebates	Vooren and Bruilett, 2015
	Shock Tax	Schwoon, 2006
	Gradual Tax	Schwoon, 2006
	Subsidy	Kauffman et al., 2009
	Subsidy (general)	van der Vooran and Alkemade, 2012
	Subsidy (tech specific)	van der Vooran and Alkemade, 2012
	Carbon Tax/Subsidy	Lee et al., 2014
	Extended Responsibility	Arfaoui et al., 2013
	Education	Adepetu et al., 2016
	Information Campaigns	Scwartz and Ernst, 2009
	Information Policy	Desmarchelier et al., 2013
	Information Policy	Rixen and Weigand, 2014
	Feebate System	Vooren and Brouilett, 2015
	Feebate System	Lee et al., 2014

Table 3.8: Policy framework as to how policy has been used to shape the market-mechanism.

7.1 Entrepreneurship

Entrepreneurial policies aim to support entrepreneurs and new start-up companies. Of the papers synthesised only three papers addressed this through a variety of policy instruments, such as providing new start-ups with additional capital (Garibay, 2015; Malerba et al., 2001), preferential taxation applied to different regions (Wang et al., 2013) and incubation regulation. For example, Garabay (2015) looked at incubation policy for supporting new venture creation with provisions such as resources and money. In general, it was found that incubation enhanced a regional economy in relation to the number of products in the market and GDP. Similarly, the selection criteria was modelled in terms of firm allocation and it was also found that directing incubation towards recent start-up firms yields a greater impact for the economy. Similarly, Wang et al. (2013) built a diffusion model that focused on entrepreneurial incentives between different regions of China. The results suggest that they managed to change the general spatial economic patterns, whereby the overall technology level increased. This was especially the case for small firms that were in less developed areas. Furthermore, Malerba (2001) analysed market entry for new companies within the computer industry. The study covered policies that supported market exploration and aided firms with additional resources. They found that incubation policies were largely ineffective in modifying market concentration. This is because a firm often dominates the market. To this end, even anti-trust had little impact in terms of averting a firm's domination in mainframe computing. This was due to customer lock-in and strong dynamic increasing returns through technological capabilities. It is further argued that if customer lock-in was smaller, either by chance or through policies that discouraged efforts of firms to lock in their customers the situation might have been different.

7.2 Competition

This leads us to policies that try to model competition. Similar to the entrepreneurship section, very few papers have modelled the competitive dynamics between organisations. These competition policy-based studies range from anti-trust regulation (Malerba, 2001) and deregulation towards a specific sector (Rixen and Weigand, 2014; Blom, 2014; Berger, 2001). Of the literature that has analysed deregulation, liberalisation was found to be a dominant strategy. For example, Blom (2014) did a sector analysis of the defence industry in response to the new European Union's Defence and Security Procurement directive (2009/81/EC), which intends to provide a new framework for policy interventions in the European defence market. This is by limiting the extent of natural protection and instead forcing co-operation and cross-border trade within the EU, eventually introducing a higher degree of market liberalisation (Edwards, 2011). Considering this, an ABM was built that captured key stylised facts and idiosyncrasies of the sector to see how the sector would respond to greater openness. The results suggest that deregulation will progressively make firms more efficient and less dependent on public procurement. Similarly, it will encourage knowledge sharing and inter-firm collaboration, whilst increasing the industry's export propensity. Another proposed policy was analysing the Mercursor free-trade agreement in South America, but from the agricultural perspective of Chile. Here, Berger (2001) built a model that investigated the diffusion pattern of a specific agricultural innovation and the expected impacts in relation to water use, incomes and structure effects of innovation processes.

7.3 Research and Development

Another key feature of the market mechanism consists of firms searching to develop and create new products for market exploitation. In this context, there are several policies from the reviewed studies that aim to promote R&D. For example, public research policies (Blom et al., 2014; Hermann and Savin, 2017), subsidies that target the development of new technologies (Hermann and Savin, 2017; Brouilett and Oltra, 2012) and feed-in tariffs (Hermann and Savin, 2017) to policy inducing collaboration projects (Heshmati and Lenz-Cesar, 2014). Blom (2014) analysed public funded research schemes to support incremental improvements to an existing product line. Similarly, Hermann and Savin (2017) created a history-friendly model for analysing the electricity market in Germany through policies that promoted technology from the public sector. Basic research was provided by the state in the form of storage technology, which firms require to store renewable generating technology. The policy maker within this context chooses the amount of money invested into basic research and this is transferred to the technology producers at no cost. Another policy instrument examined subsidising research to manufacturers by adding additional capital to their research budgets. The results suggest that the policies pose an important instrument to achieve partial or full autarky from the electricity grid, particularly after accounting for decreasing costs and increasing efficiency due to continuous improvement of the technology. Brouillet (2012), on the other hand, looked at R&D tax subsidies in regards to waste prevention, where firms, recyclers and consumers were modelled. It was found that a stringent tax subsidy can lead to radical innovation and significant changes in product design.

7.4 Invention

Once a product has been invented, two primary legislative processes have to be considered: intellectual property rights (Brabazon, 2013; Kwon and Motohashi, 2014; Antonelli and Ferraris, 2011) and authorisation. Arfaoui et al. (2013) analysed the authorisation process by which technology is released onto the market in accordance with the REACH agreement. This was a regulation integrated in 2006 that established a new philosophy for designing environmental and health products. The process involved several stages: 1) identification of substances; 2) request for authorisation before the sunset date; 3) granting or refusing authorisation; and 4) reviewing authorisation. The granting or refusal is based on the existence of innovation alternatives. For example, if there is a sufficient number of existing products the company will no longer be allowed to use the more harmful one. In that case, firms must prove that they have carried out extensive analysis of alternatives. From this, the authors abstract these into two thresholds: stringency (target thresholds) and flexibility (date for review), where they test a variety of these combinations. The model outcome stresses that stringency is the most determining feature of policy design, with timing also decisive but of secondary importance. Similarly, stringency can force disruptive technological change with significant pollution reduction; however, this results in reduction of market concentration and failures. Finally, they argue that soft regulation does not lead to technological transition because of weak incentives and selection effects.

Other policies that have looked at invention have aimed to prohibit product replication by competitors, such as copyright and intellectually property legislation. For example, Antonelli and Ferraris (20111) analysed different patent property regimes and architectural configurations in regards to invention rates. The key parameter they used was ‘patent expiration’, used to experiment with different scenarios. The authors found that the longer the protection, the slower these technologies could spread among firms. This is supported by Brabazon et al. (2012), who also found that patent policy is not a critical determinant for the long-term improvement of society. Similarly, over the different patent scenarios, none clearly outperformed the ‘no-patent’ regime.

Another perspective on intellectual property legislation has been analysing the role of non-practicing entities (NPEs). These are individuals that hold a patent but with no intention of developing it. Therefore, they are seen as controversial players in terms of their effects on innovation society. This is because it is argued that NPEs discourage innovation by generating excessive social costs through frivolous litigation (e.g. Bessen et al., 2011; Tucker, 2012; Turner, 2013; Meurer and Bessen, 2014). Kwon and Motoshashi (2014) built a patent system that can limit the amount of damages that can be awarded to NPEs, as well as reducing the injunction rate and exempting litigation costs of defendants in an NPE lawsuit. They found that NPEs in general pose an overall negative drain on society. Therefore, reducing the injunction rate was deemed the most effective strategy.

7.5 Production

If an invented technology has been approved with the appropriate legislation, it can legally be released into the marketplace. The action of a firm in making or manufacturing technology can be shaped by regulation in a variety of ways, such as training (Dawid, 2016), standards (Desmarchelier et al., 2013; Zhang et al., 2011; Vooren and Brouilett, 2015; Brouilett and Oltra, 2012), subsidies (Zhang and Nuttell, 2011; Wang et al., 2013; Brouilett and Oltra 2012), taxes (Lee et al., 2014; Brouilett and Oltra, 2012; Schwoon, 2006) and market selling price for a specific technology (Sopha et al., 2011; 2013). For example, Dawid (2016) analysed the production impact of various labour market effects. This was achieved by examining how funding enhanced different skills across regions. The author found focusing training efforts on one region only led to the worst policy outcome, whilst spreading funds equally across regions generated the largest output over the long-term. Similarly, regulatory standards have been considered across several ABMs. Zhang et al. (2011) analysed the impact of the Corporate Average Fuel Economy (CAFE) regulations on the penetration rate of AFVs. This was to set a minimum fuel standard that each manufacturer had to meet in order to avoid penalties. Despite being targeted towards firms, it is argued that it benefits the consumer due to potential cost savings. The results demonstrated that governmental pushes force manufacturers towards fuel economy mandates, which in turn leads to a decrease in social welfare. This is because the market share for fuel-inefficient vehicles increases. Similarly, van der Vooren and Brouilett (2015) looked at emission standards where firm strategies, market structure, consumer choices and policy instruments co-evolved within the automotive sector. Policy agents in this context were revised every period, with the average CO2 emissions of the vehicles sold in the previous time step. This set the benchmark for the next period. Therefore, it deduced whether the standards should be tightened or softened. Similarly, if vehicles did not meet the standards they were subsequently prohibited from selling such vehicles. Zhang et al. (2011), however, found that standards dramatically increased market concentration, which subsequently reduced CO2 emissions. Although, the rate of green technology did not increase. Similarly, Brouilett and Oltra (2012) looked at policies that constrained producers to meet a recycle percentage for each product sold on the market. If the manufacturer failed with this norm then the firm would either not be able to sell the product or would have to pay a fine. They found norms were effective at increasing the proportion of firms that switched to more environmentally friendly designs.

7.6 Complementary assets

In addition to polices that aid production and determine which products are sold in the market and at what price, there are complementary assets that support the business operations of companies (Adepetu et al., 2012; Vooran and Alkemade, 2012; Schwoon, 2006). Schwoon (2006) argued that this helps save the "chicken and the egg" problem concerning the diffusion of fuel cell vehicles. This is where car producers do not offer fuel cell vehicles because there are not enough hydrogen filling stations, and infrastructure will not be set up unless there is a significant number of FCVs on the road. This diffusion barrier is often used as an argument for government intervention. The automobile market was modelled with car producers, consumers and filling station operators as part of a dynamic system, where tax influences technological choice. It was found that a reasonable tax towards conventional cars appeared to be sufficient at promoting diffusion, even without a major infrastructure program. Adepetu et al. (2012) support these results. However, Schwoon (2006) argued that some producers might benefit from co-operation with filling station operators in order to speed up infrastructure development.

7.7 Adoption

Just as there are policies that target firm agents, there are legislations aimed towards the demand-side of the market mechanism. As demonstrated by Table 3.8, policy has been extensively looked at within this area. Consequently, the author breaks this section down into several themes: subsidies that reduce adoption costs (Epstein et al., 2011; Rixen and Weigand, 2014; Faber et al., 2010; Scwartz and Ernst, 2009; Cantano and Silverberg, 2009; Ferro et al., 2010; Sopha et al., 2013; Hemann and Savin., 2017; Vooren and Bruilett, 2015; Schwoon, 2006; Kauffman et al., 2009; van der Vooran and Alkemade, 2012; van der Vooran and Alkemade, 2012; Lee et al., 2014), sales tax that increases prices for certain technologies (Vooren and Bruilett, 2015; Schwoon, 2006; Lee et al., 2014), and information campaigns that increase innovation actors' expectations of new technology (Arfaoui et al., 2013; Adepetu et al., 2016; Scwartz and Ernst, 2009; Desmarchelier et al., 2013; Rixen and Weigand, 2014).

In the context of subsidies, Cantano and Silverberg (2009) modelled the diffusion of a new energy technology, where they analysed heterogeneous adoption thresholds towards the environment. In this context, some consumers were willing to pay more for goods that were perceived 'green'. Agents adopted once any of their neighbours had, and if the price fell below their reservation price. Results illustrated that even a limited subsidy policy can trigger diffusion that would otherwise not happen. Similarly, Vooren and Brouillat (2015) analysed rebates that supported the sales of green-tech vehicles, thus lowering the relatively high price of the technology. Tax was also considered based on CO2 emissions. This was modelled similar to Lee and Coker (2014), where the carbon tax cost correlated to CO2 emission rates. In addition, Desmarchelier et al. (2013) intertwined an eco-tax with an information policy that aimed at changing consumer preferences for adoption. Tax policies were generally considered to have a positive diffusion impact for consumers switching to alternative technologies. Interestingly, however, the information policy gave rise to a perverse effect that caused market niche failure, where most of the environmentally friendly services disappeared. In addition, Scwartz and Ernst (2009) looked at several policy strategies in regards subsidies and information campaigns that promoted pro-environmental behaviour. Their findings suggest that water-saving innovations diffuse without further promotion. Finally, Lolipito (2011) investigated the dynamics characterising interactions (innovation niches) in a network of firms and assessed the impact of two policy actions related to actors' expectations and providing subsidies. They found that an information campaign to increase innovation actors' expectations of new technology is more effective than a policy of subsidies.

In summary, this section has produced a policy framework that illustrates the key areas where regulation has been used to shape the dynamics of the system. This provides a general structure that the author hope will be extended as the domain evolves. The next section will critically discuss all the key findings of this literature and put forward proposals for future research.

8 Discussion

This review has been organised around the idea of how policy shapes system dynamics through the application of ABM. Despite being relatively new, this methodology enables researchers and modelling practitioners to analyse the emergent properties of complex adaptive systems. In this context, numerous studies have analysed how different policy instruments shape system dynamics through various policy objectives. This has created intriguing insights and offered many research opportunities for future exploration. The author aims to highlight this in more detail by analysing the opportunities and challenges to advance this domain forward.

The first part of the analysis involved systematically categorising the literature based on its system orientation and application. Papers were subsequently broken down into two research streams: theoretical and practical studies. In regards to the practical based papers, these tended to be more empirically grounded. Consequently, it was found that these studies tended to adopt a more descriptive approach when selecting components to emulate the real life system. Interestingly, however, very few papers constructed their model using geographic organised data in a landscape topology when describing their spatial processes. This was somewhat surprising, as a key benefit to ABM is the ability to measure agents moving through space and time (Holland and Miller, 1991). Theoretical models, on the other hand, were aimed towards high abstract representations of the real world system. It was found that there were very few of these types of papers in comparison to the practical ones. Whilst the practical based papers tended to be more descriptive, issues can arise regarding their complexity. This is because the more features that one integrates into the model, the higher the risk that it cannot be solved analytically. In this context, models focused towards assumptions that are more refined are arguably more accurate than models based on stylised facts (Deischal and Pyka, 2009). This is because issues can arise such as data availability, bias and quality that in turn can impact the results for when counterfactual analysis is applied.

Coupled together, ABM seems to be a useful tool for looking at how policy can shape system dynamics. However, based on its construction it is important to determine what kind of inferences it can suggest. For example, Epstein (2008) summarised that ABM can infer prediction, explanation and education. However, due to the varying degrees of accuracy and completeness in the model inputs, it will subsequently effect the output of the system. Therefore, it is important for researchers to determine whether they are used for qualitative insights or accurate quantitative forecasting (Castle and Crooks, 2006).

The second part of the analysis identified the core-components of the agent-based designs. This section was difficult to synthesise, due to some studies providing insufficient explanations in regards to the technical properties of the system. Whilst some provided good detailed specifications with systematic explanations, some lacked the necessary clarity and depth that one would expect from a peer-reviewed journal. Clarification of the system design is extremely important in order to advance this domain as it enables other academics to validate the model. This is especially needed due to the criticisms that exist when applying this methodology (see North and Macal, 2007). Therefore, providing insufficient descriptions that prohibit scrutiny does not do this tool - as a method for scientific discovery - any favours.

It was found when analysing the design specifications of the ABMs that the majority of the papers have looked at demand side dynamics, often neglecting supply. Little is therefore known about how products are effected by other firms' technologies and actions. Despite several papers addressing this relationship, more research is needed to explore the competitive dynamics of the system. In addition, very few studies have included policy agents as part of the system design. This was particularly surprising as all the papers were policy-orientated. According to Al-Alawi and Bradely (2013), including government agents gives the modeller less control in terms of estimating the sensitivity of adoption. Therefore, they structured their model to assess the impacts of different policies that were exogenous to the model. In this context, ABM seems to be a very useful tool to measure policy stringency. This is where different levels of aggressiveness is applied that can be compared against the different system outputs under varying scenarios. Consequently, it is argued that the domain would be greatly enriched if this were explored in future studies. Similarly, integrating policy agents as part of the model can also offer interesting insights into the dynamics of the system, which would have otherwise not been discovered. For example, ABMs that look at deregulation tend to be synonymous with improved performance. However, as demonstrated with the finance industry, despite deregulation aiding in the proliferation of financial innovation, after the financial crisis of 2007-2008 there has been increasing demand for re-regulation. Therefore, modelling policy makers as part of this co-evolving system can provide useful long-term insights that could greatly aid the debate.

Overall, the purpose of this study was to analyse the effectiveness of ABM as a method for analysing how different policy instruments can shape the market mechanism through various policy objectives. This was achieved by critically evaluating and classifying studies into relevant frameworks. In turn, it enabled the author to systematically compare and contrast the various design specifications of the models and see how policy shapes those dynamics. From this, the author identified several key issues and opportunities that will aim to move this domain forward.

9 Conclusion

The purpose of this review was to provide an informative and systematic analysis of agent-based literature for scholars and modelling practitioners who have an interest in this domain. The research covered a period of twenty years and the author critically evaluated the literature to gain insights into how effective ABM is as a method to analyse how policy shapes system dynamics. Despite its relative newness, this methodology seems to be a useful approach for addressing policy issues within a complex system. Various system designs exist and the author compared and contrasted the similarities between them. This holistic perspective highlighted the fundamental components that allowed one to see how policy could shape the dynamics of the system throughout various parts of the market mechanism, which aimed to overcome the missing clarity that exists within the domain. Similarly, the analysis highlighted several key opportunities and insights into the research area.

Firstly, it was found that there appeared to be a lack of abstract models that provided generic theoretical insights. This was surprising due to its usefulness as a policy tool for speculative thought experiments. One explanation to this imbalance could lie with policy-makers preferring more empirically derived models that provide forecasts targeted towards a specific domain. However, by trying to emulate the real world, issues can arise by trying to integrate too many features into the model. This is because it can negatively impact the results for when counterfactual analysis is applied. In this context, models focused towards assumptions that are more refined are arguably more accurate than models based on stylised facts. Therefore, not only would the domain benefit from more speculative thought experiments for policy analysis, but future research could also critically assess how best to strike a balance between simple and abstract designs (that may be enriched later on) and descriptive models (that can be simplified whenever justified) so that sound and robust policy assessment tools can be implemented.

Similarly, through the analysis the author identified core-components from the conceptual designs. It was found that the supply side of the market mechanism was often overlooked. Therefore, a lot of studies assumed that innovation was free from the forces of competition. Whilst this could be reasonable to assume in some instances, more often than not firms face intense rivalry from other products or new ones released into the market. Despite several studies addressing this relationship, future research should focus more on the competitive dynamics of the system.

These core-components were then combined and integrated into a policy-framework, which aims to be extended as the domain evolves over time. This was to see how different regulations have been used to shape the dynamics of the system at various parts of the innovation process. In this context, it was also found that many of the reviewed studies used policy as an exogenous parameter for comparing different scenarios. ABM, consequently, seemed to be very effective for this type of analysis. Therefore, it is recommended that further research should be undertaken in this area. In particular, measuring different levels of aggressiveness of each policy instrument using various policy objectives. This in turn will give policy-makers a greater understanding of the dynamics of the real world system that the model aims to emulate. Finally, future studies should also consider integrating policy agents as part of the system design. This is because they allow different questions to be asked that are out of reach from the former approach.

Chapter 4

The Regulatory Dilemma: An agent-based approach

Abstract

Government regulation plays a pivotal role in influencing the innovation activities of companies, industries and whole economies. However, sound regulation must be based on understanding how a policy change will affect the behaviour of various actors in the market. This implies that some form of predictive modelling is necessary for policy formation. With this in mind, an agent-based model is developed to represent typical market dynamics. Several policy instruments are then integrated into the model in order to see what effect they have on the system. Hence, the research contributes to existing literature on how regulation shapes innovation ecosystem dynamics; however, specifically facilitating the gap that analyses the stringency of two policy instruments that target towards both the inventor (i.e. through rewarding invention) and the imitator (i.e. penalising imitation). The findings suggest that the aforementioned policies are able to influence the system to preferred system states; however, they differed in regards to their effectiveness. Consequently, this gave an interesting insight into how different regulation can impact the dynamics of the system. For example, government support for R&D seemed to be able to stop the market from collapsing. In that sense, this policy-instrument implied that a pro-cyclical approach currently adopted by most EU-27 member states, might not be the most viable long-term strategy. Therefore, not only does this model help one learn what to expect and what not expect from the analysed policy instruments. It also seems to prove a useful tool

to transcend borders set by standard analytical models and open up promising avenues for future policy design. More research should extend this model with greater adaption and realism for the pre-assessment as to the effectiveness of the proposed policies.

1 Introduction

Innovation is argued to be the primary driver of economic growth (Fabricant, 1954; Solow, 1957). It is an emergent property of a complex socioeconomic system whereby regulation is used to try to steer the actors of the system towards preferred outcomes for society (Antonelli and Ferraris, 2011). However, failing to understand the complex systemic structure of the market mechanism and how it is shaped by policy can lead to detrimental effects to society. This is because the innovation process comprises of many technical and social aspects that makes predicting how actors will respond to various policies difficult to anticipate. In turn, this can cause unintended consequences, which may lead to adverse impacts on the system. Considering this, the author develops an agent-based model (ABM) of a market mechanism to analyse how various policy-instruments can shape the innovation process.

An ABM is a type of computational simulation that models a collection of autonomous decision-making entities called agents. Each agent individually assesses its situation and makes decisions based upon a given set of rules (Bonabeau, 2002), where through repeated interaction it can give rise to collective patterns of behaviour (Reynolds, 1983). Consequently, even simple ABMs can provide valuable insights into the dynamics of a real-world system that it aims to emulate (Bonabeau, 2002). Similarly, not only are they useful for demonstrating emergence from the local interaction of autonomous and heterogeneous agents, but it is also possible to extend the analysis to gain greater depths of knowledge regarding the inherent forces that drive the system and the key characteristics of what influences it. In this context, these models can be seen as a useful computational laboratory (Twomey and Cadman, 2002), where a variety of system configurations can be explored to guide decision-making (Hanusch and Pyka, 2007).

As a result of the above, ABM has been increasing in its application for policy analysis. This is because it enables to ask "what if" type policy questions that are sometimes outside the reach of traditional methodologies (Manuscript two). For example, Antonelli and Ferraris (2011) built a model to explore the effects of different system configurations of the intellectual property rights regimes with varying architectural setups of the regional structures in which knowledge interactions take place. The authors found that the dissemination of knowledge favours the emergence of creative reactions and hence results in faster rates of technological change. In addition, Lopolito et al. (2013) analysed the interactions amongst firm agents within a network and assessed the emergent dynamics from a range of different policy scenarios. They found that an information campaign targeted towards changing consumers' expectation into adopting new technology was more effective than subsidies. Furthermore, Cantona and Silverberg (2009) modelled heterogeneous consumers with different adoption thresholds regarding the introduction of a new energy technology. In this context, some consumers were willing to pay more for goods that were viewed as eco-friendly. Similarly, agents would adopt if any of their neighbours had and if the price fell below their reservation price. Results illustrated that subsidies can trigger diffusion of that particular technology that would otherwise not have happened.

The aforementioned models illustrate how different regulations can impact various policy-objectives within a market mechanism. It is a relatively new methodological approach and so there is limited research around this area. However, the author aims to address the gap of targeting policy towards both aiding the creator and penalising the imitator through increasing the stringency of regulation. Understanding these impacts is extremely important as the main inferences regarding this relationship is currently skewed towards using R&D and patent data (Manuscript one). Therefore despite these works providing valuable insights, it is important to use supporting methodologies to shed light on this debate by triangulating the findings. Considering this, the author develops an ABM to contribute towards this domain, but with particular focus towards the supply-side of the market mechanism. Therefore, facilitating the gap where competition dynamics has also been largely overlooked within the agent-based literature (Manuscript two).

The model in this context aims to replicate a market mechanism whereby agents behave without strategy when making their price and production decisions on the products that they own. The agents learn through a hill-climbing algorithm based on the profits that they make. Similarly, the agents decide whether to invent or imitate an existing technology based on pre-assigned imitation and innovation probabilities. An adaptive element is also introduced to analyse any economic cycles that may emerge within the model to demonstrate what theoretical world's society ends up in the absence of regulation. This is then used as a basis for comparison to see if it is possible to improve the system when analysing a variety of different policy scenarios.

The rest of the paper is organised as follows. Section two provides the background to the research area, including a breakdown of previous works and justification for the ABM approach. Section three then discusses the ABM design, before the analysis and results, which are presented in section four. The discussion and conclusion are set out in sections five and six.

2 Literature Review

2.1 Background and Overview

In an industry where innovation plays a key role, one wants to reward entrepreneurs for their investments in innovation. However, one also needs to do this without prohibiting follow-on creativity and without raising unreasonable barriers to market entry. Getting this balance right in sectors such as pharmaceuticals, entertainment and information and communications technology is a significant 21st century policy challenge (Reichman, 2000). A critical dimension of economic change is the conversion of knowledge and ideas into a benefit (Pol and Carroll, 2006), which may be improved products, processes or services (Schumpeter, 1942). This can be argued as critical for the development and competitiveness of firms, regions and nations (Blind, 2012a). Therefore, policies that aim to improve or promote conditions for innovation have become increasingly important (OECD, 2007).

Regulators in this context, have a wide range of policy-instruments to influence the system towards preferred outcomes for society. For example, economic policies try to provide suitable conditions within the marketplace, such as increasing competition and reducing unemployment (eg Aghion et al, 2005; Barbosa and Faria, 2011). Similarly, there are social policies that pressurize firms to focus on particular types of research, such as environmental policies that try to reduce carbon emissions (eg, Pickman, 1998; Fernadez-Cornejo, 1998). Furthermore, there are administrative policies that try to control economic actors within the system (eg Abrams, 2009; Lerner, 2009). This is to ensure companies play by a certain set of rules and conditions, such as intellectual property and copyright laws (OECD, 2007).

Despite policy trying to serve the best interests of society, regulation can also have negative implications upon it. For example, in some instances it can unintentionally erect barriers that may hinder the development of new research. A case in point is the Stop Online Privacy Act. This was a rejected bill put before the U.S. House of Representatives. It proposed several policies, such as increased powers for blocking websites, preventing search engines linking to them and consumers becoming responsible for the content that they view (USGP, 2011). However, fears arose regarding the long term implications of such a stringent policy as it may unintentionally hinder innovation in the long-term. This is because despite trying to ensure that content creators receive the fruits of their labour, future research may not get the necessary funding if the legal ramifications and risk for entrepreneurial exploitation becomes too high. Therefore, it stands to reason that if certain policies increase the uncertainty and compliance burden too aggressively, then it may negatively affect the rate of technological diffusion (OECD, 2012).

2.2 Framing the Problem

Therefore, through analysing the literature it is clear that there is a regulatory dilemma for policy makers concerning the stringency of regulation. For example, in regards to intellectual property and copyright legislation. It is argued that if policy-makers aggressively penalise companies, then firms’ will have the incentive to create something new. However, due to the reduction in imitation it can inadvertently reduce competition thereby lowering the economic pressure for invention (Harrison, 2008; Vanderkerckhove, 2008). On the other hand, if the protection is less stringent then that can entice competition, thus forcing companies to have to develop new ways of reducing cost or increasing revenue. However, this can lead to invention spillovers, which means if firms can copy new ideas without having to pay the upfront research costs it could reduce the reward for future invention, thus leading to a market collapse (Reenan 2014; Czarnitzki and Kraft, 2012).

2.2.1 Rewarding the creator

One solution to this dilemma is to provide government support in the form of R&D finance. It is argued that by rewarding companies with additional capital it can offset the risk of excessive imitation, thus aiming to help correct this under-provision problem. Makkonen (2013) highlights how government responses to correct this varies across the European Union (EU-27) member states; for example, within an economic downturn the majority of nations tend to be pro-cyclical. This is where government science and technology budgets shrink relative to the growing gross GDP.

However, it is argued that government support is essential to negate the negative impacts of the recession. In light of this, several scholars suggest that this may be a poor long-term strategy, illustrating that a counter-cyclical approach would be more appropriate (Paunvov, 2012; Makkonen 2012; Archibugi and Filippetti, 2011). Similarly, it also has been found that the economic downturn was less likely to affect those countries that have robust financial systems with strong governmental support for innovation activities prior to the crisis (Makkonen, 2012). However, it is hard to attain concrete conclusions due to the evidence around this area being sparse (Makkonen, 2013). According to Filippetti and Archibugi (2011), the evident lack of participation with economists studying innovation and the subsequent causes of the ongoing economic crisis speaks volumes (Makkonen, 2013; Archibugi and Filippetti, 2011; Paunov, 2012). One reason for this lack of attention is arguably due to the lack of timely and updated statistical data. Consequently, there is little available research regarding the impacts of government support for R&D.

According to the OECD (2010), there are two main types of government support for R&D: direct financial assistance (DFA) and indirect financial assistance (IFA), with mixed conclusions as to their effectiveness. DFA allocates money through grants and procurement whereas indirect support comes through R&D tax incentives, such as deducting tax from R&D related activities. The problematic concern with DFA is that it is not decided by the market mechanism, and thus it can be prone to policy failure. For example, government support can be awarded subjectively to firms with repeated success or larger firms deemed to be less risk. However, it is argued that SMEs tend to suffer most from financial constraints due to imperfect capital markets (Himmelberg and Petersen, 1994; Hall, 2002; Czarnitzki and Hottenrott, 2011). Therefore, it is argued that it can lead to perpetual dominance, thus reducing competition and in turn resulting in the monopolisation of markets. According to Vaergulers (2009), despite there being special themes for SMEs, more needs to be done. Alternatively, IFA is supposed to alleviate many of these issues by allowing the economic agents of the system to decide what type of project they apply for (Hall and Van Reenen, 2000), thereby allowing access to all types of firms within the economy. However, there is debate as to whether it is merely a substitute of public over private funding. In other words, it does not actually increase R&D rates but rather just rewards those that already conduct research (Etan 1999). Therefore, it is sometimes seen as nothing more than a bonus, which has little impact on decision-making. However, others argue that tax incentives increase R&D expenditure, which in turn leads to an increase in innovation output (Gonzalez and Pazo, 2005; Becker and Hall, 2013).

2.2.2 Penalising the imitator

Whilst government support for R&D seems to influence the regulatory dilemma, there is still much ambiguity about how effective it is. Consequently, it raises the notion as to whether penalising the imitator can be more effective at improving the system. For example regarding intellectual property theft, it is argued that if penalties are too severe then it causes market distortions that can negatively impact market efficiency and reduce innovation output. This is because granting monopoly is not seemed socially desirable as firms will have less incentive to invest in new ideas (Guell and Fischbaum, 1995). According to Barton (2002), this will subsequently slow down the rate of technological diffusion as it prohibits others from entering the market. This view is supported by Barbosa and Faria (2011), who found a negative association between intellectual property legislation and innovation intensity. In addition, Hunt and Bessen (2004) argue that increasing litigation rates for penalising imitation poses substantial risks for genuine inventors that try to improve on existing products for fear of litigation. Conversely, Varsakelis (2001) found that the more stringent the regulation the greater the investment in R&D. This is supported by Tuncak (2014), who through analysis of chemical regulations found that a stronger system led to an increase in patents. This was because it helped provide a safer marketplace by enforcing legitimately scrutinised products were released into the market. The findings were similar to those in a report by the ICC (2005) that looked at the pharmaceutical industry. They found that legitimate companies would have less revenue to reinvest to bring new products onto the market if the levels of counterfeit drugs rise. In that sense, imitation of existing products is perceived to be a negative drain on the economy. This is because it takes away money from innovators, which in turn reduces the incentive to invest in new products.

2.3 Innovation as a Complex System

Currently, there is much ambiguity when making sound policy decisions regarding the regulatory dilemma. One explanation could be the inherent complexity by which policy makers try to understand this phenomenon. For example, it is widely believed that the innovative process is a complex system (Katz, 2016). Regulation within this context is seen as a means of controlling agents within it. However, due to the complexity of these interactions it makes behaviour difficult to anticipate. Hence, failing to understand the complex systemic structure of the market mechanism and the integration of different policy instruments may well cause unintended consequences. Therefore, traditional reductional methodological approaches are likely to fail in these types of environments (Bonabeua, 2002). This is because actors in the system can often have conflicting goals and objectives that through their interactions may lead to unexpected patterns of behaviour. A case in point is the situation of consumers and companies. Arguably, consumers prefer the creation of new products as they will have more choice in price and quality, whereas companies prefer less competition within the market so that they can set prices and production at their preferred rate, thus capitalising on their investment. However, the latter cannot enjoy this state of affairs if other firms easily figure out how to imitate their products. This raises the notion of what would happen for both companies and consumers under a set of different research and imitation scenarios, and whether or not regulation can be used to steer these agents to better outcomes for society.

2.4 Agent-Based Modelling – An Improved Approach?

An ABM is well suited for capturing complexity within socioeconomic systems. It is a type of computational model that simulates the actions and interactions of autonomous agents, where through a collection of decision-making entities each assesses their own situation and makes a decision based on a set of predetermined rules (Bonabeua, 2002). Thus, repeated individual action leads to complex social institutions. Consequently, this gives rise to patterns, structures and behaviours that are not explicitly programmed into the models. Therefore, it offers a way to model systems that are composed of agents that interact and influence one another, and they can learn from their experiences and adapt their behaviours so that they are more suited to their environment. According to Bonabeau (2002), there are three main benefits of this approach over other modelling techniques. These are: (i) it is possible to capture emergent phenomena. This emergent phenomenon can have properties that are decoupled from the properties of the single entities; (ii) it provides a natural description of a system. For example, the system can be composed of behavioural entities, which are arguably the most natural and closest match to reality (iii) they are flexible. This flexibility comes in different dimensions, such as more agents can be included; similarly, their behaviour, degree of rationality, ability to learn and evolve can also be tuned.

Therefore, applications with ABM have been used across many different sectors and is increasingly being used to advise policy-making. It alleviates a lot of concerns advocated by Lucas in his critique of macro-economic policy, where he considers it to be unreliable to try and predict the effects of policy on the basis of the relationships observed in highly aggregated historical data. Therefore, by taking into account the microfoundations of agents – i.e. adaption and learning – it enables to offer greater insights for policy analysis (Lucas, 1976). Pyka and Fagiolo (2007) supports this, where they argue it is possible to conceive frameworks where experiments are carried out for a variety of different policy setups for a range of different configurations and behavioural rules.

Consequently, there have been a variety of ABMs that have looked at how different policy-instruments have shaped various parts of the innovation process. For example, there are models that analysed how entrepreneurial policies support entrepreneurs and new start-up companies (Garibay 2015; Malerba et al., 2001). Research and development policies such as government aiding public research (Blom et al., 2014; Hermann and Savin, 2017) and subsidies that target the development of specific technologies (Hermann and Savin, 2017; Brouilett and Oltra, 2012; Jianhua et al., 2008). In addition, there have been ABMs that have analysed intellectual property and the authorisation process of new products, thus aiming to protect invention (Brabazon 2013; Kwon and Motohashi, 2014; Antonelli and Ferraris, 2011). Similarly, adoption and diffusion models that have looked at subsidies in order to reduce adoption costs (Eppstein et al.,2011;Rixen and Weigand, 2014;Faber et al., 2010; Scwartz and Ernst, 2009; Cantano and Silverberg, 2009; Ferro et al., 2010; Sopha et al., 2013; Hemann and Savin., 2017; Vooren and Bruilett, 2015; Schwoon, 2006; Kauffman et al., 2009; Van der Vooran and Alkemade, 2012; Van der Vooran and Alkemade, 2012; Lee et al., 2014), sales tax that increases the price for certain technologies (Vooren and Bruilett, 2015; Schwoon, 2006; Lee et al., 2014), and information campaigns that increase innovation actors' expectation towards new technology (Arfaoui et al., 2013; Adepetu et al., 2016; Scwartz and Ernst 2009; Desmarchelier et al., 2013; Rixen and Weigand, 2014).

The aforementioned models are able to ask theoretical questions about how different policy scenarios will impact various policy-objectives within a complex system. However, as it is a relatively new methodological approach there is limited research around this area. Consequently, the author aims to facilitate the gap that analyses the stringency of two policy instruments that target both the inventor (i.e. through rewarding invention) and the imitator (i.e. by penalising the imitation of technology) framed in the context of the regulatory dilemma. Considering this, the author develops an ABM that represents a market mechanism, whereby firm agents behave at random when making their price and production decisions on the products that they own. Similarly, these companies decide whether to invent or imitate an existing technology based on pre-assigned imitation and innovation probabilities.

The approach aims to overcome a lot of critiques raised by Bouchard (2008) regarding neo-classical models. This is based on the notion that we have put too much faith in dogmatic axioms and models that simply just do not work because they are based on too many strong assumptions. Therefore, the author constructs the model with these criticisms in mind; for example, creating a hill-climbing algorithm where agents act in random in the search for profits, but also coupled with a mutation function that allows agent's to sometimes jump away from this algorithm (See section 3). In addition, through the analysis of the proposed model the author measures the interaction of the myriad of subtle strategies employed by the market participants through this iterative learning process. As such it is possible to separate out the effects of the market mechanism and agent strategy to determine the driving forces within it (Ladley and Bullock, 2004). This provides a basis to measure different policy-instruments and how they shape those dynamics.

3 The Simulation Model

The ABM has demonstrated that the market mechanism is capable of creating rational outcomes at the market level, even though individual participants may behave completely at random. Therefore, they can be capable of displaying characteristics closely matching those of a real market, even though real-world individuals differ in their sophistication. Considering this, the author has developed a hill-climbing algorithm where firms go through several stages of the innovation process: from production, to the marketplace, to operational and strategy decision making. Companies are considered commercial enterprises with the intent to maximise their profits. Products are defined as something that are manufactured for sale. Similarly, consumers are defined as people who purchases goods and services for personal use (See Figure 4.1).

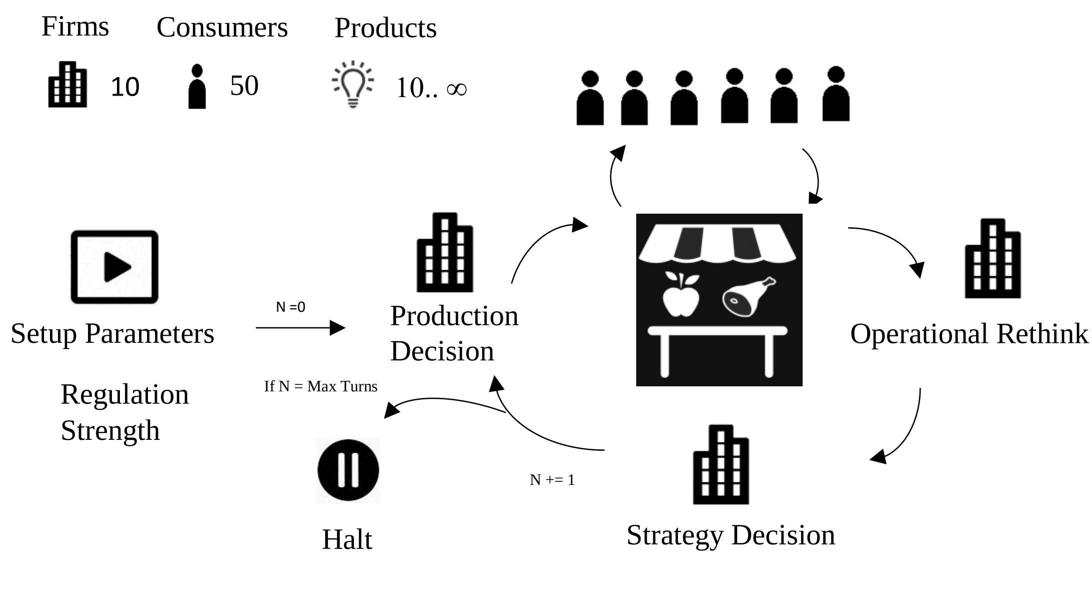


Figure 4.1: Agent-based model framework aiming to replicate typical market dynamics.

At the first stage, the setup parameters are initialised for the purposes of the simulation (See Table 4.1 for a comprehensive list; also the setup is supported by Algorithms 1 and 2). These range from duration of experiment, to what imitation and research strategies are assigned to agents, to how aggressive the different policy instruments are set. The companies go through several stages of the innovation process (see Algorithm 3). Firstly, the firms go into the production decision stage where they make price and production decisions regarding the products that they own. If they do not own a product then the company's stock of that particular item will remain at zero. If the companies hill climb strategy is the best one (starting default), then its current quantity and price will be set to 'best'. Conversely, if not then it will mean that an alternative strategy was run last time and so the current quantity and price will equal the price and quantity values of that 'alternate' strategy (see Algorithm 4). The company then produces that amount, which goes into their stock to sell in the market.

Once in the marketplace, a product price list is then created in order to see what companies are selling and for how much. This is because the consumer will purchase the lowest priced product. A purchase is made if the offering price is less than the consumer's limit price. If so, the company will reduce their stock by one and the money is added to its daily profit amount. The lowest priced company will keep on selling that product until it is out of stock. Once that has happened, it is subsequently deleted from the list and the process restarts (see Algorithm 5). After the firms have competed in the marketplace, if it was the company's hill climb best strategy then the daily profit for that day is recorded. This is to be used as a basis for comparison. The hill climb status will subsequently return to alternate (see Algorithm 6). Alternate price and quantity will then change to a random number between minus three and three. If it is not the best hill climb strategy then it means there was an alternate one, and so if the daily profit is greater than the previous best daily profit then that becomes the new best strategy (see Algorithm 8).

The final part of the days trading then looks at strategy decisions. This determines whether a company chooses to purchase or research a new product. This is dependent on the pre-assigned probability that is assigned in the initial set up conditions. If a company researches a new product then a new product object is created, with every company having product information about it. Similarly, all consumers will be assigned a limit price on this new technology. The company that researches it is declared the inventor, with the subsequent research cost deducted. However, if the company imitates another product then it will take the highest making product that the company in question does not own. It will then undercut the current market price by one, so long as this price is above manufacturing cost. If the simulation duration is not equal to the maximum number of days, the firm goes back to production decisions where the process restarts (see Algorithm 9).

This section has briefly explained the underpinning dynamics to our ABM. The next section will give a comprehensive technical explanation as to the inner workings of the code.

3.1 Technical Explanation of the model

The first part of the simulation is to create the initial starting conditions. They are made up of several parameters where the market setup is consistent for each experiment with the inclusion of several changing parameters, such as *RProb* and *IProb*. These are research and imitation probabilities that are used to compare different outcome states of the system. Similarly, the hill climber price variation is how much companies randomly change price and quantity (See Table 4.1).

Pseudo	**Parameter**	**Default Value**	**Object**	**Description**
N	Simulated turns	500		How long does the experiment last
Co	Number of Companies	10	*Co*	How many companies are in the simulation
Pr	Number of Products	10	*Pr*	Each company is given a starting product with its own demand.
Cons	Number of consumers	50	*Cons*	Every consumer has a limit price for every product
ManC	Manufacturing Cost	Rand(1,maxManc)	*Co, Pr*	Cost to produce product
maxManC	Max Manufacturing Cost	20		
maxP	Maximum Price	100		The maximum price for a product. This is equal to the consumer limit price.
Dp	Daily Profit	0	*Co, Pr*	This is the recorded amount of profit made for each product.
hillClimb	Hill Climber	Best	*Co, Pr*	Hill Climb status: Best/Alternate
cuQ	Current Quantity	0	*Co, Pr*	Companies' current quantity of product
cuP	Current Price	0	*Co, Pr*	Companies current price of product
altQ	Alternative Quantity	0	*Co, Pr*	Companies' alternative quantity of product
altP	Alternative Price	0	*Co, Pr*	Companies' alternative price of product
St	Stock	0	*Co, Pr*	Companies' stock of product
beQ	Best Quantity	rand(1, maxC)	*Co, Pr*	Companies' best quantity of product
beP	Best Price	rand(2, maxP)	*Co, Pr*	Companies' best price of product
bestCo	Best Company	0	*Co, Pr*	Best Priced Company
LimPrice	Limit Price	rand(1,100)	*Cons, Pr*	
randCo	Random Company	0		Select Random Company
hillV	Hill P\Q Variation	**{-3, -2,…,3}**		How much price and quantity can change by
mutP	Mutation Probability	0.02		The percentage rate when P/Q will jump from HillClimber
iProb	Imitation Probability	**{0,0.2,…, 0.10}**		Probability rate company will imitate
rProb	Research Probability	**{0, 0.2,…, 0.10}**		Probability rate company will research
Bv	Best Value	0	*Co, Pr*	Best value to compare against Daily Profit
Mon	Money	0	*Co*	Companies' bank balance
resC	Research Cost	-36000		Research costs is determined by calculating 20% of total turnover dividing by the total amount of products when research is at maximum. This is to reflect a high research world when the research parameter is set to 100%.

Table 4.1: Model parameters.

The model contains consumers (*Cons*), companies (*Co*) and products (*Pr*). Each company is assigned a product and a bank balance starting with zero. Similarly, each firm has product information regarding each particular product (*Co, Pr*). When setting up each company's product information, for each product the author determines the initial starting conditions as shown below:

Algorithm 1: Assigning Companies information about each product

```
For each co ∈ Co
    For each pr ∈ Pr
        hillClimb Co, Pr = "Best"
        cuP Co, Pr = rand.Int(2, maxP)
        cuQ Co, Pr = rand.Int(1, maxC)
        manC Co, Pr = rand.Int(1, maxManC)
```

Similarly, each consumer has a unique price limit for each product that they are willing to pay, which is a random number between 1 and *maxP*:

Algorithm 2: Assigning Consumer limit price to every product

```
For each cons ∈ Cons
    For each pr ∈ Pr
        LimPrice ← randInt(1, maxP) # creates a limit price
```

As demonstrated in Figure 4.1, once the simulation is run it goes through several stages of the innovation process: from production, to the marketplace, to operational and strategy decision making. Algorithm 3 demonstrates the main loop for each day of the simulation.

Algorithm 3: Main process for simulation

```
For each day in max(days)
    doProductionDecisions()
    doMarketplace()
    doOperationalDecisions()
    doStrategyDecisions()
```

At the production stage, each company will make a pre-market planned amount for production based on whether they own the product or not. If they do not own it then stock ($St_{Co, Pr}$) will remain at zero.

Algorithm 4: doProductionDecisions

```
For each co ∈ Co
        For each pr ∈ Pr
                dp Co, Pr ← 0 #set daily profit to zero
                If (Owned Co)    # if owns product
                        If (hillClimb Co, Pr ←"Best")
                                cuQ Co, Pr ← beQ Co, Pr
                                cuP Co, Pr ← beP Co, Pr
                        Else
                                cuQ Co, Pr ← altQ Co, Pr
                                cuP Co, Pr ← altP Co, Pr
                        st Co, Pr ← cuQ Co, Pr
                        dp Co, Pr ← - (cuQ Co, Pr * manC Co, Pr)
                Else
                        st Co, Pr ← 0
```

Once firms have established how much to produce and at what price, they go into the marketplace with the goods that they own. This is where consumers and companies gather within the system for the purchase and sale of the goods made. At first, both the consumer and company list is shuffled in order to ensure that there is no selection bias (i.e. if a company offers a product at the same price). A global price list is created in order to see which companies are selling what products and for how much. This is so the consumer can purchase the product at the lowest rate. A purchase is made when the offering price of a company for a particular product ($cuP_{Co, Pr}$) is less than the consumers' price limit for that product ($limPrice_{Con, Pr}$). The company's stock ($st_{Co, Pr}$) will reduce by one, and the money made is added to its daily profit amount ($dp_{Co, Pr}$). As consumers will purchase the lowest priced product, the company with the lowest price will keep on selling that product until it is out of stock. Once that has happened it is subsequently deleted from the global product list and the process restarts.

Algorithm 5: doMarketPlace

```
For each cons ∈ Cons
    For each pr ∈ Pr
        var bestCo ← ∅
        var bestPrice ← ∞
        For each co ∈ Co
            If stock Co, Pr > 0
                If CuP Co, Pr < besP Co, Pr
                besP = CuP Co, Pr
                bestCo = Co
        If bestCo != ∅
            Stock BestCo, Pr -= 1
            Utility += LimPrice Cons, Pr – CuP BestCo, Pr
            dp BestCo, Pr += CuP BestCo, Pr
```

After the firms have competed in the marketplace, daily profits (dp $_{Co, Pr}$) are recorded in their bank account (mon *Co* ← dp $_{Co, Pr}$). Each company will then evaluate their strategy by comparing it with the previous day. If it was the company's hill climbs 'best' strategy then the daily profit (dp $_{Co, Pr}$) for that day is then assigned as the best value (bv $_{Co, Pr}$), which is used as a basis for comparison. For example, if it was not the HillClimbers best strategy then it means that an alternate strategy is implemented. Consequently, if the daily profit (dp $_{Co, Pr}$) is greater than the best value (bv $_{Co, Pr}$), then that becomes the new best strategy, where price and quantity are recorded as the best strategy (besP $_{Co, Pr}$ ← altP $_{Co, Pr}$; besQ $_{Co, Pr}$ ← altQ $_{Co, Pr}$), with the hillClimb changed to 'alternate'. However, if it is less than the daily profit then hillClimb remains as 'best'.

Algorithm 6: doOperationalDecisions: Changing P/Q

```
For each co ∈ Co
    For each pr ∈ Pr
        mon Co ← dp Co, Pr
        If (hillClimb Co, Pr ←"Best")
            bv Co, Pr ← dp Co, Pr
            hillClimb ←"Alternate"
            besP Co, Pr ← altP Co, Pr
            besQ Co, Pr ←altQ Co, Pr
            altQ Co, Pr, altP Co, Pr ←Variate (AltP Co, Pr, AltQ Co, Pr)
        Else
            If dp Co, Pr > bv Co, Pr
                besQ Co, Pr ← altQ Co, Pr
                besP Co, Pr ← altP Co, Pr
                bv Co, Pr ← dp Co, Pr
                hillClimb Co, Pr ← "Alternate"
                altQ Co, Pr, altP Co, Pr ←Variate(altP Co, Pr, altQ Co, Pr)
            Else
                hillClimb Co, Pr ← "Best"
```

When trying a new strategy, price and quantity are changed. This is determined by the variation function, where price and quantity are varied between -3 and 3. A mutation function is also included so that price and quantity will randomly jump away from the hill climbing algorithm. This is because agents will not always get to the optimal price or quantity due to being comfortable with the current profits that they are generating. In addition, should the values of price and quantity be negative then this is automatically corrected.

Algorithm 7: Variate

Input: altP $_{Co, Pr}$; altQ $_{Co, Pr}$

Output: altP $_{Co, Pr}$; altQ $_{Co, Pr}$

```
minP ← manC + 1
mod ← rand(hillV)
If (rand(%) < 0.5)
        altP ← altP + mod
else
        altQ + mod
If (rand(%)< mutP
        AltP ← rand(minP, maxP)
If (rand(%)< mutP
        altQ ← rand(1, maxCon)
If altQ < 0
   altQ ← 0
If altP < 2
   altP ← 2
Return altP, altQ
```

The next step determines whether a company chooses to purchase or research a new product. The company will adopt and/or research a new product depending on the pre-assigned research and imitation probabilities.

Algorithm 8: doStrategyDecisions

```
randCo ←  rand (co ∈ Co)
If iProb_Co > rand(%)
   Adopt New Product(randCo) # selected company adopts highest
making                                    profit
If RProb_Co > rand(%)
   Research Product(randCo) # selected company researches a new
product
```

Should a firm choose to imitate another product, then the chosen product will be the one that is the highest making product that the company in question does not own. It then undercuts the current market price by 1, so long as this price is above its manufacturing cost. Additionally, should a company research a new product then a new product object is set up, with each company having product information regarding it and all consumers having a price limit for the product similar to Algorithm 1. The company that researches it is declared the inventor, with the subsequent research cost deducted accordingly. The research cost is determined by assuming that a high research company tends to invest 20% of their overall turnover (Jaruzelski et al., 2005).

Overall, the author has provided an explanation as to the underpinnings of the ABM. It is noteworthy that pseudocode is left out if deemed unnecessary. Similarly, there are several extensions that are provided within the analysis and results section for easier explanation, such as integrating the different policy instruments into the model. The next section aims to discuss the simplification of the model. In addition, how the modelling philosophy influenced the selection of the initial conditions and the sensitivity of the results is also discussed. Furthermore, what the changing parameters were when the rest of the system was constant.

3.2 Model Selection and Validation

The ABM was built with trying to limit the modelling assumptions as much possible. This is because the more assumptions that are included into the model the higher the risk that it cannot be solved analytically. Therefore, by including a minimal amount of variables and mechanisms within the system design the author aimed to alleviate many of these concerns. For example, an almost-assumption-free hill climber was developed where companies would learn to profit maximise through trial-and-error. The purpose was to demonstrate that the market-mechanism is capable of creating rational outcomes at the market level, even though individual participants behave randomly. Consequently, the algorithm was analysed in the context of a variety of different settings to validate the algorithm to ensure that it behaved as expected.

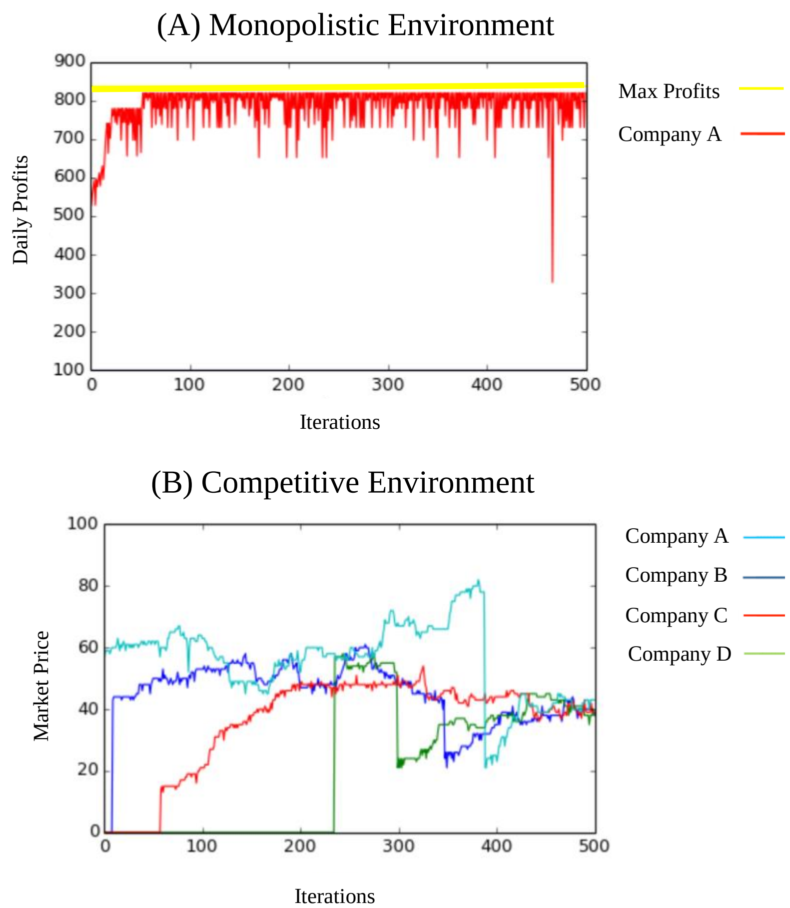


Figure 4.2: Validating the model: (a) depicts how firms learnt under a monopoly environment; (b) depicts how firms interact within a competitive environment.

As demonstrated by Fig 4.2, under a monopoly environment where a product has been invented without other companies being able to enter the market. The firm learns to profit maximise to the optimal amount over a period of about 50 iterations – the yellow line depicts the maximum profits available by aggregating the consumers' limit price. In addition, the dips on the red line illustrate the mutational leaps, where the chosen firm has tried a random price or quantity strategy. Tests were also applied to assess competition. In this context, firms were allowed to imitate someone else's innovation and thus enter an already existing market. In this scenario, companies learnt how to compete with one another through experience. For example, at around iteration 400, Company A dramatically reduces its price and as that was a more effective strategy, other firms then had to re-adjust their behaviour. In this instance, it led to a "price war" at around iteration 450. Therefore, not only does help to validate the model but it also highlights how a simple and abstract design based on as little assumptions as possible can demonstrate interesting market dynamics as witnessed in the real world.

The selection of initial conditions is also reflected in this modelling philosophy. For example, when designing the market mechanism there is a variety of conditions that could have been implemented. For example, budget constraints, venture capital and a more sophisticated product landscape. However, by restricting the amount of the initial conditions the model became easier to check for accuracy in its emulation towards reality. This is because the dimensions of a model can be so numerous that they can generate any results. Similarly, the causal relations between these assumptions become increasingly difficult to study. Considering this, sensitivity analysis was applied to assess the relevant inputs and how they influenced system behaviours. This is important as it identifies the significant parameters that may affect the results. In this context, the model was found to be sensitive to research cost. However, this was to be expected as the development of new products plays a central part in the model. Therefore, by calibrating the parameter using empirical estimates from R&D budgets it ensured that the cost of research was not too low that it had no desired effect, nor too expensive that there was no incentive to create. In addition, the non-sensitive parameters of the initial conditions were also modified in order to enhance efficiency. For example, reducing the amount of agents, the duration of the simulation and by increasing the price variance of the mutation function to speed up the way firms learnt.

Once the market mechanism was validated to a satisfactory standard counterfactual analysis was then applied. In this context, two changing parameters were implemented. These were research and imitation probabilities that are used to compare the outcomes of the system. Innovation is thus viewed as a stochastic process to reflect that firms cannot know perfectly the results of their R&D activity. Similarly, Imitation is also modelled in this way to demonstrate that some companies have a higher inclination to imitate than others do. The results from these experiments provided the basis for the policy experiments, where the author introduced two new policy parameters. One focused on reducing research cost to reflect government support for R&D (See section 4.1); whilst the other looked towards heightening the penalty for imitation by increasing the probability of firms' being caught with a fine (See section 4.2).

4.0 Analysis and Results

In this section, the author explains the analysis and findings of the experiments. First, the author ran the simulations, whereby the agents had different imitation and research probabilities. This was used to compare different system states or ‘worlds’ to see what consumers and companies preferred. Second, an adaptive element was integrated, with the aim of seeing what fixed “world” one ends up with. The final step then aimed at elaborating on these findings by testing different policy instruments. This was in order to see whether it is possible to improve on the results of step two. Due to the stochastic nature of the experiments, the author repeated each setup 1000 times to obtain statistically significant results, but highlight the average results over these independent experiments. The research and imitation strategies were the control parameters for the simulation (See Table 4.2 for an overview of the settings).

Parameter	Value	Description
Number of Companies	10	How many companies are in the simulation
Starting number of Products	10	Each company is given a starting product with its own demand.
Number of consumers	50	Every consumer has a limit price for every product
Maximum Manufacturing Cost	20	
Simulated turns	500	How long does the experiment last
Maximum Price	100	The maximum price for a product. This is equal to the consumer limit price.
Big Mutation Probability	0.05	After every turn what is the probability to jump P/Q quantity away from the hill climbing algorithm
Research Costs	36,000	Research costs is determined by calculating 20% of total turnover dividing by the total amount of products when research is at maximum. This is to reflect a high research world when the research parameter is set to 100%.
Consumer Limit Price	100	The maximum price that consumers are willing to pay
Hill Climber Price/Quantity Variation (HillV)	**{-3, -2,…,3}**	**This is the range of change of price that each turn the company will try**
Research Probability	**{0,0.2,…, 0.10}**	**This is the company’s inclination to research**
Imitation Probability	**{0, 0.2,…, 0.10}**	**This is the company’s inclination to adopt an existing technology**

Table 4.2: Updated model parameters.

The first part of the simulation was to identify what artificial environments were to be observed when the economic agents were assigned different imitation and research probabilities. These fixed worlds were used as a basis to gauge the effectiveness when altering the experiments with different policy instruments (See Figure 4.3).

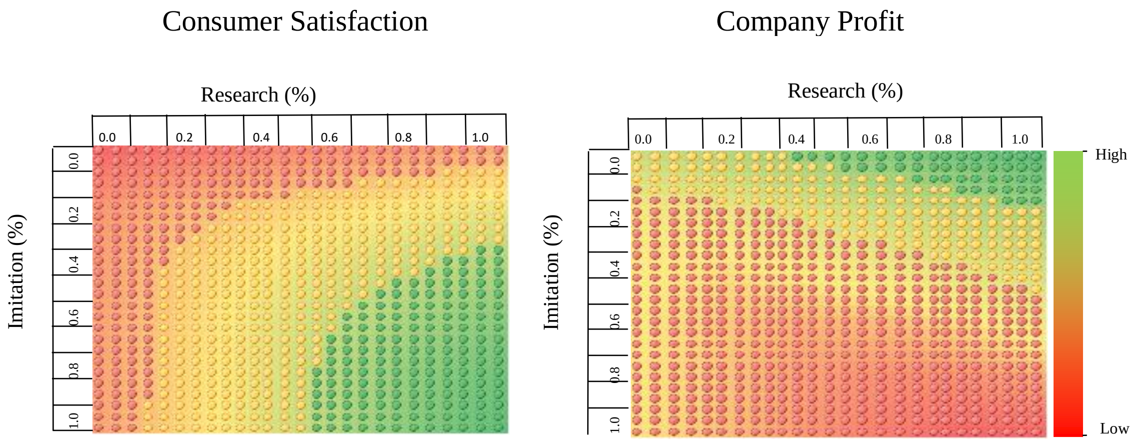


Figure 4.3: Two heat maps illustrating consumer satisfaction and corporate profits. This was measured under a range of different imitation and research scenarios.

Figure 4.3 presents two heat maps. The green represents the highest value and the red the lowest. The left map depicts consumer satisfaction and the right map illustrates the highest average profit for all companies. The x-axis highlights the imitation probabilities with the y-axis showing the research percentages.

As demonstrated, consumer satisfaction seems to be optimised in an environment when both research and imitation is set at 100%. However, companies' profits seem to be maximised when research is at 100% but imitation is at 0. Therefore, there appears to be a conflict of interest between the imitation rates. Firms were found to prefer an environment where they can capitalise on their investments and enjoy monopoly profits, whereas consumers prefer more competition as it means that there are lower priced products with more variety of innovation on the market.

In support of these findings, a Pareto analysis was undertaken. This was aimed at identifying whether there was an outcome that could increase the utility of one agent type without reducing the utility of another. Such an outcome is efficient if no utility is wasted. Therefore, within this context the aim was to see whether there were any optimal states between consumers and companies within these fixed worlds to see if it is possible to improve one agent type without hurting the other (See Figure 4.4).

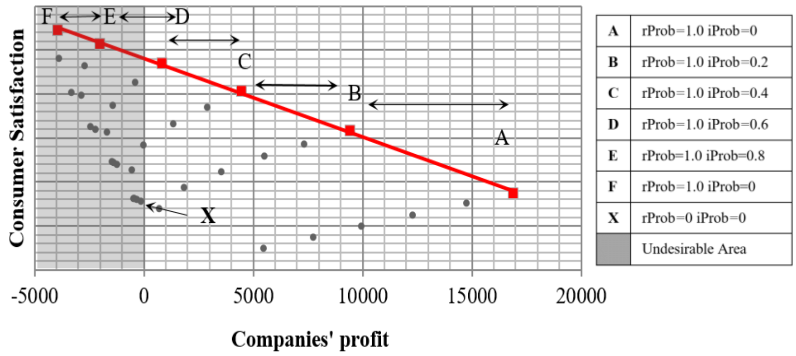


Figure 4.4: Pareto analysis of all research and imitation scenarios.

As depicted, the dots on the diagram illustrate different states of the system. For example, the dot marked ‘X’ illustrates a world where the environment has no research or imitation. The red line represents the Pareto optimal solution for both consumers and companies. The letters A to F illustrate the different strategy points on the Pareto line. Each strategy point along this is when *rProb = 1.0*, with the probability variations between *iProb* determines whereabouts on this line. Therefore, it appears that it is in the best interest of both firms and consumers to create as much novel technology as possible. However, whilst consumers maximise their utility when *iProb = 1.0*, the converse is observed with companies. This implies that it is impossible for policy makers to satisfy the optimal solution of both parties simultaneously. Consequently, a trade-off arises in regards to how much imitation policy makers should allow. In addition, policy changes between the different scenarios on the Pareto line seem to yield different impacts; for example, a policy change from A → B seems to have a larger impact than a change from C → D. Furthermore, when *iProb* is beyond 60%, it creates an unsustainable world where firms make a collective loss. In that sense, too much imitation has a negative impact on the system. Therefore, policy makers need to be aware of how much to allow before it will cause negative results.

As illustrated by Figure 4.3, there are antipodal differences between consumers and companies in the world that they prefer to live. However, it could be argued that firms will choose the world that best suits them (i.e. monopoly world free from competition), thus raises the notion what world society would end up with. Consequently, the author introduces a deviant company that aims to improve its pay-off by changing strategies based on what all other companies are doing. It stands to reason that if the deviant company can improve its position, then all other companies will adopt that strategy and so on. It therefore becomes an iterative game-theoretical question as to what would happen if a firm could adopt a new strategy in relation to what all other companies are doing in infinitely many periods (See Figure 4.5).

Figure 4.5: The adaptive cycle through the introduction of a deviant company.

The first part of this iterative process was to identify the best strategy for all the companies. This was found to be when *R = 1.0* and *I = 0* (See Table 4.3).

I \ R (£000)	0.0	0.2	0.4	0.6	0.8	1.0
0.0	546	774	996	1,227	1,475	**1,687** (SS)
0.2	67	183	355	548	731	944
0.4	-14	-55	-1	133	288	446
0.6	-34	-122	-170	-142	-42	83
0.8	-44	-139	-225	-286	-270	-202
1.0	-50	-149	-246	-331	-390	-393

Table 4.3: Pay-off matrix of all companies, highlighting starting strategy (SS) at *rProb* = 1.0 and *iProb* = 0.

Therefore, as there was no initial pure strategy equilibria the deviant company was able to improve its pay-off from all other companies. This was because the imitative strategy was very effective as no other firms were competing in the marketplace.

I \ R (£000)	0.0	0.2	0.4	0.6	0.8	1.0
0.0	489	1,458	2,454	3,346	4,281	5,043
0.2	691	1,689	2,637	3,584	4,477	5,202
0.4	930	1,909	2,811	3,749	4,685	5,454
0.6	1,130	2,050	3,015	4,012	4,930	5,605
0.8	1,319	2,288	3,236	4,163	5,142	5,801
1.0	1,482	2,499	3,429	4,357	5,360	6,065 (BR)

Table 4.4: Pay-off matrix of deviant company, illustrating its best response when all other firms are at rProb = 1.0 and *iProb* = 0.

As demonstrated by Table 4.4, the deviants best response became a highly imitative and innovative one at *rProb = 1.0* and *IProb = 1.0*. However, when all other companies adopted this new strategy it led to a market collapse. In consequence, the deviant companies response was therefore severely restricted within this new environment; for example, all strategy points were making losses except strategy point *rProb = 0* and *iProb* = 0, which was subsequently the deviants best response in relation to the previous cycle (See Table 4.5).

I \ R (£000)	0.0	0.2	0.4	0.6	0.8	1.0
0.0	8 (BR)	-23	-62	-105	-156	-193
0.2	-34	-66	-105	-141	-204	-229
0.4	-69	-105	-136	-177	-237	-269
0.6	-106	-135	-176	-223	-257	-288
0.8	-139	-178	-211	-251	-286	-319
1.0	-257	-211	-250	-290	-334	-347

Table 4.5: Pay-off matrix of deviant company illustrating its best response when all other firms are at *rProb* = 1.0 and *iProb* = 1.0.

Once all other firms adopted this new strategy: *rProb = 0* and *iProb* = 0. The results suggest that the deviant company could make improvements at all other strategy points (See Table 4.6).

I \ R (£000)	0.0	0.2	0.4	0.6	0.8	1.0
0.0	493	685	893	1,118	1,309	1,494
0.2	1,393	1,602	1,767	2,020	2,168	2,446
0.4	1,757	1,957	2,176	2,381	2,574	2,783
0.6	1,895	2,102	2,313	2,516	2,714	2,923
0.8	1,949	2,153	2,369	2,590	2,779	2,969
1.0	1,989	2,219	2,380	2,566	2,827	**3,034** (BR)

Table 4.6: Pay-off matrix of deviant company illustrating its best response when all other firms are at *rProb* = 0 and *iProb* = 0.

However, its best strategy was when *rProb = 1.0* and *iProb = 1.0*. Therefore, the agent has moved back to the highly unstable and volatile world. This adaptive process found an emergent cyclical pattern between the two strategy points: *rProb=0.0, iProb= 0.0* and *rProb=1.0, iProb= 1.0*. In other words, it seemed to have created a very unsustainable boom and bust economic cycle (See Figure 4.6).

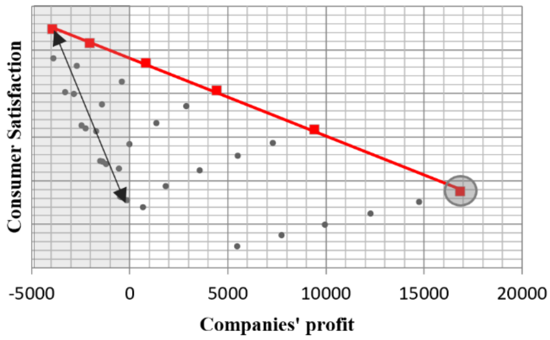


Figure 4.6: Visual representation of the economic cycle. The red line depicts the Pareto optimal for both consumers and companies. The circle depicts where firms collectively would like to be, with the arrow highlighting the cycle of where they end up.

As demonstrated in Figure 4.6, the agents ended up making overall losses between these two strategy points marked by the line. Consequently, both innovation rates and consumer welfare is severely affected within this cycle. Therefore, the authors introduced two policy-instruments to see whether it is possible to improve the system towards different strategy points on the Pareto line. These were offering governmental support in the form of R&D and penalising imitators by increasing the stringency of monetary penalties for imitation.

4.1 Government Support for R&D

Firstly, the author examined the impact of government support for R&D. This is assumed to reduce the compliance burden research has on a company (Blind, 2014; Stewart, 2010). Therefore, in respect to the ABM, one solution was to reduce the expenditure cost for researching a new product. The results of the simulation found that government aid, despite injecting the system with additional financial capital for the inventors, had surprisingly little effect until significant investment was injected. This was due to the deviant's best response strategy always being a highly imitative and innovative one. This led to similar destructive pattern as seen with the unregulated approach. However, once financial assistance surpassed 125% of total remuneration, it managed to help stabilise the system from a market collapse. This is because the deviants' best strategy shifted from *rProb =0* and *iProb = 0* to *rProb = 1.0* and *iProb = 0* (See Table 4.7).

Without Government Intervention

I \ R (£000)	0.0	0.2	0.4	0.6	0.8	1.0
0.0	**8** (BR)	-23	-62	-105	-156	-193
0.2	-34	-66	-105	-141	-204	-229
0.4	-69	-105	-136	-177	-237	-269
0.6	-106	-135	-176	-223	-257	-288
0.8	-139	-178	-211	-251	-286	-319
1.0	-257	-211	-250	-290	-334	-347

Government Intervention: From 125%

I \ R (£000)	0.0	0.2	0.4	0.6	0.8	1.0
0.0	8	13	23	29	39	**42** (BR)
0.2	-32	-27	-10	-3	1	8
0.4	-66	-57	-52	-43	-31	-24
0.6	-104	-102	-94	-91	-67	-56
0.8	-158	-142	-134	-117	-111	-102
1.0	-185	-185	-174	-171	-146	-127

Table 4.7: Pay-off matrix of deviant company comparing its best response with and without government intervention.

This implies that government intervention seems to have the desired effect in terms of stimulating innovation over the long-term, but only when there is substantial injection of capital into the system (See Figure 4.7).

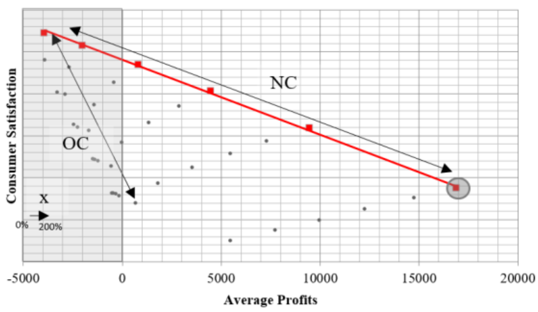


Figure 4.7: Different economic cycles, with and without government subsidies. NC = New cycle, OC = Old cycle.

As indicated by OC, the old cycle fluttered between an unsustainable economic cycle between the two points. As illustrated by Figure 4.7, invigorating the system with additional capital shifted some strategies towards sustainable levels, marked "X"; however, only at 125% did this stop the boom and bust economic cycle to a more sustainable one (see NC). Of note, only when government aid was set at 200% did all firms collectively make a profit at that strategy point.

In summary, government aid managed to stop a market collapse, creating a system that led to novel technologies being maximised. However, as there were no penalties faced by the deviant firm for imitating, this meant that the markets became unsustainable; subsequently, this led to the monopolisation of markets that in turn increased prices and consumer dissatisfaction. Furthermore, it only had the intended effect once government aid was at a very high rate. The reason for this was that despite making research essentially free, if firms can easily imitate and undercut then the creator stands to make huge losses. Considering this, policy makers must not only consider the costs of research but additional compensation costs for introducing a product to the market. Furthermore, it raises the notion as to whether other policy instruments that are aimed at slowing down ‘spill over’ effects would be more effective to counter-act the unregulated destructive economic cycle.

4.2 Intellectual Property: Increasing the Penalty Probability for Litigation

The purpose of this experiment was to analyse whether it is possible to improve the system by increasing the stringency of regulation for slowing down imitation. It stands to reason that stringent penalties that penalise imitation will greatly diminish innovation and harm consumer welfare in the long run. Arguably, this is because it can lead to monopolies, whereas weak regulation will lead to market failure as illustrated in Figure 4.5. Therefore, it raises the question as to whether it is possible to maximise innovation by increasing the stringency of the penalty. Consequently, the author included two new parameters to the ABM: regulation amount (*RA*) and regulation rate (*RR*) - *RA* is how much the fine should be, and *RR* is the probability of getting caught should a firm imitate. *RR* is determined by assuming that regulation can be as aggressive as required to the extent that it can make a company go insolvent. Therefore, by increasing the *RA* between $\{0,...,\infty\}$ when *RR* = 1.0, it becomes possible to work out how aggressive the regulation needs to be when all strategies make a loss at that particular setting. In other words, there is a cut-off point whereby it is pointless to make the regulation more aggressive past this point. This was found to be when RA = £250,000. Consequently, for the purpose of the experiment *RA* became a fixed parameter at this amount. *RR* was then considered a changing percentage parameter between 0 and 1. Hence, the author tested each amount and compared them against the different system states.

The results of the analysis found similar patterns to the non-regulated approach until *RR* = 0.37. At this rate of stringency the best deviant response changed from previously *rProb= 1.0 and I= 1.0* to between *rProb = 1.0 and I= 0.2/0.4* and then back to *rProb = 1.0 and iProb = 0.0* (See Figure 4.8).

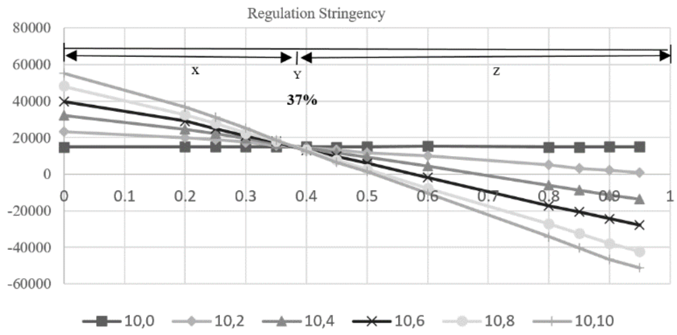


Figure 4.8: Highlighting the best deviant response strategies, highlighting five for simplicity: *rProb*=1.0, *iProb* = {0.0,.0.2,..,1.0}. X = market failure between *rProb* = 1.0, *iProb =1.0 and rProb=0.0, iProb =0.0*. Z highlights the range where stringency is so aggressive that it is in nobody's interest to imitate, *rProb=1.0, iProb =1.0.* Y, represents a period whereby one can change the strategy between *rProb=1.0* and *iProb =0.2/0.4.* (P<0.01); although we could not statistically determine between the two strategy points iProb = 10,2/10,4.

This led to two improved strategy points: *rProb = 1.0, I= 0.2,* and *rProb = 1.0, iProb = 0.4.* However, despite these strategies being statistically significantly different from all other strategies, between these two they were not. This meant that the author could not determine what the best response would be between these two settings. Interestingly, *rProb = 1.0, iProb = 0.2* strategy led to a sustainable system where all firms made a collective profit; as opposed to, *rProb = 1.0, I= 0.4* which did not (See Figure 4.9).

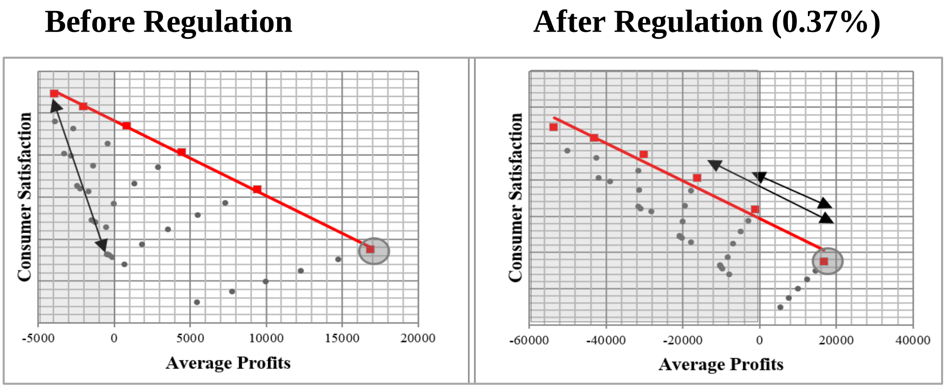


Figure 4.9: Comparison of the market before and after regulation when stringency is set at *RR = 0.37*.

Despite this being a significant improvement as oppose to government intervention, as the author could not statistically determine between the two strategy points for certain, sometimes, some companies would make an overall loss and sometimes they would just break even. The economic cycle, in other words, changes from a boom and bust to one more favourable, which was *rProb = 1.0* and *iProb = 0* to *rProb =1.0* and *iProb =0.2/0.4*. Considering this, the next step was to try and stabilise the system by injecting money back into the system, similar to what was observed with government support for R&D. This was achieved by awarding the penalties back to the inventors that the imitators stole from.

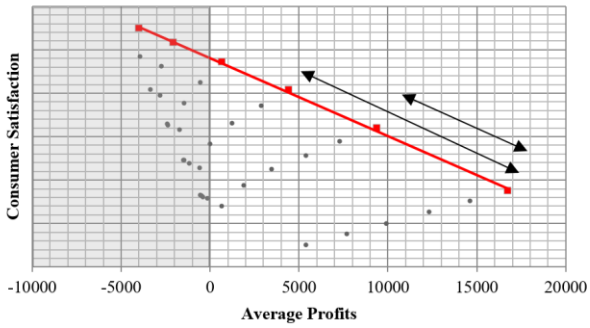


Figure 4.10: Giving investors the fines that were taken from the imitators when stringency is set at *RR = 0.37*.

As depicted by Figure 4.10, this created a more stable system where the deviant company floated once again between *rProb = 1.0* and *iProb = 0 to rProb =1.0* and *iProb=0.2/0.4*, thereby creating an artificial world that did not suffer from complete collapse nor did it inhibit creativity. In fact, innovation was maximised with consumer happiness also being improved relative to all other approaches. Furthermore, the system was also systematically stable, thus ensuring that companies made a collective profit overall.

5 Discussion

The purpose of this paper was to analyse how different policy-instruments can be used to shape the innovation process targeted towards both the creator and the imitator. The first part of the analysis measured different artificial worlds based on fixed research and imitation strategies. This was to identify in which theoretical 'worlds' companies and consumers prefer to live. It was found that novel innovation was mutually beneficial for both parties; however, the difference was between imitation probabilities. Hence, in line with classical economics consumers preferred a world with more competition as it brought in more product variety and lower prices. Conversely, companies preferred less competition so that they could enjoy their monopoly profits.

Interestingly, policy changes that occurred when already in a highly imitable world tended to have less impact on environments where this was low. This is arguably reflected in the real world; for example, breaking up a monopoly would arguably have a greater compliance burden on incumbents than, say, heightening stringency within an already competitive environment. This is supported by Stewart (2010) who argues disruptive regulation creates technological change that makes companies have to undergo radical engineering. According to Blind (2012a), in such circumstances they should allow time for firms to adapt to this high compliance burden. For example, within the European airline deregulation (SMAT), airlines were large state-owned monopolies protected from the forces of competition. Consequently, this created market distortions that resulted in an inefficient trade-off between imperfect competition and imperfect regulation (Johnson and Turner, 2016). Thus, deregulation in a series of packages gradually eliminated the major barriers to competition, and so new players emerged offering more variety and lower fares, such as low-cost airlines and niche operators (Rammurti and Sarathy, 1997).

The next part of the analysis aimed to discover what artificial world one would end up with without the need for regulation. This was achieved through the introduction of a deviant company, whereby it would try to improve its pay-off against all other firms' strategies. If that yielded a greater pay-off then all other firms would adopt it (and so on). This adaptive process illustrated an interesting business cycle. According to Burns and Mitchell (1946), this is a type of fluctuation found in the aggregate economic activity of nations that organize their work mainly in business enterprises: a cycle consists of expansions occurring at about the same time in many economic activities, followed by similar general recessions, contractions, and revivals which merge into the expansion phase of the next cycle. The reason for this contraction is known as a tragedy of the commons. This is where individual agents acting independently in their self-interest behave contrary to the common good of all users by depleting that resource through their collective action (Hardin, 1968). In that sense, this seems to be in line with the findings of Aghion et al. (2005), whereby the amount of competition in the market created an inverted relationship to the number of products that were released. This type of behaviour is not uncommon within the real world; for example, with overfishing where the world's fish stock has been gradually decreasing as companies act in their own self-interest (Agrawal, 2003).

The effects of government support for R&D was considered to try to improve the system. The results found that it managed to stop a market collapse, with the system fluctuating between a highly imitative and innovative world and a monopolistic one. This was because it provided additional capital to stop the systemic failure. In that sense, it implies that a pro-cyclical approach currently adopted by most EU-27 member states may not be the most viable long-term strategy. This is because additional capital is needed for R&D to stabilise the system. This view is supported by Paunvov (2012), Makkonen (2012), Archibugi and Filippetti (2011). However, despite this improvement it was only realised at a very high support rate. In that sense, it also supports the findings regarding why tax credits might sometimes be seen as ineffective and nothing more than a bonus (e.g. Fowkes et al., 2015). This is because policy makers need to be aware of the market mechanism, as even if research is essentially free, if firms can easily imitate that product then it can undermine the purpose of research incentives. However, subsidising research to an extent that it has an important impact on the system may also be financially implausible.

Consequently, this led to an inquiry into whether penalising the imitator could yield better results. The analysis found that the business cycle did not change until after a certain point, and from then on it resulted in a monopolistic world. However, at that point it allowed for a significant improvement in the system, whereby it enabled two other Pareto optimal strategies that were not possible with government support for R&D. However, as these two strategies were not statistically significant between each other, the author could not target policy towards a specific one. It was problematic that one strategy made collective profits for all companies whereas the other made collective losses. In other words, sometimes there were periods of economic growth and at other times there was decline. The reason for this was that the fines for the imitators were being taken out of the system. Consequently, this raised the question as to whether giving back the money to the inventors would have a better impact on the system. The results gave a very different perspective to the market dynamics, whereby it significantly improved the system and both these strategies become sustainable, thus creating a more stable world for continual growth. In light of this, just as companies are given compensation losses for firms imitating their products, regulators that fine imitators where money does not go back to the inventors should arguably re-think about re-distributing money back into the system; for example, providing additional funding for R&D.

6 Conclusion

This paper has explored how regulation can impact innovation by developing an ABM to represent typical market dynamics. Different policy instruments were then introduced to see what impact this had on the system. In this context, the author was able to explore the effects regulation can have on the innovation process as a result of systemic interactions among learning agents. Building upon ABM techniques, the paper explored heightening the regulatory environment aimed at both the imitator and creator, whereby the agents' repeated interaction gave rise to some interesting complex dynamics. Whilst criticisms could arise regarding its construction towards its emulation of a real world system, the ABM was constructed with this argument in mind. For example, when interpreting the results of the simulation the author does not intend the findings to be used as accurate quantitative forecasts, but rather interesting qualitative insights based on the dynamics that arise from the system. Therefore, this ABM was seen to serve as a valuable tool for policy analysis, supporting previous literature around this debate. The approach gave interesting insights into how markets function and therefore allowed the author to analyse how various policy-instruments can shape system dynamics. For example, it was found that a counter-cyclical regulatory approach might have a better impact than what is currently observed with the majority of EU member states. Similarly, just as companies are given compensation losses for firms imitating their products, regulators that fine imitators causing capital to be taken away from the system should possibly re-think about re-distributing that money back into the system. Therefore, the ABM has helped one to learn what to expect and what not to expect from these policy instruments. Not only has this approach seemed proven as a useful tool to transcend borders set by standard analytical models, but it has also opened up promising avenues for future policy design. In turn, this models plans to be extended towards different sectoral and technological specific areas. Further research should also extend this model with greater adaption and realism for the pre-assessment of the effectiveness of proposed policies.

Chapter 5

Discussion

1 Overview of Findings

Throughout the course of this thesis, the topic of innovation and how it is shaped by policy has been analysed from a variety of different perspectives and outlooks. Having now proposed and evaluated the relationship and the systemic properties and processes that it is dependent on. An opportunity presents itself to revisit some of those ideas to establish what has been learnt. Whilst there are findings specific to each manuscript, this section will discuss those relevant to the thesis as a whole.

The first paper aimed to analyse how different regulations can be used to impact different types of innovation. This was achieved by synthesising relevant literature to identify gaps, themes, relationships and deficiencies within the research stream. The evidence presented suggests that regulation can impact innovation. However, the views were mixed as to the consequential impacts. For example, it was found that regulation tended to create more negative results when concerned with economic policy. However, the converse was observed when analysing environmental legislation. This was found to be because it forces innovators down certain technological pathways. Similarly, in line with the findings from Blind (2012) and Stewart (2010), it is contested as to whether this leads to an increase in innovation output.

Another finding was that the stringency of regulation was an important determinant on how it impacts innovation, which in some instances leads to inverse results. A case in point is in regards to intellectual property and copyright laws. If the regulation was too stringent then firms would have the economic incentive to create something new; however, this could reduce the pressure on existing incumbents to continually need to invent. On the other hand, weak regulatory protection could heighten competition, but if firms are then able to imitate other companies' innovations without having to invest in R&D then companies would arguably lose the economic incentive to invent. Consequently, an interesting trade-off arises between the aggressiveness of policy integration and innovation output. This implies that there are optimal conditions for policy integration. Therefore, it is argued that more research is required to explore this relationship at various stages of the innovation process. Similarly, not just regulations that enhance innovation but other policy objectives, such as growth, system stability and consumer welfare.

As for the domain itself, the literature was found to be quite fragmented, covering a wide range of different sectors and industries. However, the majority of the studies were skewed towards manufacturing sectors. Therefore, a lot of innovation remains hidden from scientific investigation. A reason for concern is that service industries now represent over 80 per cent GDP (Office for National Statistics, 2016). Consequently, a lack of understanding into service innovation can be extremely problematic for policy-makers. For example, in Chapter one it was argued how classical economics contributed to the Financial Crisis of 2007 to 2008. However, due to the limited understanding regarding the complex innovations that have arisen since deregulation, it can be stated that scholars of innovation have also played a major part in the crisis. Not so much in their policy recommendations, but rather the lack of knowledge to provide any sufficient warnings to problems that may arise. According to Fagerberg et al., (2013) even sociologists and anthropologists have had rather more to say on the financial crisis compared to scholars of innovation (see Beunza and Stark, 2004; Mackenzi, 2006; Tett, 2009).

One explanation as to why the distribution of the studies is skewed could lie with data attainment problems. For example, it was observed that the main source of analysis tended to be using patent and R&D Data. Therefore, conventional indicators failed to provide suitable processes to capture less technological and

R&D intensive innovations. Considering this, the challenge for the next generation of research is to find new ways of measuring how different policy-instruments can impact different types of innovation, not only to triangulate existing findings, but also to provide greater depths into the innovation that is involved.

In light of these findings the author looked towards agent-based modelling (ABM) as a suitable tool to answer some of these issues. This was achieved by synthesising ABM literature that looked at how different regulations can be applied to shape the dynamics of the market mechanism through various policy objectives. Consequently, this deviated from the first manuscript to concentrate more on the design specifications of the ABMs to see how they were constructed and it's suitability as a policy tool. The findings suggest that it is a useful tool to not only transcend borders set by standard analytical models, but also to explore interesting avenues raised by the first manuscript for policy assessment. This is because once the market mechanism has been developed it provides an opportunity to investigate "what if" type scenarios. In this context, one can consider a variety of policy options at different levels of aggressiveness.

As to the analysis itself, it was found that the majority of papers designed their model towards the demand part of the market mechanism, thus neglecting the supply side. Therefore, a lot of studies assumed that innovation has its own market potential. Whilst this may be reasonable in some cases, more often than not firms face intense competition from other products or new ones released into the market. Despite several studies addressing this relationship, future research should focus more on the competitive dynamics of the system, such as how products are effected by other firms' technologies and actions.

In addition, it was also found that there was a lack of abstract models that provided generic theoretical insights. One explanation to this imbalance could lie with policy-makers preferring more empirically derived models that provided policy forecasts targeted towards a specific domain. However, whilst these studies tend to be more descriptive, issues can arise regarding their complexity. This is because the more features that one integrates into the model, the higher the risk that it cannot be solved analytically. In this context, models focused towards more refined assumptions are arguably more accurate than models based on stylised facts (Deichsel and Pyka, 2009). This is because issues can arise such as data availability, bias and quality that in turn can impact the results for when counterfactual analysis is applied. Therefore, not only would the domain benefit from more speculative thought experiments, but also future analysis could critically assess how best to strike a balance between simple and abstract designs (that may be enriched later on) and descriptive models (that can be simplified whenever justified) so that sound and robust policy assessment tools can be implemented.

The findings from both papers were then converged to frame the final manuscript where a methodological innovation is introduced. This ABM aimed to represent typical market dynamics where the author measured regulatory stringency targeted towards both the inventor (i.e. through rewarding invention) and the imitator (i.e. penalising imitation). The design specifications were framed largely from the second manuscript to help shed light on the issues raised by the first. Consequently, this model had a particular emphasis on the supply side of the market mechanism so that the competitive dynamics of the system could be observed. The findings presented gave interesting insights into the long-term behaviours of the system. Firstly, it was found that policy changes that have occurred in already highly imitable worlds tended to create less impact on environments where this was already low. This is arguably reflected in the world; for example, it stands to reason that breaking up a monopoly would lead to a greater compliance burden on incumbents than heightening stringency in an already competitive environment. This is supported by Stewart (2010) who argues that disruptive regulation creates technological change that forces companies to undergo radical engineering.

The second part of the analysis integrated an adaptive element in the absence of policy intervention. This was to identify what artificial worlds society would end up with. An interesting business cycle emerged whereby there were periods of economic growth and then decline. This was found to be because too much competition saturated the markets, thus leading to a market collapse. In that sense, this seems to be in line with the findings of Aghion et al. (2006), whereby the amount of competition in the market can create an inverted relationship to the number of products that is released. From these findings, the author integrated policy to try and see if the system can be improved where the effects of government support for R&D was tested at various levels of aggressiveness. When introduced it was possible to stop a market collapse as witnessed from the unregulated scenario. This was because it provided addition capital in the system to stop the systemic failure. Therefore, it implies that a pro-cyclical approach currently adopted by most EU-27 member states may not be the most viable long term strategy. Consequently in line with the discussion from the first manuscript, the author is in support with several scholars that the counter cyclical approach may not be the best strategy (see Paunov, 2012; Makkonen, 2013; Filippetti and Archibugi, 2011). However, despite this improvement in the system it was only realised at a very high support rate. In that sense, it also supports the findings regarding why tax credits might sometimes be seen as ineffective and nothing more than a bonus (e.g. Fowkes et al., 2015). This is because even if research is essentially free, if firms can still imitate that product then it can undermine the purpose of research, such as exclusivity within the market.

This led to an inquiry into whether penalising the imitator could yield better results. The analysis found that the economic cycle did not change until after a certain point, and from then on it resulted in a monopolistic world, due to the regulation being too aggressive. However, at that point of change it allowed an improvement in the system towards two Pareto optimal strategies that was previously unattainable with the other policy instrument. Similarly, as these points were not statistically significant between each other, the author could not target policy towards a specify strategy. Problematically, one of these strategies made collective profits whereas the other made a collective loss. Therefore, sometimes there could be periods of economic growth and other times there may be a decline. Through greater analysis into the dynamics of the system, it was found that this was because the fines were taking money out of the system. However, this raised the notion as to whether giving money back to the inventors would have a systemic benefit. The results gave a very interesting perspective into the long-term dynamics of the system. This is because it significantly improved the results where both strategies became sustainable, thus creating a more stable world for continual growth. In light of this, just as companies are given compensation losses for firms imitating their products, regulators that fine companies for bad practices where money is taken away from the system, should in certain contexts consider redistributing that money back into it.

In summary, this thesis has provided an interdisciplinary perspective to assess how various policy instruments can shape the dynamics of the system at various stages of the innovation process. Through converging the material of papers one and two it was possible to create a methodological innovation that could extend our knowledge regarding this domain. Not only has the agent-based approach help one learn what to expect and what not to expect from the aforementioned policies, but it has also opened up promising avenues for future policy design. The next section will aim to discuss the limitations and future directions for extending this research.

2 Limitations of Research

The scope of the work presented in this thesis has several limitations from various theoretical, practical and policy perspectives. From a theoretical perspective due to the broad nature of the research area, not all regulations could be looked at. Either this was due to insufficient evidence or it was considered outside the scope of analysis. For example, self- and co-regulation could arguably be relevant, but this was not explored within the thesis. Therefore, it could be argued that the exclusion of some policies might affect some of the generalised inferences made to inform policy and practice. Similarly, it is also important to note that it is not within the scope of the thesis to consider other methodologies used to capture the dynamics of complex systems. This could be considered a limitation as other modelling approaches might be more effective than others at answering different research objectives. Therefore, a future agenda could be to extend this analysis to include other computational methodologies and evaluate their suitability to a range of policy issues and concerns. In terms of the practical limitations, further work is needed to maximise the impact of the ABM as a policy tool. This is because the model is built very specifically around the two policy-instruments explored within the analysis. Therefore, it will need to be extended to be able to address various other policy objectives. In addition, due to the way the model was constructed criticisms could also arise regarding its emulation towards a real world system. However, the model was designed with these criticisms in mind. For example, due to the nature of the model when interpreting the results of the simulation the author does not intend the model to be used as accurate quantitative forecasts, but rather interesting qualitative insights based on the dynamics that arise from the system. In this context, issues may arise regarding its forecasting capabilities from a policy perspective. This is because if policy-makers prefer more empirically grounded models that aim to offer richer predictive estimates of the real world system being emulated, then this may hinder its application and use. However, extending the model to enhance its predictive capacity plans to be part of the future agenda explored in the next section.

3 Future Research

This thesis has aimed to set down important foundational work in developing a better understanding of the relationship between regulation and innovation. Similarly, the structures and processes that this depends on. Despite many challenges and limitations still remaining with this domain, ABM has proven a useful tool for policy assessment across a broad range of applications. Whilst the model has demonstrated a way to capture emergent behaviour that may arise through policy integration, there is still much work that needs to be done. Future research should aim to develop the model to include a wider array of policy options targeted towards a variety of different sectors and technological domains. Another future endeavour could be to include policy agents as part of the systemic process. This is because it can provide interesting insights into the dynamics of the system that might have otherwise not been discovered. For example, it was found that deregulation often enhances performance. However as demonstrated with the financial sector, despite deregulation aiding in the proliferation of financial innovation, after the financial crisis of 2007-2008 there has been increasing demand for re-regulation. Therefore, by including policy agents as part of this co-evolving process it may provide greater depths to this discussion. Another possibility could be to integrate a variety of spatial landscapes with varying levels of regulatory aggressiveness. A case in point is with online copyright infringement. This is because if policy makers introduce aggressive laws it could potentially push firms to have to relocate to legal regimes that are more permissive. In turn, this could result in regulators losing what little control they already had, thus unintentionally exacerbating the problem. Further research could also consider extending the model with greater adaption and realism for the pre-assessment of the effectiveness of proposed policies. Therefore, aiming to provide more accurate forecasts of policy integration when applied to the real world.

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