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PERSISTENCE OF INNOVATIONS: DETERMINANTS OF PERSISTENCE AND THE EFFECT OF OPENNESS ON INNOVATION PERSISTENCE

by

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Thesis for the degree of Doctor of Philosophy

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ABSTRACT

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Due to the influence of innovation on the performance of firms, a significant body of knowledge has now been developed on firms' innovation behaviour, especially innovation persistence. Innovation persistence is characterised by the relationship between past innovations and the current ones. This thesis contributes to the body of knowledge in innovation persistence by investigating persistence from three perspectives. First, this thesis investigates the innovation behaviour in times of unstable economic environment with the data covering the 2008 global financial crisis, while taking into account all four types of innovation and the effect of joint adoption. Second, this thesis seeks to deepen our understanding of the underlying causes of innovation persistence by examining the explanatory power of four theoretical explanations for the presence of innovation persistence with a novel measure of innovation persistence. This new measure indicates whether or not a firm continuously innovate. Finally, this thesis bridges the gap between the research fields of innovation persistence and open innovation. The

importance of external linkages has been confirmed in a substantial body of innovation research. This thesis investigates how openness in terms of firms' external search knowledge (i.e. search breadth and search depth) affects firms' determination to persist in innovations.

The research data used in this thesis is acquired from U.K. Community Innovation Survey (CIS) which is conducted at regular intervals by the Office for National Statistics (ONS) in order to trace firms' innovative behaviour over time. The research data is retrieved from three waves of the CIS, from the sixth to the eighth waves covering the period from 2006 to 2012. Since the period of the research data overlaps with the global financial crisis burst in 2008. This thesis is able to inspect firms' behaviour of innovation persistence in the financial crisis time. Findings of this thesis show that firms continue to innovate in times of the global financial crisis. There is innovation persistence in the product, process, organisational and marketing innovations. Moreover, complementarities between innovations increase firms' tendency to persistent in innovation. The joint adoptions of product and process innovations and product and organisational innovations enhance the persistence in the process and organisational innovations, respectively.

Prior studies have proposed four theoretical explanations for innovation persistence – 1) R&D sunk cost, 2) success-breeds-success, a virtuous cycle between innovations across time, 3) appropriation mechanisms used to protect firms' innovation achievements, and 4) innovation competence which refers to firms' capabilities to conduct innovations. The examinations of the four potential drivers of innovation persistence indicate that this potential reasoning behind innovation persistence is more capable of interpreting the underlying causes of persistence in product innovation than the persistence in the other three types of innovations – process, organisational and marketing. In addition, the

determinants of innovation persistence change with the changing circumstances of the financial environment. Previous R&D investment does not encourage firms to persist in innovations during the global financial crisis period, but the R&D investment made in the crisis time stimulate firms to innovate continuously. The established external linkages encourage firms to continue to innovate in times of the global financial crisis while the same drivers have no significant influence on subsequent innovations after the global financial crisis.

The effects of external search strategies are more profound in the persistence in product innovation than that in the other three types of innovation. Firms that search broadly are more likely to conduct product innovation and also to persist in product innovation. Besides, search depth has a positive influence on the persistence in marketing innovation. The cost-benefits analysis is much easier to be applied to a produce-based innovation than to the other types of innovation because the output of a product-based innovation tends to be a tangible property whose value could be clearly assessed. This characteristic of product-based innovations makes it easier for firms to make a contractual or collaborative arrangements with external parties.

This thesis contributes to the literature by investigating innovation persistence in the context of an economic crisis and examining the underlying causes of innovation persistence This thesis also provides new insights of the effect of the openness, i.e. the firms' external search strategies, on the firms' propensity to continue to innovate.

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Academic Thesis: Declaration Of Authorship

I, Pei-Yu Yuan .....

declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own original research.

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I confirm that:

1. This work was done wholly or mainly while in candidature for a research degree at this University;
2. 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;
3. Where I have consulted the published work of others, this is always clearly attributed;
4. 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;
5. I have acknowledged all main sources of help;
6. 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;
7. None of this work has been published before submission

Signed:

Date: 13/06/2018

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Chapter 1: Introduction

The importance of innovation to a firm's competitiveness and growth has been confirmed in the innovation literature (Aghion et al., 2001; Geroski and Toker, 1996; Geroski and Machin, 1992), and recently a growing number of studies have started to look into the issue of innovation persistence which helps sustain the competitive advantages of the firms. The idea of innovation persistence is about whether, and to what extent, the firms which have started to innovate show a strong propensity to continue to innovate in subsequent periods. Considerable research efforts have been made to investigate the phenomenon of persistence in innovation (Cefis, 2003; Clausen et al., 2011; Peters, 2007; Tavassoli and Karlsson, 2015), and the findings indicate that 'innovation is not a purely random phenomenon driven by small shocks, but it implies systematic heterogeneity across firms…' (Cefis and Orsenigo, 2001, p. 1156). The presence of systematic heterogeneity between firms indicates a fundamental difference in firms' innovation capabilities, and consequently, the heterogeneity in firms' capabilities is likely to affect the pattern of firms' innovation behaviour such as persistence in innovation (Malerba, 2007; Triguero and Córcoles, 2013). Innovation persistence signifies a firm's ability to produce a constant stream of innovations through which the firm continuously strengthens its competitive advantage. Hence it is essential for both academia and industry to better understand innovation persistence as well as the reasoning behind this phenomenon.

The role of innovation persistence is no less important than innovation. Indeed, success in innovation generates a proprietary competitive position which can offer an advantage and, in turn, superior business performance. However, a successful innovation does not guarantee that a firm will always win the competition among its rivals. Particularly, the works of Griffin (1997) and Hauser et al. (2006) point out that, in modern times, around 30% to 50% of both a firm's

sales and profit originate from new products that are launched on the market in the previous five years. Firms need and should develop consistent streams of innovation in order to improve and sustain competitive advantage (Hauser et al., 2006; Ireland and Webb, 2007). In addition, the innovation literature indicates that the performance of firms even in the same industry is highly skewed and this big difference in performance tends to last for a long time (Bartelsman and Doms, 2000). Some studies suggest that the lasting asymmetries in firms' performance may be rooted in the continuing difference in innovation among firms (Geroski et al., 1997; Peters, 2007; Tavassoli and Karlsson, 2015). Since the persistent innovation behaviour is influential on performance, there is extensive research examining the factors affecting innovation behaviour and the effect of innovation persistence. However, relatively little attention has been paid to innovation persistence in certain situations, such as the impact of financial crisis on innovation persistence, or the effect of joint adoption of different types of innovation on persistence. Moreover, the open innovation literature has confirmed the importance of external linkages on firms' innovation, but not many studies link persistence to open innovation. This is what motivates the current study to look into firms' persistence in innovation instead of innovation alone.

1.1 Literature review and identification of research gaps

1.1.1 The concept of innovation persistence

The innovation persistence literature studies the relationship between the past and the present innovations and mainly focuses on how past innovation affects the future ones. The relevant literature has proposed that "firms that innovate once have a higher probability of innovating again in subsequent periods" (Clausen et al., 2011, p. 2) and this phenomenon is termed 'innovation persistence'. Suárez (2014) points out that the concept of persistence can be

traced back to Schumpeter's (1934) creative accumulation process which characterises the development of innovation as cumulative learning and incremental improvements. Innovation is carried out along the established technological trajectories of the firms and based on the knowledge and competencies that the firms accumulate over time. The persistent behaviour can also be understood from the behavioural theory stating that firms learn from the feedback of their past tasks (Cyert and March, 1963). Firms replicate actions that were successful and end the failed ones. Therefore, firms that have succeeded in innovation have a tendency to continue to innovate, which in turn means that persistence in innovation becomes a regular pattern.

1.1.2 Empirical evidence on innovation persistence

Most of the current persistence studies examine innovation persistence by an autoregressive model in which the probability of a firm to innovate is explained by the lagged innovation variable that indicates whether or not the firm innovated in a previous period. If the coefficient of the lagged innovation variable is positive and significant, the presence of innovation persistence is observed. The findings of the recent empirical studies are somewhat inconsistent because the degree of innovation persistence varies according to the indicator of innovation activities (Duguet and Monjon, 2004). Using patents as innovation indicators, prior works suggest that there is no clear evidence of innovation persistence and that innovation persistence is only present among top patentees (Cefis, 2003; Cefis and Orsenigo, 2001; Geroski et al., 1997). In contrast to studies using patent data, recent studies that used innovation survey data such as the Community Innovation Survey (CIS) find strong evidence for innovation persistence (Ganter and Hecker, 2013; Martínez-Ros and Labeaga, 2009; Tavassoli and Karlsson, 2015; Triguero and Córcoles, 2013).

Most of the existing research focuses exclusively on a technologically-oriented aspect of the innovation. Product and process innovations are the sole subjects of persistence studies (Antonelli et al., 2012; Clausen et al., 2011; Le Bas and Poussing, 2014; Martínez-Ros and Labeaga, 2009; Suárez, 2014). Little is known about the persistence of non-technological innovation such as persistence in organisational and marketing innovations. Two of the more recent studies, however, extend the boundaries of the persistence literature and include non-technological innovation. The first exception is the work of Ganter and Hecker (2013) who include organisational innovation in their study of innovation persistence. The second exception is the study of Tavassoli and Karlsson (2015) who expand their research topic including both the organisational and marketing innovations in their study of innovation persistence. Although both of these two studies are conducted based on the CIS survey data, the findings of the two studies contradict each other. Ganter and Hecker (2013) find no evidence to support the presence of persistence of organisational innovation while Tavassoli and Karlsson (2015) show that firms devote constant effort to conduct organisational innovation. The causes of the inconsistent results of these two studies are not clear so far. It is possible that the contradictory finding may result from the country-specific characteristics or may be due to the difference in the data period used in their studies. Further study is needed to increase our understanding of persistence in non-technological innovation such as organisational and marketing innovations.

Most of the current studies using CIS data have confirmed the presence of innovation persistence, but these studies implicitly condition innovation persistence to the stability of the economic environments from which the empirical data were collected. Suárez (2014) argues that, in turbulent times, what firms did in the past may not be useful for the issues the firms need to deal with in the present, which implies that past innovation is not necessarily useful for

developing new innovation in the present. Using panel data covering the 1998-2001 Argentine Great Depression, Suárez (2014) reveals that innovation persistence is not corroborated when the persistence is examined in a conventional way in which persistence is corroborated by the effect of past innovation on the present innovation. Innovation persistence is observed when firms' innovative behaviours are differentiated such as continuous innovator, new innovator, sporadic innovator and non-innovator. Innovation persistence is found to be more common for the continuous and new innovators, but not among the sporadic group.

While studying innovation persistence, the interrelationship between different innovations is often ignored. Le Bas and Poussing (2014) investigate innovation persistence for two types of innovators: complex and single innovators. The complex innovators conduct both product and process innovations simultaneously while the single innovators carry out only one of the two types. Their findings show that complex innovators are more inclined to persist in innovation than are single innovators as the former are more efficient in drawing on a variety of sources for new ideas and then converting these ideas into innovations in a continuous stream. The benefit of simultaneously conducting multiple types of innovation does not only lie in the rich variety of ideas but also in the complementarities between different types of innovation. Milgrom and Robert (1990) have stated that product and process innovations are complementary since they mutually reinforce each other. Battisti and Stoneman (2010) also point out that firms tend to adopt clusters of innovations rather than individual innovations. Therefore, the interrelationship between different innovations is not negligible while investigating the propensity of the firms to innovate.

Most of the extant innovation persistence literature fails to incorporate the complementary relationship between different types of innovation, the exception

being the study of Martínez-Ros and Labeaga (2009). They find that the complementarities between product and process innovations are crucial in the decision to continue to innovate in terms of synergies and capacities from the joint adoption of the two types of innovation. These complementarities affect the probability of future innovation, which means that the complementary relationship between innovations would moderate the persistence of innovation. However, Martínez-Ros and Labeaga (2009) only focus on the persistence in product and process innovations. Several studies have pointed out that organisational innovation is important in the adoption of technological innovation (Battisti and Stoneman, 2010; Damanpour et al., 2009; Damanpour and Aravind, 2012; Schubert, 2010). Camisón and Villar-López (2014) find that organisational innovation helps the development of firms' technological capabilities for product and process innovations. Battisti and Stoneman (2010) find that significant complementarities arise from the joint adoption of the technological innovation and organisational innovation. Therefore, this thesis explores the interrelationship between different types of innovation as the potential for synergies and extra gains derived from the joint adoption of complementary innovations may influence firms' propensity to continue to innovate.

1.1.3 Determinants of innovation persistence

Although previous research has drawn several inferences from innovation theory as the theoretical basis of innovation persistence, little attention has been paid to study the practicalities of these inferences. Innovation persistence has far-researching implications for topics in innovation theory, strategic management and public policy. Ganter and Hecker (2013) point out that the presence of innovation persistence substantiates endogenous growth theory. The presence of innovation persistence shows that incumbent firms and cumulative knowledge-building act as the catalysts for innovation and economic growth, which

somewhat echoes Schumpeter's Mark II model. At the firm level, managers could use persistence of innovation as a strategy to gain competitive advantage and to differentiate themselves from rival firms. From a public policy perspective, the presence of innovation persistence underlines the importance of designing innovation support programmes to open up the continuous loop of innovation. With so many far-reaching implications, it is essential to understand the underlying reasons for innovation persistence.

The extant persistence studies have provided four possible explanations for firms' persistent behaviour of innovation: 1) **R&D sunk cost.** R&D has been proved to be an important source of innovation in the innovation literature (Amara et al., 2008; Raymond and St-Pierre, 2010; Romijn and Albaladejo, 2002). Firms that can afford the sunk cost of R&D are more capable of conducting innovation. Following this logic, firms could introduce a constant stream of innovation if they continue to invest in R&D. 2) **Success-breeds-success.** This reasoning highlights the importance of the commercial success of past innovation. Profits from past innovation can be reinvested in the current innovative activities (Clausen et al., 2011; Peters, 2007; Tavassoli and Karlsson, 2015). 3) **Appropriation strategy.** Appropriation practices such as patent, copyright, and trademark help firms to protect their invention from imitation before they succeed in introducing new innovations (Cohen et al., 2000; Leiponen and Byma, 2009; Tavassoli and Karlsson, 2015; Wang and Chen, 2010). 4) **Innovation competence.** Innovations can be considered as the accomplishment of accumulated competencies. As the nature of knowledge is cumulative, the accumulation process of competencies can be characterised with the economies of scale (Clausen et al., 2011; Ganter and Hecker, 2013; Peters, 2007). Firms which have produced past innovations gain an advantage in making future innovations, which incentivises firms to continue to innovate. A more detailed description of the four theoretical explanations is provided in Chapter 3 (section 3.2.2).

Although each of the theories provides a reasonable explanation for the phenomenon of innovation persistence, there is conclusive empirical evidence supporting the explanatory power of the theories in innovation persistence. The current literature constructs corresponding factors based on the four theoretical explanations and includes these factors in the econometric model while examining innovation persistence. Innovation persistence is measured by the lagged innovation, and the other factors are merely control variables. This study argues that the research design of prior studies is to predict the probability of future innovation, rather than the persistence of innovation. Prior studies focus on detecting the presence of persistence, and their research designs are not tailored to examine the underlying causes of innovation persistence. Due to the far-reaching implications of innovation persistence, this thesis argues that it is important to clearly understand the determinants of innovation persistence, which will help both managers and policy makers to design an effective mechanism to stimulate innovation.

1.1.4 Innovation persistence and open innovation

Both the ideas of innovation persistence and open innovation, particularly the level of openness, are gradually attracting more attention, but only a very few studies link these two concepts. The underlying inspiration for this thesis to bridge this two research fields is that one sub-study of this thesis reveals that openness to external parties (i.e. collaboration with other firms) encourages firms to continue to innovate. Therefore, the third sub-study of the thesis further explores the role of openness in firms' persistence behaviour in innovation. The basic idea of openness is that a firm should open up the boundaries of the organisation and engage with various types of partners to access novel ideas and to acquire resources from the external environment (Chesbrough, 2006; Dahlander and Gann, 2010). The idea of openness is not a brand new concept in

the literature on innovation management (Huizingh, 2011; Trott and Hartmann, 2009). Since the mid-1980s, firms have started to develop innovations collaboratively. For instance, Rothwell and Zegveld (1985) have proposed the network model of innovation and highlighted the need for external linkages within the innovation process. Tidd (1995) studies how the open and connected model of innovation facilitates the development of products and services in the home automation industry. Huizingh (2011) indicates that, in reality, it is rare that firms adopt a fully closed approach to conduct innovation because a multitude of components and capabilities required for the innovation are outside of the firms. Thus, it is necessary for firms to connect with external parties such as suppliers, research institutions, marketing agencies or even competitors, which, to some extent, makes the developing process of innovation more open. Since firms do not innovate in complete isolation, it is important for studies on firms' innovation behaviour to reflect how firms carry out innovation.

The openness of firms' innovation process significantly improves firms' innovation performance and their propensity to innovate, but little is known about whether openness affects long-term trends towards the development of innovation. As the concept of openness became more and more popular following Chesbrough's (2006) coining of the term 'open innovation' to describe the phenomenon of opening up firms' innovation process, substantial efforts have been undertaken to understand how openness impacts on firms' innovation activities and the firms' innovation performance: collaborative networks and innovation performance (Belderbos et al., 2010, 2004; Frenz and Ietto-Gillies, 2009; Knudsen and Mortensen, 2011; Parida et al., 2012). Some studies focus on the effect of collaborative network (i.e. collaboration with customer, supplier, or competitor) (Frenz and Ietto-Gillies, 2009; Nieto and Santamaría, 2007; Tsai, 2009; Tsai and Wang, 2009), and others investigate firms' external search strategies such as search breadth and search depth (Chiang and Hung, 2010;

Cruz-González et al., 2015; Laursen and Salter, 2006; Leiponen and Helfat, 2010; Love et al., 2014). In spite of the focus on how openness affects innovation performance, some studies look into whether openness increases firms' propensity to conduct innovation (Leiponen and Helfat, 2010; Robin and Schubert, 2013). Both Leiponen and Helfat's (2010) and Robin and Schubert's (2013) studies show that firms that either collaborate with external parties or incorporate external sources of knowledge into their in-house innovation projects have a higher probability of introducing innovation successfully. Findings of these two studies lead the present study to consider whether openness encourages firms to produce a constant stream of innovations; in other words, whether openness affects firms' persistence in innovations.

1.2 Objectives of the thesis

Although a significant body of knowledge has now been developed on innovation persistence, the field of innovation persistence mainly focuses on the identification of whether firms innovate persistently. The underlying reasons behind innovation persistence, though, are not clearly understood. Besides, prior studies fail to reflect the ways that firms carry out innovation (i.e. joint adoption of different types of innovation and collaboration with external parties for innovation), which may lead to a misunderstanding of the dynamics of firms' innovation behaviour. This thesis aims to fill the following research gaps:

1. Lack of sufficient empirical research on innovation persistence in non-technological innovation.
2. Lack of empirical analysis of innovation persistence during unstable economic environment such as financial crisis.
3. Few studies on innovation persistence take into account the impact of complementarities between innovations.

4. There is still a need for empirical evidence for the determinants of innovation persistence.
5. Lack of linkage between the innovation persistence and the openness of innovation.

1.3 Research design

To advance our understanding in the field of innovation persistence, this thesis attempts to address the gaps identified above through three sub-studies. In the first sub-study, this thesis aims to fill the first two research gaps by answering the following questions: 1) whether there is persistence in both technological innovation such as product and process innovations and non-technological innovation such as organisational and marketing innovations. 2) Is innovation persistence moderated by the complementarities between different types of innovation? The first sub-study follows the approach of prior innovation persistence studies in which persistence is measured by a lagged innovation in an autoregressive model used to test the relationship between the past and present innovation.

In the second sub-study, the author seeks to understand the underlying reason(s) behind innovation persistence: what are the determinants of innovation persistence? As the main objective is to identify factors influencing innovation persistence, this thesis creates a new measure as a proxy for innovation persistence. Following a similar logic in prior studies in which persistence is examined by the relationship between firms' innovation activities in two consecutive time periods between *t* and *t-1*, the present study identifies the presence of innovation persistence according to firms' behaviour from *t-1* to *t*. If a firm reported the introduction of innovation in two consecutive time periods, it is considered as being persistent in innovation. Thus, the dependent variable

represents the *persistence* of innovation rather than innovation alone. Adopting the new measure of innovation persistence allows this thesis to directly investigate factors affecting innovation persistence and to identify the determinants of innovation persistence.

In the third sub-study, the focus is on the effect of openness in terms of firms' external search strategy on innovation persistence. Findings of the second sub-study show that collaboration with external parties has a positive impact on innovation persistence. In the third sub-study, the author further explores how openness is related to innovation persistence. Following Laursen and Salter's (2006) approach, the external search strategy is constituted of search breadth and search depth. Both the external search breadth and depth can be considered as strategic choices of firms as search is not without cost, and firms have to achieve a balance between the potential benefit and the cost of search activities. By linking the concepts of openness and innovation persistence, this will help us understand how strategic management is related to firms' long-term innovation deployment. Based on the research design of the second sub-study, innovation persistence is measured by firms' continuous involvement in innovation in two consecutive time periods between *t* and *t-1*. In a similar vein to the second sub-study, the application of innovation persistence itself as the dependent variable enables this thesis to assess the relationship between openness and innovation persistence. Moreover, the research data used in this thesis cover a period of time from 2006 to 2012. Since the 2008 global financial crisis occurred in the middle of the period under survey, this thesis is able to examine the explanatory power of the four theoretical explanations for innovation persistence during and after the global financial crisis.

1.4 Research data

The research data used in this thesis are from the UK Community Innovation Survey (CIS), which is conducted every two years by the Office for National Statistics (ONS) on behalf of the Department of Business Innovation & Skills (BIS). The survey is based on a core questionnaire developed by the European Commission (Eurostat) and Member States. The main purpose of the survey is to collect information about business innovation in the UK. The survey is voluntary and covers enterprises with 10 or more employees. The CIS also has a wide sectoral coverage including both manufacturing and service sectors and consists of a stratified sample of firms drawn from the ONS Inter-Departmental Business Register (IDBR). This thesis uses the three latest available UK CIS which are the sixth, seventh, and eighth waves. The CIS6 covers the period 2006-2008, CIS7 covers the period 2008-2010, and CIS8 covers the period 2010-2012. The time period of CIS7 overlaps with the global financial crisis in 2008; thus firms' innovation activities during this period to some extent are influenced by the global crisis. Each of the respondent firms in each wave of the CIS has its own reference number which is a unique registration number in IDBR. This unique reference number enables this thesis to identify firms that attended the three waves of CIS (CIS 6, CIS 7 and CIS 8) and then construct a balanced panel dataset for the analysis of innovation persistence.

1.5 Outline of the thesis

This first chapter briefly describes the main focus of this research and the plan to fill the gaps in the innovation persistence literature. The framework of this thesis is outlined below in Table 1-1 which summarises the relevance of the key issues, identifies research gaps, sets out research questions and defines the expected contributions.

The main body of this research has been divided into three chapters corresponding to three research questions. In Chapter 2, the author investigates whether or not there is innovation persistence in both technological and non-technological innovations. As the research data used in this thesis cover the period of the 2008 global financial crisis, this thesis is able to observe firms' innovation behaviour in times of unstable economic environment. Furthermore, the author takes into account the effect of complementarities between different types of innovation on innovation persistence. In Chapter 3, this thesis attempts to understand the determinants of innovation. The author creates a new measure as a proxy for innovation persistence and examines the relationship between innovation persistence and the four potential theoretical explanations. Chapter 4 links the research field of open innovation with the research field of innovation persistence and examines how openness in terms of firms' external search strategy affects innovation persistence. Finally, conclusions and implications of this research are summarised in Chapter 5.

Table 1-1 Framework of the thesis

	Research background (key issues)	Research gaps	Research questions	Expected contributions
Chapter 2	Innovation persistence and complementarities between innovations	• The current literature does not take into account the effect of the macroeconomic environment • The existing literature overlooks non-technological innovation and the effect of complementarities between innovations on innovation persistence	• Do innovative firms continue to innovate in times of global financial crisis? • Is innovation persistence moderated by the complementary relationship between innovations?	• Explore whether innovation persistence exists in times of financial crisis • Examine how complementarities between innovation affect innovation persistence
Chapter 3	Determinants of innovation persistence in distinct economic environments (before, during and after the global financial crisis)	• Empirical studies into the reasoning behind innovation persistence are scarce	• What are the determinants of innovation persistence innovation? • Do the reasons motivating firms to persist with innovation change with changes in the macroeconomic environment?	• Examine the effectiveness of potential reasoning behind innovation persistence • Explore if the incentives to persist in innovation change with the changing circumstances of financial environment such as the 2008 global financial crisis

Chapter 4	Innovation persistence and the openness of innovation process	• There are few studies linking the persistence literature with the open innovation literature	• Does the level of openness of a firm's innovation process affect its determination to persist with innovation?	• Bridge the gaps between innovation persistence literature and open innovation literature • Explore whether the openness in terms of a firm's search breadth and search depth affect innovation persistence

Chapter 2: Persistence and Complementarity of Innovation in the Global Financial Crisis

Abstract

The existence of innovation persistence has been confirmed in the literature. However, most of the literature focuses on the persistence of technological innovation, i.e. product and process innovation. In order to achieve an in-depth understanding of innovation persistence, this study broadens the research subject to non-technological innovation and the service industry to examine persistence in both technological and non-technological innovations. Results of this study find persistence in both technological innovation and non-technological innovation. The technological innovations include 1) product innovation and 2) process innovation, and the non-technological innovations are 3) organisational innovation and 4) marketing innovation. The results show that there is the presence of persistence in all four types of innovation, even though the level of persistence differs among them. In addition, this research finds that the complementary relationship between specific types of innovation enhances innovation persistence. The levels of persistence in process innovation and organisational innovation are higher in firms that conducted product innovation simultaneously in the previous period. This is one of the few studies that look at the persistence and complementarity relationship for both technological and non-technological forms of innovation.

2.1 Introduction

In recent years, literature on innovation has confirmed the existence of innovation persistence within technological innovation such as product and process innovations (Antonelli et al., 2012; Cefis and Orsenigo, 2001; Clausen et al., 2011; Maslach, 2015; Raymond et al., 2010; Schmidt and Rammer, 2007; Triguero and Córcoles, 2013). These studies state that firms that innovate once are more likely to innovate again in the future. This phenomenon is termed *innovation persistence*. However, most of the innovation persistence literature focuses only on technological innovation, including product and process innovation, in manufacturing industries and ignores the complementary relationship between different types of innovation.

The present study expands current knowledge on innovation persistence in two ways. A number of innovation studies have highlighted the importance of non-technological innovation, i.e. organisational and marketing innovations (Battisti and Stoneman, 2010; Camisón and Villar-López, 2014; Damanpour et al., 2009). Battisti and Stoneman (2010) point out that while conducting innovations, firms do not simple adopt a single type of innovations because the firms would also develop a cluster of related innovations in the production process, organisation relationship, and marketing strategy in order to reap the full benefit of those innovations. Given the relatively new significance of non-technological innovation in academic studies, the more recently studies start to include organisational and marketing innovations into the research on innovation persistence (Ganter and Hecker, 2013; Tavassoli and Karlsson, 2015). Nevertheless, the existing studies do not provide conclusive results on the persistence of non-technological innovation. The present study contributes to the literature by explicitly investigating innovation persistence in the four types of innovation activities: product, process, organisational, and marketing innovations.

Camisón and Villar-López (2014) point out that organisational innovation favours the development of technological innovation capabilities, which leads to superior performance. Damanpour et al. (2009) study the consequence of the adoption of various innovations over time and discover the positive effect of innovation on firms' performance. Tether (2005) suggests that firms need to align their organisational and marketing strategies with technological innovation as the introduction of non-technological innovations will help firms succeed in fostering further innovations. These studies suggest that there is a complementary relationship between different types of innovation, which means that the simultaneous adoption of different types of innovation contributes to a better innovation performance. In the studies of Martínez-Ros and Labeaga (2009) and Le Bas and Poussing (2014), they find that the complementarities between product and process innovations are important in the decision to persist in innovations. However, these two studies only focus on technological types of innovation. In order to achieve an in-depth understanding of innovation persistence, this study goes beyond the research setting of extant literature and broadens the research subject to non-technological innovation and the service industry to examine persistence in both technological and non-technological innovations.

This study is supported by the UK Community Innovation Survey which is conducted at regular intervals to trace firms' innovative behaviour over time. The present study aims to understand firms' behaviour of innovation persistence for both technological and non-technological innovations and the effect of complementarities on innovation persistence.

Results of this study find persistence in all four types of innovation, but the level of persistence differs among them. The *transition probability model* suggests that there is strong persistence in all four types of innovation. Furthermore, the econometric estimation shows that the persistence in various types of innovation

is true state dependence. Regarding the complementary relationship among the four types of innovation, the levels of persistence in process innovation and organisational innovation are higher in firms that conducted product innovation simultaneously in the previous period. The joint adoption of product and process innovations in the previous period has a positive effect on the development of present process innovation, and the joint adoption of product and organisational innovations increases the probability of introducing organisational innovation in the following period. The main contribution of this study is to extend prior research on innovation persistence by including non-technological innovation and to examine the effect of complementarities on innovation persistence. This is the first study to look at the complementarities' effect on persistence in non-technological innovation.

Following this introduction, the literature section briefly illustrates several theoretical explanations for the presence of innovation persistence. A short review of the previous empirical literature on innovation persistence is provided, which then leads to the development of the study's hypotheses. The methodology section presents the research data and econometric model employed to examine innovation persistence, and the following section presents the econometric results. The empirical results are then discussed, and this research concludes with a review of the main findings and suggests some implications of this research.

2.2 Literature Review

2.2.1 The theoretical reasoning behind innovation persistence

The concept of innovation persistence refers to the fact that firms which innovated in the past are more likely to facilitate innovation in the following periods (Clausen et al., 2011). The innovation persistence highlights the

importance of existing innovations on future ones. The experience of successful innovations encourages future innovations by broadening innovative firms' technological opportunities which make the development of the following innovation more likely, by increasing firms' market power, and by providing funding that can be invested in future innovations (Peters, 2007; Phillips, 1971). This privileged situation increases the probability that the firms continue to innovate.

Previous studies provide several theories to explain why some firms persist in innovation and others do not. The first line of reasoning is the "success-breeds-success" assumption (Flaig and Stadler, 1994; Geroski et al., 1997). The idea is that successful innovation generates profit, which can finance current and future innovations. Successful innovation not only cultivates future innovation with internal resources but also eases difficulties in finding external resources, particularly financial support. Innovation ventures are risky and capital-intensive. The nature of innovation ventures makes it harder for them to acquire resources from capital markets and other sources of finance to fund innovation (Arrow, 1962). However, the record of successful innovation addresses the concerns of external financers, as successful innovation can be an illustration of innovation capability and possible future success in innovation (Tavassoli and Karlsson, 2015). The positive feedback from the initial successful innovation creates a virtuous cycle in which firms continue to innovate. Suárez (2014) argues that, in the case of successful innovation, the decision-making process routinely drives innovation. Innovation success thus breeds innovation success by acquiring essential resources from within, and outside, the organisations (Ganter and Hecker, 2013).

The second line of reasoning understands innovation persistence from a competence-based perspective. This perspective recognises persistence in innovation as a positive feedback loop among knowledge accumulation and

capability building and innovation (Ganter and Hecker, 2013). Knowledge is fundamental to innovation, and the combination of various pieces of knowledge leads to innovation. Existing knowledge used in today's innovation will simultaneously generate new knowledge which in turn becomes an important input for future innovation (Anand et al., 2007). Evolutionary theory suggests that the learning-by-doing effect increases firms' knowledge stock and innovation capability which, in turn, increases the probability of future innovation. The characteristic of knowledge accumulation and the learning effect combined offer a better position from which to persist in innovation, regardless of which types of innovation they are concerned with. For instance, firms that learn how to cooperate with external partners are better in the management of relationships with other firms, which is crucial under an open innovation regime (Clausen et al., 2011; Tavassoli and Karlsson, 2015; Triguero and Córcoles, 2013).

The third line of reasoning posits that innovation persistence is due to the sunk costs of research and development (R&D). In adapting to new technologies, R&D activities require a large investment in facilities, laboratories, machinery, information of new technologies, and learning and training costs. Once such costs are incurred, they are irrecoverable. Therefore, these sunk costs constrain the entry to, and exit from, innovation. For non-innovators, these sunk costs impede new entrants but for innovators, they reduce the costs of future innovation, and the R&D investments over time will generate physical and knowledge capital, which increases the probability of recovering their investment. Besides, R&D is not the kind of activity that can be conducted sporadically because the tacit knowledge required is contained within the human capital. Therefore firms have to recognise that commencing R&D activities is a long-term commitment. Ganter and Hecker (2013) indicate that this dual-sided block explains the persistence of innovation as well as the persistence of non-innovation.

2.2.2 Four different Types of Innovation

The literature identifies innovation as one of the most important factors contributing to a firm's performance. Firms' innovation activities can be roughly divided into two groups – technological innovation and non-technological innovation. According to the third edition of the OECD's Oslo Manual (2005) definition, technological innovation includes product innovation and process innovation which are mainly stimulated by new technologies: "A product innovation is the introduction of a good or service that is new or significantly improved with respect to its characteristics or intended uses (OECD, 2005, p.48)" and "a process innovation is the implementation of a new or significantly improved production or delivery method (OECD, 2005, p.49).

Tether (2005) suggests that firms need to align their organisational and marketing strategies to facilitate technological innovation, so the introduction of non-technological innovation will help them succeed in this. Non-technological innovation has long been neglected, but it is gradually attracting more attention. The importance of non-technological innovation is reflected in the third edition of the OECD's Oslo Manual. The innovation classification is broadened, and two types of non-technological innovation are added; these are organisational innovation and marketing innovation. According to the OECD (2005, p. 51), "An organisational innovation is the implementation of a new organisational method in the firm's business practices, workplace organisation or external relations", and marketing innovation is defined as "the implementation of a new marketing method involving significant changes in product design or packaging, product placement, product promotion or pricing" (p.49).

Although innovation has various aspects, many studies favour the technological aspect over the non-technological one. Numerous studies have used R&D as a measure of the capacity to innovate (Armbruster et al., 2008; Mothe and Uyen

Nguyen Thi, 2010). Some studies investigated the effect of technological innovation on a firm's performance. In most of the empirical works, technological innovation is measured either by innovation performance – innovation as *output*, or by technological effort for innovation – innovation as *input* (Camisón and Villar-López, 2014).

The importance of non-technological innovation is reported in several studies (Armbruster et al., 2008; Caroli and van Reenen, 2001; Greenan, 2003; Piva et al., 2005). These studies indicate that organisational innovation acts as an antecedent which facilitates the development of product and process innovations. Furthermore, organisational innovation also acts as an important source of competitive advantage because organisational innovation *per se* has a significant influence on a firm's performance with regard to productivity and lead time. Damanpour and Aravind (2012) encourage innovation scholars to expand their subjects into organisational and management aspects.

2.2.3 Empirical Research on Innovation Persistence

Since the first work conducted in the 1990s, empirical studies on innovation persistence have flourished (Flaig and Stadler, 1994; Malerba and Orsenigo, 1999); however, findings of these studies are not consistent. Earlier studies find that there is low or no clear-cut persistence of innovation (Cefis and Orsenigo, 2001; Geroski et al., 1997) while more recent studies posit that innovation persistence does exist (Ganter and Hecker, 2013; Martínez-Ros and Labeaga, 2009; Peters, 2007). It is interesting that findings suggesting no clear-cut persistence of innovation are mainly obtained from empirical research using patent data (Cefis, 2003; Cefis and Orsenigo, 2001, 2001; Geroski et al., 1997) while supportive evidence for innovation persistence is found in empirical studies using panel data based on surveys such as the Community Innovation Survey (CIS)

(Clausen et al., 2011; Ganter and Hecker, 2013; Suárez, 2014; Tavassoli and Karlsson, 2015).

A possible explanation for the inconsistent research findings in the literature may be that patents are not equivalent to innovations. According to Griliches (1979) and Pakes and Griliches (1980, p. 378), "patents are a flawed measure (of innovative output) particularly since not all new innovations are patented and since patents differ greatly in their economic impact." Since not all new innovations are patented, it is reasonable for studies using patent data to conclude that there is low or no clear-cut persistence of innovation. Instead of using patents as the measurement of innovation, studies using survey data are able to use innovation *per se* as the measurement because CIS directly collects information on the introduction of innovations. For instance, all the respondent firms are asked whether or not they introduce new or significantly improved products. Besides, CIS also collects information of firm characteristics, such as turnover, partnership, size, and industries. The availability of large amounts of data allows researchers to control this observed firm heterogeneity in order to differentiate between true and spurious persistence.

2.2.3.1 Persistence of Technological Innovation

Firms' innovation activities can be roughly divided into two groups – technological innovation and non-technological innovation. According to the definition in the third edition of the OECD's Oslo Manual (2005), technological innovation includes product innovation and process innovation which are mainly stimulated by new technologies: "A product innovation is the introduction of a good or service that is new or significantly improved with respect to its characteristics or intended uses (OECD, 2005, p.48)" and "a process innovation is the implementation of a new or significantly improved production or delivery method (OECD, 2005, p.49). Most of the extant persistence studies focus on

product and process innovations no matter what type of data (i.e. patent data or survey data) they used to carry out an analysis.

Geroski et al. (1997) use patent data collected in the US and the UK to examine the persistence of product innovation and find that very few innovative firms innovate persistently. Cefis and Orsenigo (2001) gathered patent data from six countries to examine innovation persistence across industries and countries. Their results reveal the persistence of innovation, although it is not very high and it gradually declines as time goes by. Raymond et al. (2010) examine the persistence of technological innovation in Dutch manufacturing firms and discover true persistence in high-tech firms and spurious persistence in low-tech firms. The presence of innovation persistence can result from two causes: state dependence or unobserved effects, or omitted variables correlated over time (through serially correlated errors or individual effects) (Heckman, 1981). The first cause is recognised as true state dependence which means that past innovations do increase the probability of current innovations (true persistence) while the other is considered as spurious persistence. Clausen et al. (2011) investigate the impact of innovation strategies on innovation persistence using a Norway R&D survey and suggest that persistence of innovation is strongly influenced by different innovation strategies across firms. Antonelli et al. (2012) employ survey data collected from Italian manufacturing firms and find clear evidence of persistence in both product and process innovations, with the highest level of persistence being found in R&D-based innovation activities. Triguero and Córcoles (2013) explore innovation persistence using both R&D (input) and innovation (output); they find that both R&D and innovation are highly persistent at the firm level. Moreover, they delve into the interrelationships among R&D and innovation and find a feedback process between them. In other words, having R&D increases the probability of engaging in innovation and vice versa. Maslach (2015) studies how firms react when their technological innovation ends in failure.

He finds that firms change innovation activities when they fail in novel innovation, but they persist in innovation when they fail in incremental innovation. Given that several studies report that there is persistence in product and process innovation, this study tests the following hypotheses:

H1 (a): The probability of conducting product innovation depends positively on having conducted product innovation in the past.

H1 (b): The probability of conducting process innovation depends positively on having conducted process innovation in the past.

2.2.3.2 Persistence of non-technological innovation

Non-technological innovation has long been neglected but is gradually attracting more attention. The importance of non-technological innovation is reflected in the third edition of the OECD's Oslo Manual. The innovation classification is expanded, and two types of non-technological innovation are added; these are organisational innovation and marketing innovation. According to the OECD (2005, p. 51), "An organisational innovation is the implementation of a new organisational method in the firm's business practices, workplace organisation or external relations", and marketing innovation is defined as "the implementation of a new marketing method involving significant changes in product design or packaging, product placement, product promotion or pricing" (p.49).

It is understandable that non-technological innovation such as organisational and marketing innovations is ignored in the persistence studies using patent data. Patents are much more closely related to technological innovation than to non-technological innovation. Besides, research data on organisational and marketing innovations was not readily available until the OECD introduced organisational and marketing innovations into the guidelines for collecting and interpreting innovation data, and included respective questions within CIS questionnaires in

2005 (Schmidt and Rammer, 2007). However, despite the availability of data on organisational and marketing innovation, most of the persistence studies still concentrate on persistence in product and process innovation.

While developing innovation, firms do not restrict their endeavours to technological aspects, but they also undertake some other managerial and marketing actions to support their innovation projects. These actions include teamwork, reduction of hierarchical levels, continuous improvement, and just-in-time and supply chain management among others (Armbruster et al., 2008). Tether (2005) suggests that firms need to align their organisational and marketing strategies to facilitate technological innovation as the introduction of non-technological innovation will help the firms succeed in technological innovation. Damanpour and Aravind (2012) encourage innovation scholars to expand their subjects into organisational and management aspects. There is ample evidence indicating that organisational innovation has no less a profound impact on a firm's performance and growth than technological innovation does (Camisón and Villar-López, 2014; Ganter and Hecker, 2013; Jansen et al., 2005; Schmidt and Rammer, 2007). Some studies consider organisational innovation an essential prerequisite of technological innovation; that is, the success of product and process innovations relies on the degree to which the organisational structures and processes fit into the implementation of new technologies (Armbruster et al., 2008; Greenan, 2003; Piva et al., 2005).

Researchers are starting to inspect the role of organisational innovation in innovation persistence. For instance, Le Bas et al. (2011) find that organisational innovation is a crucial determinant of innovation persistence, and Haned et al. (2014) reveal similar results, showing that organisational innovations have a positive effect on persistence in technological innovation. Furthermore, this influence is much stronger for complex innovators who conduct both product and

process innovations. Although the papers of Le Bas et al. (2011) and Haned et al. (2014) start to look at the role of organisational innovation in their studies of innovation persistence, the latter study is not interested in the persistence of organisational innovation but in the *impact* of organisational innovation on persistence of technological innovation. Ganter and Hecker (2013) explore persistence patterns of various types of innovation such as product, process, and organisational innovation. Their result reveals that a firm's propensity to conduct organisational innovation increases with the previous adoption of technological innovation, firm size and public financial support for innovation. However, there is no evidence to support persistence in organisational innovation. Tavassoli and Karlsson (2015) investigate persistence in all four types of innovation. Their analysis shows that persistence exists in three of the types of innovation, the exception being marketing innovation. Persistence in marketing innovation is present in their baseline model but disappears after controlling for firms' observed heterogeneity. This implies that marketing innovations have spurious persistence and hence no casual inference can be drawn. To clarify whether there is persistence in non-technological innovation this study tests whether

H1 (c): The probability of conducting organisational innovation depends positively on having conducted organisational innovation in the past.

H1 (d): The probability of conducting marketing innovation depends positively on having conducted marketing innovation in the past.

2.2.4 Complementarity between Four Types of Innovation

Another reason to incorporate non-technological innovation into the focus of interest is that there are complementarities between different types of innovation. For instance, radical innovation often leads to changes in products and in

production processes, as well as in marketing, delivery, and geographic scope of the productivity or service activities. Reichstein and Salter (2006) suggest a complementary relationship between product and process innovation. Moreover, this relationship is stronger when the level of the novelty of innovation is higher. Martínez-Ros and Labeaga (2009) examine complementarity between product and process innovations and find that the implementation of a production can trigger corresponding process innovation, and vice versa. Therefore, research on innovation should account for the mutual interaction between different types of innovation. Furthermore, it has been proved that the joint adoption of different types of innovation is beneficial to a firm's business performance. For example, Camisón and Villar-López (2014) find that organisational innovation enhances firms' capabilities to achieve technological innovation and that both organisational and technological innovations enable firms to achieve superior performance. These findings suggest a complementary relationship between different types of innovation. Roberts and Amit (2003) argue that the superior performance does not result from a single type of innovation but from the impact of the composition of various forms of innovation.

Damanpour et al. (2009) study the consequences of the adoption of various innovations over time and discover the positive effect of innovation on a firm's performance. Innovative firms are more likely to achieve superior performance as a result of the implementation of various types of innovation; however, the level of performance dispersion is extensive, and this huge difference in firms' performance tends to persist over time. Some studies have indicated that superior and sustained performance is rooted in a constant stream of innovation (Antonelli et al., 2015; Damanpour et al., 2009; Deschryvere, 2014). However, most of the empirical studies of innovation use cross-sectional data and focus mainly on technological innovation.

In short, little is known about non-technological innovation compared to technological innovation and the interrelationship between them. Additionally, only a few studies have investigated firms' innovation activities longitudinally. This study seeks to bridge this gap by tackling two issues – the persistence of innovation in various types of innovation, and the effect of complementarity of various innovations on innovation persistence.

H2 (a): The probability of conducting product innovation depends on the complementarity between product innovation and the other three types of innovation in the past.

H2 (b): The probability of conducting process innovation depends on the complementarity between process innovation and the other three types of innovation in the past.

H2 (c): The probability of conducting organisational innovation depends on the complementarity between organisational innovation and the other three types of innovation in the past.

H2 (d): The probability of conducting marketing innovation depends on the complementarity between marketing innovation and the other three types of innovation in the past.

2.3 Methodology

2.3.1 Data and Sample

This research uses data from four waves of the UK Community Innovation Survey (CIS 5-CIS 8, 2004-2012), which is conducted every two years by the Office for National Statistics (ONS) on behalf of the Department of Business Innovation & Skills (BIS). The survey is based on a core questionnaire developed by the European Commission (Eurostat) and Member States. The main purpose of the

survey is to collect information about business innovation in the UK. The survey is voluntary and covers enterprises with 10 or more employees. The CIS also has a wide sectoral coverage including both manufacturing and service sectors, and comprises a stratified sample of firms drawn from the ONS Inter-Departmental Business Register (IDBR). Firms that participate in CIS have their own unique IDBR reference numbers, which are unique reference numbers assigned to business organisations. This unique reference number allows the researcher to retrieve firms' information such as date of founding and date of termination from the Business Structure Database (BSD) and to construct a panel dataset from the four waves of CIS.

To examine the hypotheses, a model that relates past and present innovation activities is built which employs a panel dataset including manufacturing and services firms. The latest three waves of CIS, from CIS 6 to CIS 8, are the main source of the research data. Each wave of CIS covers a three-year period, and there is a one-year overlap between two consecutive CIS surveys. For instance, CIS 6 covers the period 2006-2008, CIS 7 covers the period 2008-2010, and CIS 8 covers the period 2008-2010. This study's results only consider firms which are observed in three waves and contain no missing values. Under these rules, the sample is confined to 964 observations corresponding to 482 firms. Besides, this study incorporates firms' innovation status from CIS5 in order to control for the initial condition problems (Wooldridge, 2005).

2.3.2 Research Framework

Figure 2-1 depicts the research framework of the present study. It can be seen that the innovation persistence is determined by the relationship between innovative activities in two successive periods. It further proposes that this relationship is influenced by the complementary relationship between different types of innovation. In addition, several important controls are included in the

model to eliminate or reduce the bias arising from the confounding effects. This framework guides the definitions and measures of the major variables used in this study.

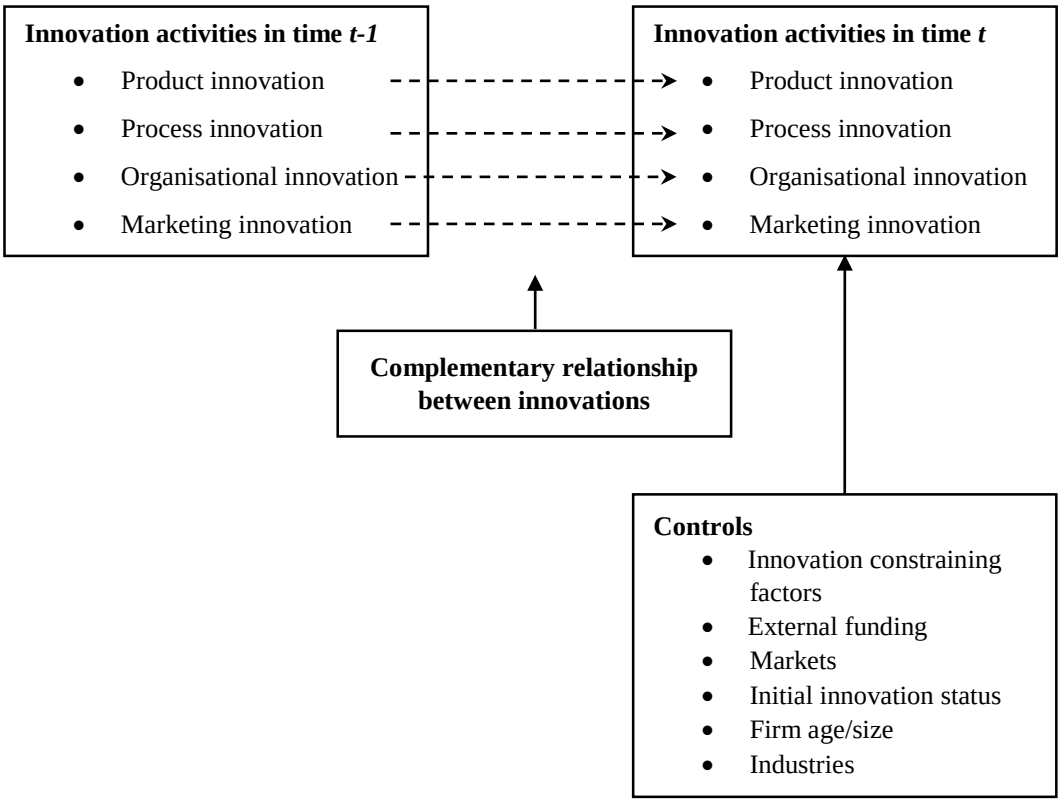

Figure 2-1 Research framework

2.3.3 Econometric Model

The dependent variables employed are binary, so a probit regression model is used to investigate the persistence of firms' innovative activities among four different types of innovation. As the persistence of innovation is tested by the realisations of innovation activities across the analysed time periods, the specific estimation model employed is a dynamic random effect probit model (RE probit model). One important problem in dynamic non-linear models is the initial conditions problem. Wooldridge (2005) indicates that the coefficient of the lagged dependent variable is overestimated when individual effects and the initial conditions are not properly controlled. He proposed an alternative Conditional

Maximum Likelihood estimator that assumes that the initial conditions are exogenous. The equation for the model is as follows:

$$y^{*}_{it} = \gamma y_{i,t-1} + X_{it}\beta + \varepsilon_i + \mu_{it}, \qquad (1)$$

$$y_{it} = 1 \text{ if } y^{*}_{it} > 0 \text{ ; 0 otherwise,} \qquad (2)$$

where $i = 1, \dots, N$, $t = 1, \dots T$ and the subscript i indicates firms and t indicates time periods. The above estimation model requires an important assumption on the initial observation y_{i1} and its relationship with ε_i, the unobserved individual effects: if the start of the analysed process does not coincide with the start of the available observations, y_{i1} cannot be treated as exogenous and its correlation with the error term would cause bias in the estimation of the lagged dependent variable, γ. This is also known as an initial condition problem. Wooldridge (2005) proposes modelling ε_i conditional on y_{i1} and $\overline{X}_i$. His model for the individual-specific component already incorporates the Chamberlain-Mundlak specification (Mundlak, 1978) and can be written as

$$y^{*}_{it} = \gamma y_{i,t-1} + X_{it}\beta + \overline{X}_{it}\alpha + \varepsilon_i + \mu_{it}, \qquad (1)$$

$$\varepsilon_i = b_0 + b_1 y_{i1} + \zeta_i. \qquad (4)$$

After substituting, the equation becomes

$$y^{*}_{it} = \gamma y_{i,t-1} + X_{it}\beta + \overline{X}_{it}\alpha + b_0 + b_1 y_{i1} + \zeta_i + \mu_{it}. \qquad (5)$$

Wooldridge's (2005) model has the advantage of being less restrictive on exogeneity assumption and is easier to implement than the Heckman estimator (Antonelli et al., 2012). While employing the RE probit model, this study follows Peter's (2007) stepwise procedure strategy. Peter (2007) points out that the strict exogeneity of the explanatory variable is a major limitation of the RE probit model, which means that the feedback effects between the future innovation and explanatory variables are ruled out. However, this assumption is contested for some of the variables usually explaining innovation – e.g., firm size, industries,

or R&D expenditure. First, this study begins with a baseline model specification including only the lagged dependent variable, initial condition and some basic control variables such firm size, age and industry. Then in the second step, the additional explanatory variables are included.

2.3.4 The Variables

2.3.4.1 Dependent variables

This study employs four different types of innovation activities as dependent variables. They are product innovation, process innovation, organisational innovation, and marketing innovation. Each dependent variable is constructed as a binary variable. If a firm reports that the specific type of innovation is introduced during the survey period, the dependent variable is coded 1, otherwise it is coded 0.

The dependent variable for product innovation is constructed from questions asking whether the firm introduces new or significantly improved goods or services. The dependent variables for process innovation are constructed from questions asking whether the firm introduces any new or significantly improved processes for production or supplying of goods or services. The dependent variable for organisational innovation is constructed from questions asking whether the firm introduces new business practices for organising procedures; or new methods of organising work responsibility and decision making; or new methods of organising external relationships with other firms or public institutions. The dependent variable for marketing innovation is constructed from questions asking whether the firm implements changes to marketing concepts or strategies.

2.3.4.2 Independent variables

Persistence is measured by including the lagged dependent variable $y_{i,t-1}$. In order to understand whether persistence of innovation can be affected by the presence of complementarity among different types of innovation, this study also incorporates the other three types of innovation conducted in time *t-1* into the econometric model.

The research data used in this study covers the period of global financial crisis in 2008. To approximate the impact of economic plight on firms' innovations, some innovation-constraining factors are included: economic risk, cost of innovation, cost of finance, availability of finance, and uncertainty of demand. In times of the global financial crisis, financial institutions become more cautious than usual about providing loans to firms. This means that it was more difficult for firms to access external financial resources for innovation than it was in other more standard periods of time. A range of the innovation literature has shown that financial resources are crucial to the development of innovations (Ganter and Hecker, 2013; Suárez, 2014). Both the studies of Ganter and Hecker (2013) and Suárez (2014) find that the recipient firms have a higher probability of achieving innovations. Therefore, this study includes three funding variables: funding from the UK local government, funding from the UK central government, and funding from the EU institutions.

Besides, Paunov's (2012) study on firms' investments on innovation in times of global crisis finds that the crisis led many firms to abandon ongoing innovation projects. Moreover, she indicates that firms strongly reliant on foreign markets are more likely to abandon innovation projects. The demand shock could have led to a decrease in revenue, which would have imposed financial constraints, forcing firms to stop innovation. Thus, the present study includes four market variables indicating which geographic markets the firms sell their goods or services: 1)

local market: within approximately 100 miles of the firms, 2) national market: the UK national, 3) EU markets: European countries, and other markets: all other countries. The following Table 2-1 contains the definition of the variables that are used in this study and Table 2-2 reports the means, standard deviations, and minimum and maximum values of the variables for the sample (N= 964).

Table 2-1 Description of the variables

Name of variables	Description
Dependent variable	
Product innovation (PDinn)	Binary variable: coded 1 if the business introduces new or significantly improved goods or services, otherwise coded 0.
Process innovation (PCinn)	Binary variable: coded 1 if the business introduces new or significantly improved processes for producing or supplying goods or services, otherwise coded 0.
Organisational innovation (ORGinn)	Binary variable: coded 1 if the business introduces new business practices or new methods of organising work responsibilities and decision making or new methods of organising external relationships, otherwise coded 0.
Marketing innovation (MARinn)	Binary variable: coded 1 if the business implements changes to marketing concepts or strategies, otherwise coded 0.
Independent variable	
Lagged dependent variable	Binary variable: referring to the status of dependent variable in previous period.
Initial condition	Binary variable: coded 1 if the business reports to introduce innovation in CIS5 survey.
Other innovation	Binary variable: referring to the status of innovation in previous period.
Interaction term of innovation activities	The four different lagged dependent variables create six interaction terms of innovation activities.
Local fund	Binary variable: coded 1 if the business reports it receives public finance support from local or regional authorities.

Central fund	Binary variable: coded 1 if the business reports it receives public finance support from central government.
EU fund	Binary variable: coded 1 if the business reports it receives public finance support from European Union institutions or programmers.
Local market	Binary variable: coded 1 if the business sells goods or services to UK regions.
National market	Binary variable: coded 1 if the business sells goods or services to the UK nationally.
EU market	Binary variable: coded 1 if the business sells goods or services to European countries.
Other market	Binary variable: coded 1 if the business sells goods or services to all other countries.
Innovation constraints	Binary variable: coded 1 if the business reports that the factor highly constrains its innovation activities.
Mundlak-type variables	All time-variant variables are used to create corresponding time-invariant variables.
Age	The age of a firm (the last year of the survey period minus the year when a firm was established)
Firm size	The number of employees in log form.
Industry	Firms are classified according to OECD technology-intensity classifications.

Table 2-2 Descriptive statistics (N=964)

	Variables	Mean	Std. Dev.	Min	Max
Dependent variables					
1	$PDinn_t$	0.32	0.47	0	1
2	$PCinn_t$	0.21	0.41	0	1
3	$ORGinn_t$	0.44	0.50	0	1
4	$MARinn_t$	0.20	0.40	0	1
Independent variables					
5	$PDinn_{t-1}$	0.31	0.46	0	1
6	$PCinn_{t-1}$	0.21	0.41	0	1
7	$ORGinn_{t-1}$	0.41	0.49	0	1
8	$MARinn_{t-1}$	0.20	0.40	0	1
9	Eco_risk_{t-1}	0.14	0.34	0	1
10	$Cost\_high_{t-1}$	0.16	0.37	0	1
11	$Cost\_finance_{t-1}$	0.12	0.32	0	1
12	$Access\_finance_{t-1}$	0.11	0.31	0	1
13	$Uncertainty_{t-1}$	0.08	0.28	0	1
14	$Local\_funding_{t-1}$	0.06	0.24	0	1
15	$Central\_funding_{t-1}$	0.05	0.22	0	1
16	$EU\_funding_{t-1}$	0.02	0.15	0	1
17	Local market	0.65	0.48	0	1
18	National market	0.76	0.43	0	1
19	EU market	0.39	0.49	0	1
20	Other market	0.29	0.45	0	1
21	Firm age	29.01	9.75	-	40
22	Firm size (in log form)	5.80	1.02	2.77	9.11

23	Initial: PDinn	0.30	0.46	0	1
24	Initial: PCinn	0.21	0.41	0	1
25	Initial: ORGinn	0.48	0.50	0	1
26	Initial: MARinn	0.26	0.44	0	1
27	Low	0.17	0.38	0	1
28	Medium-low tech.	0.06	0.24	0	1
29	Medium-high tech.	0.07	0.25	0	1
30	High tech.	0.02	0.15	0	1
31	Service	0.67	0.47	0	1

Table 2-3 shows the correlations between the four types of innovation in time (t) and time (*t-1*) and Table 2-4 presents the correlation matrix for all variables used in this study.

Since the main interests of this study are persistence of innovation and complementarities between different types of innovation, the focus is on the relationship between dependent variables and lagged dependent variables shown in Table 2-3. Regarding the innovation persistence, the relationship between the past and current innovations for identical types of innovation is shown, i.e. product innovation in time *t* and product innovation in time *t-1*. The correlations between the past and current innovations are significant and positive for all four types of innovation. It is plausible to expect to find support for hypotheses H1 (a), H2 (a), H3 (a), and H4 (a). Concerning the complementary relationship between different types of innovation, their correlation is also positive and significant. It is likely that there is complementarity among different types of innovation.

Table 2-3 Correlations for Innovations in times *t* and *t-1* (N=964)

	$PDinn_t$	$PCinn_t$	$ORGinn_t$	$MARinn_t$	$PDinn_{t-1}$	$PCinn_{t-1}$	$ORGinn_{t-1}$	$MARinn_{t-1}$

	1	2	3	4	5	6	7	8
1	1.00							
2	0.40*	1.00						
3	0.24*	0.30*	1.00					
4	0.20*	0.17*	0.25*	1.00				
5	0.46*	0.30*	0.21*	0.18*	1.00			
6	0.34*	0.44*	0.20*	0.14*	0.45*	1.00		
7	0.26*	0.22*	0.33*	0.19*	0.34*	0.29*	1.00	
8	0.16*	0.12*	0.16*	0.35*	0.28*	0.23*	0.32*	1.00

Table 2-4 Correlations for variables (N=964)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1	1.00																														
2	0.40*	1.00																													
3	0.24*	0.30*	1.00																												
4	0.20*	0.17*	0.25*	1.00																											
5	0.46*	0.30*	0.21*	0.18*	1.00																										
6	0.34*	0.44*	0.20*	0.14*	0.45*	1.00																									
7	0.26*	0.22*	0.33*	0.19*	0.34*	0.29*	1.00																								
8	0.16*	0.12*	0.16*	0.35*	0.28*	0.23*	0.32*	1.00																							
9	0.06*	0.07*	0.10*	0.07*	0.14*	0.06	0.13*	0.12*	1.00																						
10	0.05	0.03	0.10*	0.01	0.09*	0.05	0.11*	0.09*	0.44*	1.00																					
11	-0.02	-0.01	0.02	-0.02	0.04	-0.02	0.01	0.04	0.30*	0.40*	1.00																				
12	0.03	0.01	0.02	-0.02	0.08*	0.07*	0.07*	0.06*	0.19*	0.24*	0.63*	1.00																			
13	0.07*	0.04	0.02	0.02	0.06*	0.07*	0.00	0.02	0.23*	0.19*	0.14*	0.11*	1.00																		
14	0.12*	0.11*	0.10*	0.04	0.14*	0.17*	0.11*	0.04	0.08*	0.14*	0.04	0.07*	0.14*	1.00																	
15	0.19*	0.14*	0.10*	0.00	0.25*	0.19*	0.13*	0.04	0.08*	0.06	-0.01	-0.02	0.13*	0.27*	1.00																
16	0.07*	0.11*	0.09*	0.04	0.14*	0.11*	0.11*	0.04	0.02	0.08*	-0.01	-0.03	0.08*	0.27*	0.37*	1.00															
17	-0.01	-0.02	-0.01	0.02	-0.03	-0.02	-0.02	0.02	-0.07*	0.01	-0.03	0.01	-0.01	-0.02	-0.01	-0.03	1.00														

18	0.16*	0.11*	0.09*	0.08*	0.19*	0.10*	0.11*	0.05	0.04	0.03	0.01	-0.04	0.01	-0.01	0.01	0.05	-0.30*	1.00														
19	0.27*	0.22*	0.15*	0.07*	0.27*	0.17*	0.16*	0.05	0.01	0.07*	0.03	0.03	0.04	0.05	0.13*	0.05	0.18*	0.36*	1.00													
20	0.26*	0.17*	0.16*	0.09*	0.24*	0.15*	0.13*	0.08*	0.01	0.05	-0.01	-0.01	0.06*	0.12*	0.22*	0.15*	0.19*	0.25*	0.70*	1.00												
21	0.02	-0.01	-0.01	0.04	0.03	-0.01	-0.01	0.03	0.02	-0.02	-0.04	-0.05	0.04	-0.04	0.03	0.01	0.03	0.11*	0.12*	0.13*	1.00											
22	-0.02	0.00	0.05	0.04	-0.01	-0.01	0.00	0.02	-0.03	0.00	0.00	-0.04	0.07*	-0.04	0.01	-0.04	-0.10*	0.12*	-0.07*	0.00	0.16*	1.00										
23	0.28*	0.16*	0.15*	0.09*	0.30*	0.17*	0.19*	0.12*	0.08*	0.03	-0.04	-0.05	0.10*	0.07*	0.16*	0.08	0.01	0.13*	0.21*	0.23*	0.03	0.06	1.00									
24	0.25*	0.11*	0.05	0.13*	0.22*	0.16*	0.08*	0.12*	0.12*	0.07*	-0.03	-0.05	0.15*	0.08*	0.11*	-0.01	0.09*	0.09*	0.22*	0.17*	0.08*	0.06	0.51*	1.00								
25	0.26*	0.19*	0.19*	0.13*	0.24*	0.15*	0.25*	0.15*	0.08*	0.07*	0.00	0.03	0.05	0.07*	0.12*	0.06*	0.04	0.09*	0.17*	0.18*	0.02	0.03	0.33*	0.18*	1.00							
26	0.11*	0.09*	0.10*	0.15*	0.15*	0.07*	0.13*	0.18*	0.06	0.05	0.00	0.02	0.00	0.01	0.08*	0.07*	0.04	0.07*	0.11*	0.09*	0.02	0.05	0.31*	0.22*	0.45*	1.00						
27	0.06	0.07*	-0.03	-0.03	0.03	0.06	-0.02	-0.02	0.02	0.07*	0.01	0.00	0.07*	0.07*	0.02	0.02	-0.07*	0.13*	0.05	-0.02	0.09*	-0.02	0.04*	0.15*	-0.04	-0.03	1.00					
28	0.15*	0.02	0.07*	-0.07*	0.11*	0.03	0.08*	-0.02	0.11*	0.11*	-0.01	-0.03	0.02	0.14*	0.11*	0.05	0.03	0.15*	0.22*	0.21*	0.04	-0.06	0.02	0.08*	0.03	0.00	-0.12*	1.00				
29	0.18*	0.12*	0.10*	0.06	0.14*	0.11*	0.11*	0.03	0.01	0.05	-0.01	0.04	0.04	0.05	0.08*	-0.01	0.04	0.09*	0.31*	0.34*	0.02	-0.03	0.20*	0.14*	0.10*	-0.01	-0.12*	-0.07*	1.00			
30	0.15*	0.07*	0.08*	0.08*	0.15*	0.09*	0.07*	-0.01	-0.02	-0.01	-0.03	-0.03	0.08*	-0.01	0.18*	0.16*	0.04	0.07*	0.16*	0.24*	0.05	0.02	0.14*	0.16*	0.05	-0.03	-0.07*	-0.04	-0.04	1.00		
31	-0.27*	-0.15*	-0.09*	0.00	-0.20*	-0.15*	-0.11*	0.02	-0.07*	-0.13*	0.02	0.01	-0.11*	-0.15*	-0.18*	-0.09*	0.00	-0.25*	-0.37*	-0.35*	-0.12*	0.05	-0.20*	-0.29*	-0.05	0.04	-0.66*	-0.37*	-0.39*	-0.22*	1.00	

* Denotes significance at the 5% level

2.4 Results

2.4.1 Transition probability matrices

To answer the research questions relating to innovation persistence, this study first uses a transition probabilities matrix (TPM) to obtain an initial approximation of persistence of the four types of innovation. The TPM discloses the information about the probability of changing status from one state to another. In this study, 'state' is the innovation of firms in each period (i.e. being an innovator or a non-innovator). The TPM is formulated as follows:

$$TPM = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1d} \\ \vdots & & \ddots & \vdots \\ p_{d1} & p_{d2} & \cdots & p_{dd} \end{bmatrix},$$

where $p_{ij=}(Y_t = j \mid Y_{t-1} = i)$.

Pij measures the probability of changing from state i to state j for the vector Y while moving from time (*t-1*) to time (t). Y consists of several variables measuring different types of innovation such as product innovation, process innovation, organisational innovation, and marketing innovation.

Table 2-5 Transition probabilities

		Innovation status in *t+1*	
Type of innovation	Innovation status in *t*	NON-INNO	INNO
Product	NON-INNO	85%	15%
	INNO	34%	66%
Process	NON-INNO	89%	11%
	INNO	40%	60%
Organisational	NON-INNO	67%	33%

	INNO	29%	71%
Marketing	NON-INNO	87%	13%
	INNO	51%	49%

Table 2-5 illustrates the transition probability of firms' innovation status for the four types of innovation. The values on the diagonal are an indication of persistence, as they indicate the fraction of firms that stay in the same class, as innovators or non-innovators. If the sum of the diagonal values of the TPM matrix is equal to or greater than 100% probability and all the elements of the diagonal value of the TPM matrix are larger than 50%, there is strong persistence, while there is a weak persistence if the sum of the diagonal values of the TPM matrix is equal to or greater than 100% probability but not all the elements of the diagonal value of the TPM matrix are larger than 50% (Clausen et al., 2011; Tavassoli and Karlsson, 2015). The results show that there is strong persistence in all four types of innovation but that the degree of persistence in each type differs.

In product innovation, 66% of the innovators in one year persisted in innovation in the subsequent year, while 34% stopped their involvement in product innovation; and 85% of the non-innovators in one year remained static, while only 15% started to innovate. In process innovation, 60% of the innovators in one year persisted in innovation in the subsequent year, while 34% stopped their involvement in process innovation; and 89% of the non-innovators in one year remained static, while only 11% started to innovate. In organisational innovation, 71% of the innovators in one year persisted in innovation in the subsequent year, while 29% stopped their involvement in organisational innovation; and 67% of the non-innovators in one year remained static, while only 33% started to innovate. Lastly, in marketing innovation, 49% of the innovators in one year persisted in innovation in the subsequent year, while 51% stopped their involvement in

marketing innovation; and 87% of the non-innovators in one year remained static, while only 13% started to innovate.

Although marketing innovation is the sole innovation whose diagonal values of persistence are under 50%, its level of persistence is very close to strong persistence. The threshold for strong persistence requires that all the diagonal values are above 50%, and the diagonal values of the marketing innovation model are 87% and 49%, respectively, which is very close to the threshold. To sum up, persistence exists in all the four types of innovation, although the levels of persistence differ. Among the four types of innovation, persistence in organisational innovation is relatively high, while persistence in process innovation is the lowest. The result of the TPM supports hypotheses H1 (a), H1 (b), H1 (c) and H1 (d).

2.4.2 Econometric estimations and main findings

2.4.2.1 Innovation persistence

This section presents the results of the dynamic random effect probit model in order to identify the true state dependency in the persistence of the four types of innovation. I first estimate an extremely parsimonious model, which includes only lagged innovation, the initial condition of innovation and some basic control variables such as firm size, age, time, and industry dummies; i.e. models (1), (3), (5) and (7). Then additional explanatory variables are added to the base models to see whether the estimation of persistence is affected; i.e. Models (2), (4), (6) and (8) to test H1 (a) – H1 (d). The econometric results are shown in Table 2-6.

For product innovation, past product innovation has a positive effect on current product innovation; that is to say, a product innovator in a previous period has a higher probability of conducting product innovation than that of a non-product innovator (Model (1)). The impact of past product innovation holds even after the

observed and unobserved firm characteristics are included in the regression model (Model (2)). Thus, H1 (a) is supported, suggesting that there is persistence in product innovation. For process innovation, past process innovation has a positive impact on present process innovation. In other words, firms that are involved in process innovation in a previous period are more likely to conduct process innovation in the subsequent period (Model (3)). The impact of past process innovation holds even after the observed and unobserved firm characteristics are included in the regression model (Model (4)), and therefore it is possible to interpret the significant effect of past process innovation as a true persistence. Thus, H1 (b) is supported, suggesting that there is persistence in process innovation.

Concerning organisational innovation, past organisational innovation has a positive influence on the introduction of organisational innovation at the present time (Model (5)). The impact of past organisational innovation holds even after the observed and unobserved firm characteristics are included in the regression model (Model (6)), which supports H1 (c), suggesting that there is persistence in organisational innovation. Lastly, the results concerning marketing innovation (Models (7) and (8)) are similar to those of the above three innovations, in terms of the significance of past innovation. Past marketing innovation has a positive influence on the introduction of marketing innovation at the present time (Model (7)). The impact of past marketing innovation holds even after the observed and unobserved firm characteristics are included in the regression model (Model (8)). Therefore, H1 (d) is supported, suggesting that there is persistence in marketing innovation.

2.4.2.2 Complementarities

For Hypotheses H2 (a) to H2 (d), the relevant coefficients are those derived from the interaction term of lagged innovation with the other three types of innovation

conducted in a previous period. As stated in the literature review, some studies suggest that there are complementarities between different types of innovation and that the complementarity effect can lead to superior firm performance (Martínez-Ros and Labeaga, 2009). It is very likely that any two types of innovation are developed simultaneously. I test this relationship by introducing several interaction terms of various innovations which represent joint innovation; i.e. for product innovation (Model (2)), this study introduces interaction terms between the innovation of interest and the remaining three types of innovation, respectively. For example, for the product innovation model (Model (2)) the interaction terms are lagged product innovation*lagged process innovation, lagged product innovation*lagged organisational innovation, and lagged product innovation*lagged marketing innovation. In other words, I multiply product innovation with other types of innovation. Following this logic, corresponding interaction terms are introduced into the process, organisational, and marketing innovation models (Model (4), Model (6), and Model (8)).

For product innovation, only the interaction term of '$PDinn_{t-1}$ * $Marinn_{t-1}$' is significant and its coefficient is negative, which shows that firms are less likely to engage in product innovation if they conducted both product and marketing innovations in previous periods. For process innovation, only the interaction term of '$PDinn_{t-1}$ * $PCinn_{t-1}$' is significant and its coefficient is positive, which shows that firms are more willing to introduce process innovation if they conducted both product and process innovations in previous periods. For organisational innovation, only the interaction term of '$PDinn_{t-1}$ * $ORGinn_{t-1}$' is significant and its coefficient is positive, which shows that firms are more willing to introduce organisational innovation if they conducted both product and organisational innovations in previous periods. Lastly, for marketing innovation, none of the coefficients of the three interaction terms is statistically significant.

To examine whether the results of complementarities are biased by the potential multicollinearity problem, this study performs F-test to test whether the effect of the newly added interaction terms on innovation persistence are jointly significant or not. This study uses Model (2), (4), (6) and (8) as the unrestricted models for the four types of innovations (product, process, organisation and marketing), respectively. The corresponding restricted models are created by removing the interaction terms. For example, to build the restricted model for the product innovation, I remove three interaction terms ($PDinn_{t-1}$ * $PCinn_{t-1}$, $PDinn_{t-1}$ * $ORGinn_{t-1}$ and $PDinn_{t-1}$ * $MARinn_{t-1}$) and the other three innovation variables ($PCinn_{t-1}$, $ORGinn_{t-1}$ and $MARinn_{t-1}$) which are added only because of the creation of interaction terms.

The results show that the interaction terms are jointly significant across all four models. The results of the F-tests for the four types of innovation are $F(6, 935) = 5.34$, $p < 0.0001$, $F(6, 937) = 4.21$, $p = 0.0003$, $F(6, 937) = 2.27$, $p = 0.0349$ and $F(6, 937) = 2.67$, $p = 0.0143$, respectively. This is consistent with the earlier results for the product, process and organisation innovation as there are at least one significant interaction term for these three types of innovation. Take product innovation as an example, one interaction term ('$PDinn_{t-1}$ * $Marinn_{t-1}$' in this case) has significant explanatory power (as shown in the Models (2) results in Table 2-6), so it is reasonable that the group of interaction terms has jointly significant effect on the dependent variable, which is shown from the result of the F-test. It is worth to mention that the F-test for marketing innovation indicates that the effect of the interaction terms is jointly significant. However, there is no significant interaction term in the Model (8) for marketing innovation, which may be caused by the multicollinearity problem.

Table 2-6 Random effect probit model estimates

	1	2	3	4	5	6	7	8
	$PDinn_t$	**$PDinn_t$**	**$PCinn_t$**	**$PCinn_t$**	**$ORGinn_t$**	**$ORGinn_t$**	**$MARinn_t$**	**$MARinn_t$**
	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.
$PDinn_{t-1}$	1.096***	0.681***		-0.702***		-0.444*		-0.225
	(0.0997)	(.251)		(0238)		(0.235)		(0.233)
$PCinn_{t-1}$		-0.400	1.261***	0.793***		-0.251		-0.267
		(0.270)	(0.108)	(0.291)		(0.259)		(0.273)
$ORGinn_{t-1}$		-0.273		-0.284	0.704***	0.505***		-0.278
		(0.209)		(0.212)	(0.111)	(0.157)		(0.196)
$MARinn_{t-1}$		0.0205		-0.122		-0.00725	1.030***	0.550**
		(0.262)		(0.280)		(0.251)	(0.109)	(0.262)
$PDinn_{t-1}$*$PCinn_{t-1}$		0.290		0.659**				
		(0.300)		(0.318)				
$PDinn_{t-1}$*$ORGinn_{t-1}$		0.183				0.440*		
		(0.259)				(0.250)		
$PDinn_{t-1}$*$MARinn_{t-1}$		-0.671**						0.251
		(0.291)						(0.276)
$PCimm_{t-1}$*$ORGinn_{t-1}$				-0.298		-0.0584		
				(0.300)		(0.278)		
$PCinn_{t-1}$*$MARinn_{t-1}$				-0.109				0.276
				(0.312)				(0.294)
$ORGinn_{t-1}$*$MARinn_{t-1}$						-0.317		0.148
						(0.269)		(0.280)
Eco_risk_{t-1}		-0.161		0.437		-0.221		0.386
		(0.271)		(0.295)		(0.235)		(0.274)
$Cost\_high_{t-1}$		0.231		-0.287		-0.247		-0.368
		(0.2666)		(0.274)		(0.230)		(0.261)
$Cost\_finance_{t-1}$		-0.534		0.527		0.535		0.196
		(0.386)		(0.421)		(0.335)		(0.381)
$Access\_finance_{t-1}$		0.0672		-0.965**		-0.199		-0.604*
		(0.343)		(0.394)		(0.304)		(0.357)

$Uncertainty_{t-1}$	0.0263	−0.228	0.393	−0.0120
	(0.317)	(0.338)	(0.286)	(0.331)
$Local\_funding_{t-1}$	−0.483	−0.0883	0.207	−0.214
	(0.479)	(0.452)	(0.437)	(0.427)
$Central\_funding_{t-1}$	−1.244**	−0.0958	−0.321	−0.325
	(0.600)	(0.452)	(0.479)	(0.465)
$EU\_funding_{t-1}$	−0.563	0.803	−0.296	0.308
	(0.653)	(0.669)	(0.645)	(0.654)
Local market	0.255	−0.0235	0.0109	0.300
	(0.214)	(0.234)	(0.191)	(0.218)
National market	−0.164	0.125	0.0629	0.709**
	(0.288)	(0.318)	(0.247)	(0.295)
EU market	−0.537*	0.741**	−0.125	−0.0213
	(0.281)	(0.317)	(0.256)	(0.299)
Other market	0.571**	−0.134	0.783***	0.0109
	(0.290)	(0.314)	(0.277)	(0.314)
Avg. $PDinn_{t-1}$		1.340***	0.461*	0.458
		(0.318)	(0.255)	(0.279)
Avg. $PCinn_{t-1}$	1.299***		0.883***	0.301
	(0.319)		(0.284)	(0.299)
Avg. $ORGinn_{t-1}$	0.773***	1.151***		0.820***
	(0.254)	(0.294)		(0.251)
Avg. $MARinn_{t-1}$	0.609**	0.0203	0.549**	
	(0.301)	(0.312)	(0.263)	
Avg. Eco_risk_{t-1}	0.231	−0.504	0.712**	−0.237
	(0.379)	(0.419)	(0.338)	(0.374)
Avg. $Cost\_high_{t-1}$	−0.414	0.299	0.778**	0.471
	(0.369)	(0.383)	(0.329)	(0.348)
Avg. $Cost\_finance_{t-1}$	0.248	−0.745	−0.840*	−0.320
	(0.478)	(0.545)	(0.438)	(0.472)
Avg $Access\_finance_{t-1}$	0.393	1.077**	0.120	0.385
	(0.449)	(0.509)	(0.409)	(0.443)
Avg. $Uncertainty_{t-1}$	0.174	0.387	−0.965**	−0.0940
	(0.426)	(0.451)	(0.392)	(0.427)

Avg. Local_funding$_{t-1}$		0.631		0.330		-0.00682		0.687
		(0.557)		(0.534)		(0.511)		(0.513)
Avg Central_funding$_{t-1}$		2.274***		0.133		0.132		-0.389
		(0.811)		(0.578)		(0.591)		(0.584)
Avg. EU_funding$_{t-1}$		-0.703		-0.770		0.582		-0.430
		(0.829)		(0.853)		(0.811)		(0.818)
Avg. local market		-0.562*		-0.317		-0.175		-0.343
		(0.312)		(0.337)		(0.276)		(0.306)
Avg. national market		0.403		-0.200		-0.0863		-0.766**
		(0.363)		(0.396)		(0.303)		(0.348)
Avg. EU market		0.952***		-0.154		0.292		0.0279
		(0.346)		(0.382)		(0.316)		(0.356)
Avg. other market		-0.627*		0.0971		-0.738**		0.123
		(0.360)		(0.391)		(0.342)		(0.378)
Avg. firm age	0.0275	0.0215	-0.0113	-0.0186	-0.160***	-0.170***	0.0142	0.0315
	(0.0481)	(0.0555)	(0.005)	(0.0596)	(0.0465)	(0.0502)	(0.0509)	(0.0563)
Avg. firm size	-0.337	-0.378	-0.303	-0.302	-0.352	-0.189	0.307	0.384
	(0.276)	(0.339)	(0.291)	(0.368)	(0.261)	(0.279)	(0.272)	(0.303)
Firm age	-0.0296	-0.0241	0.00858	0.0148	0.155***	0.163***	-0.0104	-0.0268
	(0.0480)	(0.0553)	(0.0504)	(0.0595)	(0.0462)	(0.0498)	(0.0506)	(0.0558)
Firm size	0.317	0.340	0.314	0.325	0.425*	0.292	-0.275	-0.335
	(0.272)	(0.332)	(0.287)	(0.362)	(0.257)	(0.273)	(0.269)	(0.298)
Medium-low tech.	0.421**	0.446	-0.0716	-0.482	0.346	0.263	-0.394	-0.628*
	(0.207)	(0.282)	(0.221)	(0.304)	(0.226)	(0.255)	(0.273)	(0.322)
Medium-high tech.	0.449**	0.265	0.230	-0.192	0.404*	0.336	0.359*	0.183
	(0.209)	(0.278)	(0.205)	(0.288)	(0.223)	(0.257)	(0.215)	(0.261)
High tech.	0.569*	0.688	0.153	-0.323	0.545	0.491	0.824***	0.791**
	(0.336)	(0.470)	(0.317)	(0.437)	(0.343)	(0.394)	(0.309)	(0.391)
Service	-0.337***	-0.243	-0.245*	-0.153	-0.0373	0.136	0.111	0.220
	(0.123)	(0.157)	(0.132)	(0.182)	(0.129)	(0.144)	(0.137)	(0.165)
Initial	0.395***	0.355**	0.0466	-0.119	0.339***	0.225**	0.306***	0.256**
	(0.103)	(0.147)	(0.124)	(0.174)	(0.107)	(0.111)	(0.107)	(0.165)
_cons	-0.639**	-1.210***	-1.017***	-1.690***	-1.098***	-1.510***	-1.605***	-2.060***
	(0.310)	(0.465)	(0.323)	(0.530)	(0.320)	(0.404)	(0.329)	(0.468)

/lnsig2u	−12.71	−1.635	−12.23	−1.161	−1.834**	−1.566**	−12.28	−2.199
	(15.57)	(1.247)	(25.90)	(0.834)	(0.907)	(0.754)	(33.69)	(1.540)
Log likelihood	−472.70	−407.70	−415.09	−359.36	−589.63	−547.75	−421.30	−390.95
Wald test (chi2)	227.01	173.23	163.34	142.54	108.23	146.09	118.90	133.72
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
observations	964	964	964	964	964	964	964	964
number of firms	482	482	482	482	482	482	482	482

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

2.5 Discussion

This study seeks to understand the role of persistence in various types of innovation and determine whether the complementarities between any two types of innovation affect a firm's propensity to innovate.

Although the results of the TPM suggest that persistence exists in the four types of innovation, the share of transitions exhibiting persistence is relatively small compared with that from the extant literature (Clausen et al., 2011; Ganter and Hecker, 2013; Tavassoli and Karlsson, 2015; Triguero and Córcoles, 2013). For example, the share of persistence in product innovation ranges from 63% (Tavassoli and Karlsson, 2015) to 92% (Ganter and Hecker, 2013). One possible explanation for this is that the time frame of research data used in this study is characterised by the disorder of banking market conditions and uncertainties in the market resulting from the 2008 global financial crisis, which rendered it difficult to introduce successful innovation in normal time. It is no wonder that the harsh business environment made firms hesitant about conducting innovation. The use of the TPM only allows me to suggest that prior conditions affect future events. Therefore, one can say that 'history matters' because the innovation status in time *t* is not randomly distributed in the populations of firms. However, it is not appropriate to conclude a causal relationship between past innovation and current innovation based on the outcome of the TPM.

Antonelli et al. (2013) argue that innovation persistence is the outcome of a special quality, a talent, embodied in the firm and such innovation persistence is *path*-dependent rather than *past*-dependent. In order to identify whether there is a true state dependence or a spurious state dependence, this study employs a dynamic random effect probit model to investigate the determinants of the persistence of innovation. The econometric results suggest that persistence exists for the four types of innovation. These results from the probit model are

consistent with results obtained from the TPM. For persistence in product innovation and process innovation, it is not entirely unexpected to find persistence in them, as a few empirical studies have found evidence for these claims. For persistence in organisational innovation, results of this study suggest that there is true state dependence between the past and current organisational innovation. This finding is consistent with Tavassoli and Karlsson's (2015) study showing that past organisational innovation has a behavioural effect on future organisational innovation. Regarding marketing innovation, my results contrast with Tavassoli and Karlsson's (2015) finding in which marketing innovation does not have true state dependency on future marketing innovation. My results from both the TPM and the probit model suggest that the probability of conducting marketing innovation depends positively on introducing marketing innovation in the past. In other words, there is a persistence relationship between past and present marketing innovations.

The empirical evidence suggests that a persistence of innovation exists for all four types of innovation but that the levels of persistence differ. The persistence in organisational innovation is the highest; for this, the present research proposes two possible explanations. First, under the pressure from the global financial crisis, firms were forced to take actions in response. As Campello et al. (2010) state, constrained firms generally suffer from a shortage of financial resources, so they have to cut their technology, employment, and capital spending. These changes signify that firms can no longer operate in the same manner as they did and they have had to find new strategies to do things. Second, organisational innovation is an enabler of technological innovation capabilities (Camisón and Villar-López, 2014). If firms wish to continue to introduce product or process innovation, they may need to consider conducting organisational innovation as well.

With regard to the level of persistence in the four types of innovation, the econometric estimations imply that, to some extent, firms seem to prioritise technological innovation over non-technological innovation. If one looks at the coefficients of lagged dependent variables in the eight regression models, the coefficients in product and process innovations are larger than those in organisational and marketing innovations. This phenomenon could be explained by R&D sunk costs theory: both product and process are more closely related to the advent of technologies, which means that R&D investment is crucial for firms dedicated to these types of innovation. As explicated in the literature review, R&D investment is a fixed cost, which can also be considered a sunk cost. These costs would be irrecoverable if the firm did not conduct any innovations, which results in these sunk costs forming a barrier to exit from innovation.

Concerning the complementarities, some of the combinations of innovation are found to be complementary. The complementary effects are found in all types of innovation except marketing innovation. First, this study looks at the complementarities in product innovation (Model (2)); no complementary relationship is confirmed. Nevertheless, this study finds that the combination of lagged product innovation and lagged marketing innovation has a negative effect on the introduction of product innovation. In the field of innovation, relatively little attention is paid to the effect of marketing innovation (Chen, 2006; Halpern, 2010; Hauser et al., 2006; Naidoo, 2010). Although there are some studies which look into the complementarity between innovations, most of the research focuses on the relationship between product and process innovations (Ballot et al., 2015; Martínez-Ros and Labeaga, 2009). This study proposes two explanations for the negative effect of joint adoption of product and marketing innovations on persistence in product innovation. First, the theory of new product development process (NPD) states that the process of innovative activities can be categorised into three broad phases; these are conception, implementation and marketing

(Tiwari and Buse, 2007; Verworn et al., 2008). This process suggests that the marketing phase begins after the development of a new product. Firms may have several new product development projects in place at the same time, and each project may be at a different stage in its development process. The joint adoption of product and marketing innovations simultaneously may signify that some of the firms' product development projects have just begun and are undergoing the development process, while other projects have completed the development of the new product and are entering the marketing phase. The adoption of marketing innovation in the previous period infers that some innovation projects are ready to be launched on to the market. These nearly completed projects are less risky than completely new innovation projects. There is already a certain level of risk and uncertainty inherent in innovation. In the face of the 2008 financial crisis, the external environment also imposes additional strain on the firms. In order to eliminate the risk and uncertainty, firms may need to be more conservative than they would usually be. In other words, innovative firms may decide to cease or delay the development of new product innovations. Thus, firms that adopted both product and marketing innovations in the previous period are less willing to conduct new product innovation than those that only adopted product innovation.

Second, the literature on marketing innovation provides some insights on the reason of the negative relationship between the joint adoption of product and marketing innovation and persistence of product innovation. Past studies of marketing innovation posit that a market-orientated firms is likely to be innovative, which would result in superior performance (Agarwal et al., 2003; Haned et al., 2014; Narver and Slater, 1990). Market orientation is defined as recognition of market dynamism and understanding and satisfying customers and relevant stakeholders (Day, 1994; Naidoo, 2010; Narver and Slater, 1990). Several marketing studies have suggested that there is a mutual support between

product and marketing innovation. Gunday et al. (2011) indicate that the needs of customer are fulfilled through marketing activities and innovations, which then create the needs for further product innovation. Mariadoss et al. (2011) find that several marketing capabilities such as packing, pricing and marketing communication are important drivers of technical innovations. Furthermore, market orientation helps eliminate the risk of product failure through developing an in-depth understanding of the target market and operating with the knowledge base of market-sensing and customer-linking (Agarwal et al., 2003; Lukas and Ferrell, 2000; Ngo and O'Cass, 2012). Although the marketing literature suggests that there are synergy benefits of marketing and product innovations, there are few studies taking into account the external economic environment in which firms develop their innovations. There is little direct evidence of the relationship between product and marketing innovation in the context of turbulent economic environment, such as a financial crisis. A market-oriented firm is presumed to have superior capabilities of market-sensing and then adapt its business plan accordingly. The present study argues that firms that invest in marketing innovation possess a higher market-sensing capability which enables them to quickly notice the changes in the external environment. In the economic environment characterised as highly uncertain, firms with higher marketing capability will realise their inability to accurately predict market trend, customer demand, competitor positions and reactions, and the outcome of their decisions on the development of new products (Miller and Toulouse, 1986; Naidoo, 2010). Therefore, these market-oriented firms become more cautious about investing in product innovation project that is in the early stage of development because a new project tends to contain a great deal of uncertainty about the success of product innovation. This is probably the reason why the joint adoption of adoption of product and marketing innovations in previous period has a negative impact on the future development of product innovation.

For process innovation, only the joint adoption of product and process innovations in the previous period has a significant positive impact on firms' engagement in process innovation. In other words, persistence in process innovation is stronger in firms that have conducted product and process innovations simultaneously. One possible explanation may be that product innovation would trigger future process innovation, as stated in the literature review.

For complementarities in organisational innovation, only the joint adoption of product and organisational innovations in the previous period has a positive impact on firms' engagement in future organisational innovation. That is, persistence in organisational innovation is stronger in firms that have conducted product and organisational innovations simultaneously.

It is worth noting that in both process and organisational models, the combination of lagged dependent variable with lagged product innovation is the only combination that has an influence on firms' involvement in the process and organisational innovation. Martínez-Ros and Labeaga (2009) argue that persistence will depend on the type of innovation which the firms conduct. When firms are more dedicated to product innovation for creating new products or improving existing ones, it may also be necessary to develop process innovation for the production of new or improved products. In accordance with Abernathy and Utterback's A-U model, "innovations in the early stage of the technological trajectory are essentially product-oriented, then become more process-oriented, and eventually become essentially incremental, as product and process innovations both decline in frequency and significance (Martínez-Ros and Labeaga, 2009, p. 65)". To clarify, this study does not assert that there is not necessarily a chronological process between product innovation and process innovation; instead, process innovation may also trigger product innovation. The positive coefficient of interaction terms of product and process innovations

suggests that firms are more likely to persist in process innovation if they conducted both product and process innovation simultaneously in previous periods.

In a similar vein, when firms develop new products, they may need new business practices for organising procedures, or new methods of organising work responsibility and decision making, or new methods of organising external relationships with other firms or public institutions. Previous studies have highlighted the importance of organisational innovation in developing other types of innovations. Ballot et al. (2015) posit that it is important to create organisational coherence while developing innovations as coherence ensures the benefit of complementarity. Organisational (re)structuring leading to administrative and structural improvement acts as a facilitator of product, process and marketing innovations (Gunday et al., 2011). Damanpour et al.'s study (1989) found that administrative innovation stimulate technical innovation in public library and the study of Straopoli (1998) shows that organisational rearrangements and coordination mechanisms enhances technological innovations in the pharmaceutical industry. The findings of this study on the complementary relationship between product and organisational innovations is consistent with previous studies. Firms conducting both product and organisational innovation have a higher incentive to persist in doing organisational innovation as they may need to continue to adapt the organisational structure for other types of innovations.

Apart from the lagged innovation, which shows the persistence, some observable firm characteristics turn out to affect future innovation significantly. The innovation-constraining factors have no impact on product and organisational innovations, as these factors are not significant. The variable, a lack of access to finance, has a negative effect on the introduction of process and marketing

innovations. This means that firms are less willing to innovate when they lack access to finance. This result is consistent with Paunov's (2012) finding, which illustrates that innovation projects are more likely to be abandoned by firms whose decreased revenue imposes a burden on innovation. Funding from different levels of governments seems unimportant, as these variables are not significant in most of the econometric models. Only central funding is significant in the analysis of product innovation, but its coefficient is negative. This result seems to contradict Paunov's (2012) finding, suggesting that firms are less likely to stop innovation if they have access to public funding.

2.6 Conclusions

This study investigated whether innovative firms exhibit the persistent behaviour of innovation. This study distinguished between four types of innovation, while employing a panel of Community Innovation Survey, which enabled us to trace the innovative behaviour of firms in the UK during the period 2006-2012. The main contribution of this work is that it has extended prior studies by investigating persistence in both technological and non-technological innovations, as well as the effect of complementarities on innovation persistence. Extant innovation persistence literature often ignores non-technological innovation, except for the works of Ganter and Hecker (2013) and Tavassoli and Karlsson (2015). However, these two works do not look into the interrelationships among different types of innovation.

In this study, persistence in all four types of innovation is confirmed. The results from the transition probability model (TPM) suggest that there is persistence in the four types of innovation, but that the levels of persistence differ. Among the four types of innovation, persistence in organisational innovation is relatively high, while persistence in marketing innovation seems to be the lowest. Then

Wooldridge's model is applied to identify whether the persistence is true or a spurious state dependence. The findings of technological innovation are consistent with what has been found in the literature; that there is persistence in product and process innovation. However, findings regarding non-technological innovation are less consistent with what was found in the prior studies. For instance, Ganter and Hecker (2013) find no support for persistence in organisational innovation, while Tavassoli and Karlsson (2015) posit that there is persistence in various types of innovation except for marketing innovation. The empirical evidence of this study shows that there is persistence in technological innovation, product and process innovations, non-technological innovation, organisational and marketing innovations. Nevertheless, the level of persistence is not equal in different types of innovation. Firms tend to prioritise technological innovation over non-technological innovation.

This study also finds that there is a complementary relationship between innovations. Firms which conduct process and product innovation in a previous period are more willing to develop process innovation, which means that persistence in process innovation is stronger in firms that have conducted process and product innovations simultaneously. In a similar vein, firms that conduct organisational and product innovation in a previous period are more willing to develop organisational innovation, which means that persistence in organisational innovation is stronger in firms that have conducted organisational and product innovations simultaneously. On the other hand, this study finds that the combination of lagged product and lagged marketing innovations have a negative effect on the adoption of product innovation.

Most of the extant theories used to explain persistence in innovation focus mainly on technological innovation. The empirical evidence of persistence in organisational and marketing innovations is somewhat controversial. Contrary to

the findings of Ganter and Hecker (2013) and Tavassoli and Karlsson (2015), the current study finds evidence for the persistence in organisational and marketing innovations. More work is needed to identify whether there is persistence in organisational and marketing innovation, or whether these divergent results are due to the heterogeneity of research data used to examine persistence; for instance, the CIS from different countries and time periods. Besides, findings of the present study are inconsistent with what is found in Suárez's (2014) work indicating that innovating firms tend to stop innovations in an unstable economic environment, which suggests that further investigation of the issue is needed, in order to account for the effect of the effect of the macroeconomic environment on firms' innovating behaviours in particular.

Results of this study may have implications for both managers and policy makers. Concerning the policy implications, the presence of innovation persistence implies that innovation seems to be a self-efficient process that is expected to reproduce itself over time. Policies should not only support the good innovators that contribute to the country's level of economic growth but also should encourage non-innovative firms to start to innovate. Once innovation is initiated, it would create a virtuous cycle, which would have a long-lasting effect on firms' decisions on innovations and firms' performance. Regarding managerial implications, the joint adoption of different types of innovation increase firms' probability of innovation persistence; therefore, managers could consider whether the knowledge base created in doing one type of innovation can be reutilised in alternative innovations. Managers have to consider how to maximise profit from innovations through both the economies of scales and the complementary relationship between innovations.

The underlying reasons why firms persist in non-technological innovation are still unclear, and the empirical evidence of persistence in non-technological innovation is also rather limited compared to that of technological innovation.

More work is needed to investigate the causes and consequences of persistence in various types of innovation.

Chapter 3: Determinants of Innovation Persistence during and after global financial crisis

Abstract

A growing body of empirical literature supports key assertions of innovation persistence and then draws inferences that the presence of new innovation is conditioned on the presence of past innovation. The existing literature has proposed several explanations to reason firms' constant engagement in innovations, but few of them investigate the effectiveness of the potential explanations. The most common reasons behind persistence are 1) presence of sunk cost, 2) success-breeds-success which refers to the fact that the successes in prior innovations yield resources to cultivate future innovations, 3) appropriation mechanisms act as a key incentive for the engagement in innovations, and 4) competence in innovation helps firms introduce a constant stream of innovations. Although some studies investigate the reasoning behind innovation persistence, the dependent variable used is a binary variable indicating the presence of innovation. Precisely, these studies examine the impact of these potential determinants on the probability of occurrence of new innovation rather than on persistence *per se*. The present study argues that in theorising the causes behind innovation persistence, adopting the continuity of innovations as a dependent variable may be more appropriate than adopting the presence of innovations. This idea is tested by constructing a binary variable indicating firms' successive engagement in innovations, innovation persistence. Results of this study show that the four causes are more capable of explaining the presence of persistence in product innovation but are less effective in explaining the

persistence of the other three types of innovation. Moreover, this study finds that the determinants of innovation persistence change with the changing circumstances of the financial environment. Past R&D investment does not affect the persistence of product innovation in times of global financial crisis, but it increases the probability of the persistence of product innovation after the crisis. Firms with established external collaborative relationships show the propensity to continue to innovate in times of global financial crisis, but the effect of the collaborative relationship disappears after the crisis.

3.1 Introduction

Literature on innovation persistence has confirmed that past innovations play a decisive role in the development of future innovations (Antonelli et al., 2012; Cefis and Orsenigo, 2001; Clausen et al., 2011; Maslach, 2015; Raymond et al., 2010; Tavassoli and Karlsson, 2015; Triguero and Córcoles, 2013). Prior studies have used the insights of innovation theory and outlined potential reasons behind innovation persistence as 1) presence of sunk cost, 2) positive feedback from prior innovation, leading to success in innovation breeding further success, 3) appropriation mechanisms that protect valuable intellectual property of current innovation, which would be reused for the development of future innovations, and 4) presence of firms' innovative competencies that give rise to a sequence of innovations (Clausen et al., 2011; Suárez, 2014; Tavassoli and Karlsson, 2015; Triguero and Córcoles, 2013). However, very few studies test the effectiveness of those factors in explaining innovation persistence. As mentioned in Chapter 2, most innovation persistence studies focus on the relationship between past innovations and current innovations and apply the autoregressive model to test this relationship. Persistence is measured by the coefficient of the lagged dependent variable. To some extent, these studies make predictions of the occurrence of future innovation. Unlike the extant persistence studies, this study introduces a direct measure of innovation persistence which directly characterises a firm's innovation behaviours over time. Innovation persistence is measured by whether a firm continuously introduces innovations in two successive time periods. This new measure enables this study to test the effectiveness of those potential factors in explaining the presence of innovation persistence. Furthermore, this study also argues that the causes of innovation persistence change in different economic circumstances. This study examines the determinants of innovation persistence in two different time frames – during and

after the 2008 financial crisis – to see whether there are differences in determinants.

Findings of this study suggest that the four theoretical explanations are more capable of explaining the persistence of product innovation than that of the other three types of innovation. All the four factors are important in explaining the persistence of product innovation, but the importance of these factors to some extent is shaped by the condition of the prevailing macroeconomic environments. The presence of persistence of the other three types of innovation could only partially explained by some of the four theoretical explanations. Thus, the underlying reasons for persistence in the process, organisational, and marketing innovation are still unclear.

Following this introduction, the literature section first introduces the concept of innovation persistence and then presents recent literature which links financial crisis and innovation. This section also summarises several underlying theories which are often used to explain innovation persistence and also illustrates how this leads to the development of hypotheses in this study. The methodology section presents the research data and econometric model used to examine the hypotheses. The following section presents the econometric results and discusses the empirical results. The last section concludes the main findings of this study.

3.2 Literature review

3.2.1 The persistence of innovation: empirical evidence

Innovation persistence has been identified in some of the recent literature on this subject. Prior innovation persistence studies using patent data discover that only a few firms innovate persistently (Cefis and Orsenigo, 2001; Geroski et al., 1997; Malerba and Orsenigo, 1999), and the recent studies using innovation survey data

reveal that persistence of innovation is often seen in product and process innovations (Antonelli et al., 2012; Ganter and Hecker, 2013; Martínez-Ros and Labeaga, 2009; Tavassoli and Karlsson, 2015). The explanation for the divergence between studies using patent data and innovation survey data is detailed in Chapter 2 (section 2.2.3). Most of the persistence literature focuses on technological innovation such as product and process innovations (Antonelli et al., 2012; Clausen et al., 2011; Martínez-Ros and Labeaga, 2009; Triguero and Córcoles, 2013). In the more recent studies of Ganter and Hecker (2013) and Tavassoli and Karlsson (2015), researchers working on this topic start to direct their efforts towards non-technological innovation such as organisational and marketing innovations.

The extant literature has provided several explanations of why innovation might demonstrate state dependence over time. This thesis organises commonly cited explanations of innovation persistence: 1) sunk costs in R&D, 2) success-breeds-success, where the success of innovations significantly affects the conditions for following innovations, 3) appropriation mechanism for protecting innovation, and 4) innovation capability, which refers to the scale effect on the accumulation of competence in innovation. However, few studies look into the reasoning behind the patterns of persistent innovation; most studies are primarily interested in the question of whether or not, and to what extent, innovation is persistent. This study deviates somewhat from current persistence literature by shifting the focus to the underlying causes of the presence of innovation persistence. The four causes for the phenomenon of innovation persistence are detailed in the following section.

3.2.2 Four possible explanations of innovation persistence

3.2.2.1 Sunk costs in R&D

R&D investments have generally been recognised as an important driver of innovations (Belderbos et al., 2004; Deschryvere, 2014; Paunov, 2012; Raymond and St-Pierre, 2010). Based more or less implicitly on a linear view of innovation, the persistence of innovation would originate from the continuity of R&D expenditure. Tavassoli and Karlsson (2015) suggest that the persistence of R&D investments would lead to the persistence of innovation. Clausen et al. (2011) posit that the successive engagement in innovations can be explained by the sunk nature of R&D costs.

When a firm decides to conduct R&D, it incurs start-up costs in establishing and equipping R&D facilities, hiring and training staff, and collecting information on novel technologies and market opportunities (Mañez et al., 2009). Once incurred, these costs are largely unrecoverable and can, therefore, be considered as sunk costs (Sutton, 1991). Investment in R&D generates sunk costs which form a barrier to exit from R&D activities for R&D performers because the investment would be recognised as a loss if the firm ceases its R&D activities. Firms continue R&D if it would cost them more to stop R&D. From this perspective, the presence of sunk costs to some extent acts as a motive for continuing to engage in R&D activities (Le Bas and Poussing, 2014).

R&D is an important component of innovations. Although there is no guarantee that investment in R&D will lead to innovation, it is however expected that persistent R&D performers have a higher probability of succeeding in innovation and recouping their investment than sporadic R&D performers have (Triguero and Córcoles, 2013). Calusen et al. (2011) point out that the success of innovation relies on the stability of R&D as the key to success may lie in the human capital of

R&D researchers. R&D is not an activity that can be easily stopped and then started again. The knowledge embodied in the human capital of researchers cannot be well cultivated if the R&D is carried out sporadically. The avoidance of pecuniary loss is not the only reason retaining firms' persistence in R&D and innovations. The start-up costs of R&D have been paid at the initiation of R&D investment. The costs to initiate a new R&D activity are lower for established R&D performers than non-R&D performers. Thus, firms involved in R&D have a greater incentive to continue to conduct R&D and innovation.

The R&D sunk cost perspective is often used to explain persistence in product and process innovations (Duguet and Monjon, 2004; Suárez, 2014; Tavassoli and Karlsson, 2015) because these two types of innovation are more closely related to the advent of technologies, which means that R&D investment is crucial for firms dedicated to these types of innovation. Duguet and Monjon (2004) believe that firms that manage to support the sunk costs of R&D are able to introduce product or process innovations. Tavassoli and Karlsson (2015) argue that R&D investment is an essential ingredient of product innovation and that the stability of R&D seems to lead to persistence in product innovation. Triguero and Córcoles (2013) also find high persistence in technological innovation.

3.2.2.2 Success-breeds-success

The success-breeds-success perspective emphasises that prior successful innovations generate profit which can finance current and future innovations (Flaig and Stadler, 1994; Geroski et al., 1997). Innovation is often characterised as risk- and capital-intensive activity and the development process of innovation is often kept secret. The characteristics of innovations make it difficult for external financiers to assess firms' innovation projects and thus impede firms' application for external financial support. Therefore, it is important for innovative firms to finance their innovations using internal finances which are primarily

raised from prior successful innovations. The success of innovations equips innovative firms with greater market power and enables firms to earn extraordinary revenue (Suárez, 2014). Past innovations thus help cultivate future innovation.

Geroski et al. (1997) examine the presence of innovation persistence in UK and US firms. Their results suggest that very few innovative firms persist in innovation. The success-breeds-success pattern of innovations is limited to highly innovative firms for a limited period of time. Tavassoli and Karlsson (2015) posit that success-breeds-success is suitable to explain persistence in product innovation. Successful product innovation not only helps firms achieve financial gain but also expands firms' technological opportunities, which improves the chances for future product innovation success.

Resource constraints is another theoretical perspective similar to success-breeds-success. The resource constraints perspective expresses that innovative firms frequently encounter difficulties with financial resources, particularly for the access to external financial support. It is understandable that external financiers are less willing to provide business loans to innovative firms due to the risk and uncertainty embodied in innovations. However, the records of prior successful innovation help alleviate external financiers' concerns about innovations. External financiers may interpret prior success as a signal that the focal firms possess superior innovation-developing capabilities, which increases the probability of success in future innovations. Therefore, prior successful innovations not only help fund future innovations but also help firms to apply for external financial resources. The positive feedback from the initial successful innovation creates a virtuous cycle in which firms continue to innovate (Ganter and Hecker, 2013; Suárez, 2014).

3.2.2.3 Appropriation strategies

The third line of reasoning is the appropriation strategies. Appropriation refers to a mechanism for innovative firms to protect profit generated from their innovations. Wang and Chen (2010) indicate that the innovation literature has long been concerned about how well innovative firms can appropriate the economic value generated from their innovations. The concern is raised from the rapid diffusion of innovation knowledge and the threat of imitation by rival firms. Teece (1986) state that in competition over innovation it is common that the fast second or even slow third innovation follower outperforms the innovators. He explains that the economic value of innovation may accrue to the owners of specific complementary assets instead of the innovator when the innovation is easy to imitate. It is vital for innovative firms to protect their innovation outcomes. Otherwise, firms may not obtain sufficient return to reach break-even point or to survive from the competition. Some innovation literature has identified appropriability as one of the key incentives for the engagement in innovations (Cohen et al., 2000; Leiponen and Byma, 2009). Various practices can be adopted to protect a firm's innovations; these include formal methods such as patents, trademarks, and other forms of intellectual property rights as well as informal methods such as secrecy, lead time, and sales and service efforts (Laursen and Salter, 2014; Leiponen and Byma, 2009; Tether and Massini, 2007). The choice of appropriation practices is contingent on the types of property that require protections and the firms' capability. For instance, patents are often emphasised in the study of intellectual property (IP) protections, but they are mainly used by large firms; conversely, small firms stress that lead time is the most important protection mechanism (Leiponen and Byma, 2009). Although firms have their own preference for appropriation strategies, they commonly employ a variety of practices to protect their innovations (Cohen et al., 2000).

Besides, appropriation strategies also complement the success-breeds-success strategy to encourage firms to continue to innovate. The success-breeds-success model only happens in situations where firms obtain extraordinary profit and invest these profits into future innovations. The extraordinary profit from past innovations can be only made possible if these innovations are well protected.

3.2.2.4 Competence-based perspective

Innovations are the accomplishment of an accumulation of specific competencies (Rosenberg, 1976) and this accumulation process is characterised by economies of scale (Arrow, 1962; Dosi, 1988; Winter and Nelson, 1982). Innovation literature stipulates that the capability to innovate is gradually built up through the involvement in a series of research projects in which firms broaden their knowledge and learn how to innovate. This process is also termed 'learning-by-doing'(Cohen and Levinthal, 1990). When developing innovations, a firm discovers and learns new knowledge and then recombines it with old knowledge in order to carry out innovations. This is why the persistence literature hypothesises that past innovations influence the present innovations (Duguet and Monjon, 2004; Ganter and Hecker, 2013; Le Bas and Poussing, 2014).

In spite of the cumulative nature of knowledge stocks, a firm's knowledge base is also subject to economies of scale (Clausen et al., 2011; Ganter and Hecker, 2013; Le Bas and Poussing, 2014). Ganter and Hecker (2013, p. 1433) elaborate that "innovation continuously builds on previous knowledge, while simultaneously laying a foundation for future learning and knowledge production. Therefore, previous innovation nurtures the knowledge base and provides inputs for future innovation activity that may result in a virtuous cycle of knowledge production". The more pieces of knowledge the firm acquired in the past, the more it could recombine them in order to produce new pieces of knowledge. The average cost of producing new knowledge falls as the volume of knowledge output increases.

In other words, the production of knowledge is subject to economies of scale as well as the production of innovations. As a result, past innovations provide innovative firms with an incentive to pursue more innovations.

It is worth mentioning that, unlike the above three reasons, the competence-based perspective is the only one that is not biased toward persistence in technological innovation such as product innovation and process innovation (Tavassoli and Karlsson, 2015). Regardless of which types of innovation we are concerned with, knowledge is the fundamental material for innovations, and a combination of knowledge leads to innovations. Clausen et al. (2011) argue that the learning process can also apply to the management of relationships with external partners. For instance, firms which have experience in cooperation with external partners perform better in the establishment of effective partnerships.

3.2.3 Innovation at times of economic downturn

The global financial crisis of 2008 has severely affected the economies of OECD countries (Hud and Hussinger, 2015). According to OECD's Science, Technology and Industry Outlook 2012, the unemployment rate reached a post-war height of 8.5% in 2009, and the GDP declined by 4% in 2009 as compared to 2008.

Several studies have found that firms tend to postpone or stop their innovations at times of economic downturn. Filippetti and Archibugi (2011) contrast firms' expenditure on innovation in 2006, before the crisis, with that in 2008, during the crisis. They reveal that the 2008 global financial crisis has a significant influence on firms' investment in innovations across Europe. The percentage of firms that increase their budget for innovation drops dramatically from 40.2% to 10.6% because of the global financial crisis, while the percentage of firms that decrease their expenditure on innovation rises from10.8% to 26.7%. Campello et al. (2010) reveals that in Europe, 69% of financially constrained firms considered

cancelling their investment due to the financial crisis. Paunov (2012) also finds that the global financial crisis led many firms in Latin America to stop their ongoing innovation projects.

Success in innovation requires the presence of several favourable conditions such as cash flow availability, proper managerial incentive, conditions of the financial market, and presence of human capital and organisational capital. The challenge of meeting those favourable conditions is likely to amplify in an economic downturn, which would make success in innovation very unlikely. If firms delay or stop their innovation during the times of financial crisis, there would be no presence of innovation persistence.

Most of the existing literature does not take into account the macroeconomic environment while studying the persistence of innovation, the exception being the study of Suárez (2014) who looks into innovation persistence in a turbulent business environment – that of the 1998–2001 economic crisis. Suárez (2014) indicates that the current persistence studies overlook the influence of changes in the macroeconomic environments and argues that existing persistence literature somewhat assumes that the competencies or resources firms accumulated in the past would remain useful for the present or future innovations; thus, firms tend to continue to innovate once they have begun to do so. The findings of Suárez's study reject the presence of innovation persistence, indicating that in times of crisis existing innovations do not necessarily lead to new innovations in the present.

In times of global financial crisis, firms generally suffer from a shortage of financial resources, which compels them to cancel investment in technologies, to lay off staff, or even to sell assets (Campello et al., 2010). These changes in the working condition of firms signify the need for better management as a survival mechanism (Naidoo, 2010). Firms can no longer operate in the same way as they

did in the past. The motivations for innovating in a pro-cyclical economic condition may differ from that in times of financial crisis. The four determinant factors used to infer innovation persistence in a pro-cyclical economic condition may not be suitable to explain the presence of innovation persistence in a counter-cyclical economic condition.

Besides, the explanatory powers of the four determinant factors are not properly examined in the literature. This thesis seeks to test the effectiveness of those four determinant factors in explaining the presence of innovation persistence and whether or not the underlying reasoning behind innovation persistence changes with the changing circumstances of financial environment.

Regarding the determinant factor of R&D cost, prior studies indicate that firms that could afford the costs of R&D are more likely to continue to innovate. This thesis posits that if a firm continues to invest in R&D in times of crisis, it has a strong motivation to persist in innovating. On the ground of this, the following hypotheses are developed:

> Hypothesis 1(a): The effect of R&D cost prior to the financial crisis on the persistence of product innovation differs from that during the crisis.
>
> Hypothesis 1(b): The effect of R&D cost prior to the financial crisis on the persistence of process innovation differs from that during the crisis.
>
> Hypothesis 1(c): The effect of R&D cost prior to the financial crisis on the persistence of organisational innovation differs from that during the crisis.
>
> Hypothesis 1(d): The effect of R&D cost prior to the financial crisis on the persistence of marketing innovation differs from that during the crisis.

For the determinant factor of success-breeds-success, because the 2008 global financial crisis was rooted in the banking sector, banks and credit institutions became extremely cautious about lending to personal and business sectors,

particularly innovative firms (Cowling et al., 2012; Lee et al., 2015). Campello et al. (2010) find that half of the US firms used their internal generated cash to fund investment in times of the global financial crisis and more than half of the financially constrained firms cancel their investment projects when they fail to raise external funds. Both success-breeds-success and resource constraints stress that financial resources are crucial to the development of innovation; thus, this thesis develops the following:

> Hypothesis 2(a): The effect of financial constraints prior to the financial crisis on the persistence of product innovation differs from that during the crisis.
>
> Hypothesis 2(b): The effect of financial constraints prior to the financial crisis on the persistence of process innovation differs from that during the crisis.
>
> Hypothesis 2(c): The effect of financial constraints prior to the financial crisis on the persistence of organisational innovation differs from that during the crisis.
>
> Hypothesis 2(d): The effect of financial constraints prior to the financial crisis on the persistence of marketing innovation differs from that during the crisis.

With regard to the determinant factor of appropriation strategies, the appropriation strategies help firms protect their innovations from imitation and appropriate returns from innovations. However, the returns of a firm's innovations are not only determined by its appropriation strategies but also by the total value of the innovations, which is strongly influenced by environmental dynamism (Sirmon et al., 2007; Wang and Chen, 2010). The environmental dynamism is the rate and unpredictability of changes of the external environment

(Dess and Beard, 1984; Wang and Chen, 2010). Wang and Chen (2010) find that the value of innovations a firm can appropriate from its innovation decrease in a highly dynamic market. This study argues that the effect of appropriation strategies on innovation persistence may be contingent on the dynamism of a firm's external environment. Thus:

> Hypothesis 3(a): The effect of appropriation strategies prior to the financial crisis on the persistence of product innovation differs from that during the crisis.
>
> Hypothesis 3(b): The effect of appropriation strategies prior to the financial crisis on the persistence of process innovation differs from that during the crisis.
>
> Hypothesis 3(c): The effect of appropriation strategies prior to the financial crisis on the persistence of organisational innovation differs from that during the crisis.
>
> Hypothesis 3(d): The effect of appropriation strategies prior to the financial crisis on the persistence of marketing innovation differs from that during the crisis.

Regarding the determinant factor of competence in innovation, previous studies indicate that the 'learning-by-doing' and the 'scale effect of knowledge accumulation' encourage firms to continue to innovate as they become more sophisticated in terms of innovating. On these grounds, the thesis tests the explanatory power of innovation competence and whether or not the relationship between innovation competence and persistence of innovation changes with changing financial circumstances. This leads to the following:

Hypothesis 4(a): The effect of innovation competence accumulated prior to the financial crisis on the persistence of product innovation differs from that during the crisis.

Hypothesis 4(b): The effect of innovation competence accumulated prior to the financial crisis on the persistence of process innovation differs from that during the crisis.

Hypothesis 4(c): The effect of innovation competence accumulated prior to the financial crisis on the persistence of organisational innovation differs from that during the crisis.

Hypothesis 4(d): The effect of innovation competence accumulated prior to the financial crisis on the persistence of marketing innovation differs from that during the crisis.

3.3 Methodology

3.3.1 Data and sample

This research uses the data of the UK Community Innovation Survey (CIS) which is conducted every two years by the Office for National Statistics (ONS) on behalf of the Department of Business Innovation & Skills (BIS). The survey is based on a core questionnaire developed by the European Commission (Eurostat) and Member States. The main purpose of the survey is to collect information about business innovation in the UK. The CIS is a voluntary survey and covers enterprises with 10 or more employees. The CIS also has a wide sectoral coverage including both manufacturing and service sectors. The respondent firms in the survey comprise a stratified sample drawn from the ONS Inter-Departmental Business Register (IDBR). Firms that participated in the CIS have their own unique IDBR reference numbers, which are unique reference numbers assigned to

business organisations. These unique reference numbers allow researchers to retrieve firms' information such as date of founding and date of termination from Business Structure Database (BSD) and to construct a panel data from each wave of the CIS.

In order to understand the determinants of innovation persistence during and after the global financial crisis, the latest three waves of CISs, which are CIS6, CIS7, and CIS8, are used as the source of our sample. Each wave of the CIS covers a three-year period. For instance, CIS6 covers the period 2006-2008, CIS7 covers the period 2008-2010, and CIS8 covers the period 2010-2012. In this study, the CIS7 is recognised as the global financial crisis period because the financial crisis in the US peaked in 2008 and then evolved into a global financial crisis. The global economy was in a severe downturn until the third quarter of 2009 (Naidoo, 2010). For the first quarter of 2009, the annualised rate of decline in GDP was 14.4% in Germany, 15.2% in Japan, 7.4% in the UK, 18% in Latvia, 9.8% in the Euro area and 21.5% for Mexico (Kennard and Hanne, 2015). The US recession that began in December 2007 ended in June 2009, according to the US National Bureau of Economic Research (NBER) and the financial crisis appears to have ended about the same time (NBER, 2012).

The main interest of this study is to investigate whether the determinants of innovation persistence during the crisis are different from those after the crisis period. Thus, this study confines the selection of the sample to firms which responded to all three waves of the CIS and then further divides the sample firms into two subsamples. One subsample contains observations only from CIS6 and CIS7, representing samples during the global financial crisis period and the other subsample includes observations only from CIS7 and CIS8, representing samples after the global financial crisis period. Observations containing missing values are excluded from my sample. Under these rules, the sample during the crisis period

has 1,030 observations corresponding to 515 firms and the sample after the crisis period has 972 observations corresponding to 486 firms.

3.3.2 Econometric model

The probit model is applied in this study to examine the causes behind the presence of innovation for four different types of innovation. This analysis is performed on two sets of cross-sectional data. One is during the global financial crisis (CIS6 and CIS7), and the other is after the global financial crisis (CIS7 and CIS8). All these independent variables are captured with a time lead design; for instance, concerning firms' persistence behaviours during the crisis period (CIS7) all the explanatory variables are measured in CIS6. Similarly, regarding firms' persistence behaviours after the crisis period (CIS8), the explanatory variables are from CIS7.

$$
\begin{aligned}
Persistence_{i,t} = {} & \beta_0 + \beta_1 * \log(R\&D)_{t-1} + \beta_2 * lack\ finance_{t-1} + \beta_3 * demand\ uncertainty_{t-1} \\
& + \beta_4 * appropriation_{t-1} + \beta_5 * Edu.degree_{t-1} + \beta_6 * collaboration_{t-1} + \beta_7 \\
& * local\ fund_{t-1} + \beta_8 * central\ fund_{t-1} + \beta_9 * EU\ fund_{t-1} + \beta_{10} \\
& * local\ fund_{t-1} + \beta_{11} * new\ market_{t-1} + \beta_{12} * market\ share_{t-1} + \beta_{13} \\
& * PD_{t-1} + \beta_{14} * PC_{t-1} + \beta_{15} * ORG_{t-1} + \beta_{16} * MAR_{t-1} + \beta_{17} * age + \beta_{18} * size \\
& + \beta_j * industry_j
\end{aligned}
$$

3.3.3 Dependent variables

This study aims to identify determinants of innovation persistence for all four types of innovation – product, process, organisational, and marketing innovations. Thus, this study constructs four dependent variables representing persistence in different types of innovation, respectively. The four dependent variables are persistence of (1) product innovation, (2) process innovation, (3) organisational innovation, and (4) marketing innovation. Each dependent variable is constructed

as a binary variable. If a firm reports that it introduced innovation in two successive survey periods, the dependent variable is coded 1, otherwise 0. For example, if a firm conducts product innovation in CIS6 and CIS7 or in CIS7 and CIS8 it is coded 1, otherwise 0.

3.3.4 Independent variables

The main variables of interest in this study are proxies for the four drivers of innovation persistence. First, the R&D sunk cost is measured by innovation-related investment in a log transformation. Second, the financial constraints factor is measured by two variables: (1) lack of finance and (2) demand uncertainty. These two types of constraining factor are chosen because access to finance is particularly limited in the 2008 global financial crisis and customers tend to be conservative with their spending during an economic downturn, which results in demand uncertainty (Archibugi et al., 2013; Campello et al., 2010; Lee et al., 2015). Third, the appropriation strategy is measured by four intellectual property protection practices: (1) applying for a patent, (2) registering an industrial design, (3) registering a trademark, and (4) producing materials eligible for copyright. Fourth, the innovation competence is measured by the level of education of firms' employees and the number of collaboration partners. The education level represents the quality of firms' workforce and is measured by the percentage of employees who hold a university degree. Collaboration is measured by the number of partners the firms work with for innovations. This factor is included because past studies have indicated the importance of external knowledge on firms' internal innovation process (Clausen et al., 2011; Huizingh, 2011; Kesidou and Snijders, 2012; Ritter and Gemünden, 2003; Trott and Hartmann, 2009). Collaboration with external partners can be seen as a firm's competence in establishing and maintaining relationships with external partners.

3.3.5 Control variables

The control variables are carefully chosen to avoid the potential endogeneity problem. The most common cause of the endogeneity problem is the omitted variables which arise when the causality between an uncontrolled variable and independent or dependent variables exists (Hamilton and Nickerson, 2003). To avoid this problem, this study surveys the literature extensively and include all available relevant variables. This study also examines the correlation between the variables for the potential multicollinearity problem which causes biased regression coefficients. Since there is no highly correlated variable and most of the variables are lowly or not correlated in this study, the results will not be seriously biased by the multicollinearity problem. The first set of control variables are public financial supports which are measured by funding from different levels of government: local funding, central funding, and EU funding. Several studies point out that the availability of financial support helps to alleviate resource constraints on innovation development (2012) and the recipient firms are more likely to persist in innovation than non-recipient firms (Ganter and Hecker, 2013).

The second set of control variables are related to a firm's ambitions which are measured by firms' motivations for innovation. Leiponen and Helfat (2010) indicate that firms pursuing multiple parallel objectives are more likely to innovate. This study argues that firms which persist in innovations even during harsh times have strong motivations to innovate. The present study includes two variables which motivate firms to innovate: entering new markets and increasing market share.

The third set of control variables are various types of innovation activities. While developing innovations, firms do not limit their effort to technological aspects (Armbruster et al., 2008). Instead, innovation firms need to align their various types of innovation activities in order to achieve superior performance (Tether,

2005). The complementary relationship between different types of innovation helps firms succeed in introducing new innovations. Given the complementary relationship among innovations, this study also controls for the effect of other types of innovation on the four types of innovation persistence (Battisti and Stoneman, 2010; Martínez-Ros and Labeaga, 2009). In addition, this study also includes firm size and industry dummies in the econometric model. Table 3-1 lists the variables of interest in this study.

Table 3-1 Description of the variables

Name of variables	Description
Dependent variables	
1. Persistence in product innovation	Binary variable: coded 1 if the business implements product innovation in two successive periods.
2. Persistence in process innovation	Binary variable: coded 1 if the business implements process innovation in two successive periods.
3. Persistence in organisational innovation	Binary variable: coded 1 if the business implements organisational innovation in two successive periods.
4. Persistence in marketing innovation	Binary variable: coded 1 if the business implements marketing innovation in two successive periods.
Independent variable	
5. R&Dsunk cost$_{t-1}$	Firms' R&D expenditure in log form.
6. Lackfinance$_{t-1}$	Binary variable: coded 1 if the business reports that the factors highly constrain its innovation activities, otherwise coded 0. These factors include economic risk, high innovation cost, cost of finance, and lack of access to finance.
7. Uncertainty$_{t-1}$	Binary variable: coded 1 if the business reports that the demand uncertainty highly constrains its innovation activities, otherwise coded 0.
8. Appropriation$_{t-1}$	Binary variable: coded 1 if the business reports that it has applied patent, industry design, trademark, or copyright to protect its innovations, otherwise coded 0.
9. Edu. degree$_{t-1}$	The percentage of employees who hold a university degree or higher qualification.
10. Collaboration$_{t-1}$	The number of external partners that the business cooperates with for innovations.
11. Local fund$_{t-1}$	Binary variable: coded 1 if the business reports that it receives public financial support from the local or regional authorities, otherwise coded 0.
12. Central fund$_{t-1}$	Binary variable: coded 1 if the business reports that it receives public financial support from the central government, otherwise coded 0.
13. EU fund$_{t-1}$	Binary variable: coded 1 if the business reports that it receives public financial support from the European Union institutions or programmers, otherwise coded 0.
14. Entering new market$_{t-1}$	Binary variable: coded 1 if the business reports that entering new markets is an important motivation for its innovation activities, otherwise coded 0.
15. Increasing market share$_{t-1}$	Binary variable: coded 1 if the business reports that increasing market share is an important motivation for its innovation activities, otherwise coded 0.

16. $PDinn_{t-1}$	Binary variable: referring to the status of product innovation in previous period.
17. $PCinn_{t-1}$	Binary variable: referring to the status of process innovation in previous period.
18. $ORGinn_{t-1}$	Binary variable: referring to the status of organisational innovation in previous period.
19. $MARinn_{t-1}$	Binary variable: referring to the status of marketing innovation in previous period.
20. Firm age	The age of a firm (The last year of survey period minus the year when a firm established).
21. Firm size	The number of employees in log form.
22. Low tech.	Industry dummy variable: Firms are classified according to OECD technology intensity classifications.
23. Medium-low tech.	Industry dummy variable: Firms are classified according to OECD technology intensity classifications.
24. Medium-high tech.	Industry dummy variable: Firms are classified according to OECD technology intensity classifications.
25. High tech.	Industry dummy variable: Firms are classified according to OECD technology intensity classifications.
26. Service	Industry dummy variable: Firms are classified according to OECD technology intensity classifications.

Table 3-2 Descriptive statistics

	Variable	Obs	Mean	Std. Dev.	Min	Max	Obs	Mean	Std. Dev.	Min	Max
		During crisis (CIS 6: 2006-2008, CIS 7: 2008-2010)					After crisis (CIS 7: 2008-2010, CIS 8: 2010-2012)				
	Dependent variables										
1	Persistence in Pdinn	515	0.36	0.48	0	1	486	0.40	0.49	0	1
2	Persistence in Pcinn	515	0.19	0.39	0	1	486	0.20	0.40	0	1
3	Persistence in ORGinn	515	0.38	0.49	0	1	486	0.42	0.49	0	1
4	Persistence in MARinn	515	0.13	0.34	0	1	486	0.18	0.39	0	1
	Independent variables										
5	Log (R&D)	515	5.45	2.19	*	*	486	5.42	2.10	*	*
6	Lack of finance	515	0.27	0.44	0	1	486	0.31	0.46	0	1
7	Uncertainty	515	0.08	0.27	0	1	486	0.09	0.28	0	1
8	Appropriation	515	0.59	1.03	0	4	486	0.60	1.06	0	4
9	Education degree	515	20.85	27.15	0	100	486	21.85	27.02	0	100
10	Collaboration	515	2.50	2.10	0	7	486	2.31	1.98	0	7
11	Local funding	515	0.11	0.31	0	1	486	0.12	0.32	0	1
12	Central funding	515	0.09	0.28	0	1	486	0.10	0.30	0	1
13	EU funding	515	0.04	0.19	0	1	486	0.05	0.22	0	1
14	Enter new markets	515	0.34	0.47	0	1	486	0.33	0.47	0	1
15	Increase	515	0.48	0.50	0	1	486	0.49	0.50	0	1

	market share										
16	$PDinn_{t-1}$	515	0.64	0.48	0	1	486	0.65	0.48	0	1
17	$PCinn_{t-1}$	515	0.44	0.50	0	1	486	0.40	0.49	0	1
18	$ORGinn_{t-1}$	515	0.71	0.46	0	1	486	0.66	0.47	0	1
19	$MARinn_{t-1}$	515	0.38	0.49	0	1	486	0.38	0.49	0	1
20	Firm age	515	26.40	10.48	*	37	486	28.67	10.12	*	39
21	Firm size	515	5.69	1.15	2	*	486	5.65	1.09	2	8
22	Low tech.	515	0.19	0.39	0	1	486	0.19	0.39	0	1
23	Medium-low tech.	515	0.09	0.29	0	1	486	0.10	0.30	0	1
24	Medium-high tech.	515	0.11	0.31	0	1	486	0.11	0.31	0	1
25	High tech.	515	0.02	0.14	0	1	486	0.03	0.17	0	1
26	Service	515	0.59	0.49	0	1	486	0.57	0.50	0	1

* Denotes the frequency of the cell below 10 and is not allowed to be displayed.

Table 3-3 Correlations of variables (N=1001)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1	1.00																									
2	0.35*	1.00																								
3	0.19*	0.29*	1.00																							
4	0.17*	0.14*	0.25*	1.00																						
5	0.25*	0.23*	0.09*	0.06*	1.00																					
6	0.00	0.04	0.03	-0.01	0.02	1.00																				
7	0.04	0.02	0.01	0.04	0.08*	0.18*	1.00																			
8	0.29*	0.14*	0.07*	0.12*	0.33*	-0.01	0.04	1.00																		
9	0.12*	0.10*	0.00	0.00	0.22*	0.03	0.08*	0.16*	1.00																	
10	0.24*	0.19*	0.11*	0.06*	0.29*	0.06	0.11*	0.30*	0.24*	1.00																
11	0.08*	0.11*	0.06	0.02	0.08*	0.08*	0.06*	0.06	0.11*	0.20*	1.00															
12	0.23*	0.11*	0.10*	0.03	0.30*	0.04	0.05	0.32*	0.20*	0.26*	0.20*	1.00														
13	0.09*	0.10*	0.08*	0.01	0.15*	0.01	0.04	0.17*	0.17*	0.18*	0.32*	0.30*	1.00													
14	0.21*	0.10*	0.10*	0.16*	0.14*	0.11*	0.11*	0.18*	0.15*	0.14*	0.06	0.15*	0.10*	1.00												
15	0.16*	0.13*	0.03	0.17*	0.12*	0.07*	0.05	0.19*	0.06	0.11*	-0.04	0.08*	0.03	0.34*	1.00											
16	0.59*	0.17*	0.06*	0.12*	0.17*	0.03	0.04	0.26*	0.07*	0.23*	0.09*	0.17*	0.08*	0.19*	0.19*	1.00										
17	0.20*	0.58*	0.13*	0.11*	0.18*	0.03	0.07*	0.14*	0.08*	0.27*	0.12*	0.10*	0.07*	0.09*	0.12*	0.22*	1.00									
18	0.00	0.09*	0.56*	0.13*	0.05	0.07*	0.01	0.04	0.02	0.09*	0.04	0.03	0.04	0.06	0.03	-0.02	0.09*	1.00								

19	0.05	0.06	0.10*	0.55*	-0.06	0.02	0.05	0.11*	0.01	0.06	0.00	0.00	0.01	0.18*	0.16*	0.12*	0.12*	0.18*	1.00							
20	0.06	0.02	0.03	0.03	0.17*	-0.03	0.01	0.08*	-0.07*	-0.01	-0.13*	-0.01	-0.10*	-0.01	0.02	0.00	-0.01	0.01	-0.01	1.00						
21	-0.05	0.01	0.08*	0.05	0.25*	-0.08*	-0.02	0.07*	-0.20*	0.00	-0.11*	-0.03	-0.13*	-0.02	0.09*	0.00	0.01	0.10*	0.03	0.24*	1.00					
22	0.00	0.06	-0.02	-0.06*	0.05	0.01	-0.01	-0.04	-0.12*	-0.07*	-0.01	-0.03	-0.06	0.00	0.00	-0.01	0.03	0.00	-0.10*	0.09*	0.04	1.00				
23	0.09*	0.01	0.05	-0.04	0.12*	0.05	0.03	0.17*	-0.10*	0.13*	0.07*	0.05	0.01	0.07*	-0.02	0.05	0.02	0.03	-0.02	0.10*	0.04	-0.16*	1.00			
24	0.17*	0.07*	0.07*	0.02	0.16*	0.03	0.02	0.12*	-0.10*	0.07*	0.06	0.07*	0.02	0.06	0.02	0.09*	0.00	-0.01	-0.08*	0.01	-0.06	-0.17*	-0.11*	1.00		
25	0.12*	0.03	0.04	0.02	0.2*	-0.03	0.07*	0.12*	0.06*	0.13*	-0.02	0.22*	0.06	0.06*	0.08*	0.08*	0.03	0.01	-0.03	0.05	0.02	-0.08*	-0.05	-0.06	1.00	
26	-0.2*	-0.11*	-0.06*	0.06	-0.27*	-0.05	-0.1	-0.18*	0.2*	-0.11*	-0.07*	-0.12*	0.01	-0.1*	0	-0.11*	-0.1	0	0.16*	-0.15*	0	-0.57*	-0.38*	-0.41*	-0.19*	1.00

* Denotes significance at the 5% level

3.4 Results

3.4.1 Descriptive analysis

Table 3-2 provides a descriptive analysis of the data used in this study. The information on firms' persistence behaviour during crisis period is illustrated in the left panel of Table 3-2 and the information on firms' innovation behaviour after crisis period is described in the right panel of Table 3-2. Figure 3-1 shows a paired comparison for each type of innovation. The level of persistence of all types of innovation increased by around 5% after the global financial crisis, with the exception of persistence in process innovation.

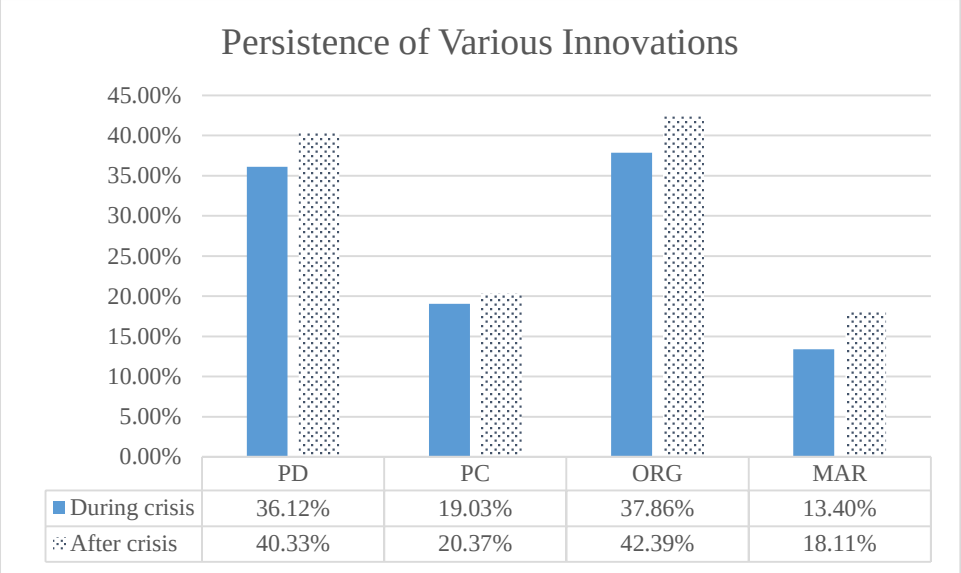

Figure 3-1 Persistence of various innovations during and after crisis periods

3.4.2 Econometric results

This study examines the effectiveness of the four theoretical explanations of innovation persistence and attempts to identify the determinants for different types of innovation – these are the product, process, organisational, and marketing innovations. Since the interest of this study is not only on identifying the

determinants of innovation persistence but also on testing whether the effectiveness of these determinants changes in different economic environments such as in and out of the global financial crisis. The analysis is made on two sets of cross sectional data. The full results of the probit estimation are shown in Table 3-5. Table 3-4 summarises regression results of the four potential determinants of innovation persistence, which shows the significant outcomes only. In the following paragraph, this study draws a parallel between the results from analysis of two sets of cross-sectional data.

Table 3-4 Summary of the effects of the four determinants of innovation persistence

Determinants		Persistence of product innovation		Persistence of process innovation		Persistence of organisational innovation		Persistence of marketing innovation	
		During	After	During	After	During	After	During	After
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
R&D sunk cost	$Log(R\&D)_{t-1}$		+	+	+				
Success-breeds-success	$Lack\ finance_{t-1}$		-					-	
	$Uncertainty_{t-1}$		-						
Appropriation strategies	$Appropriation_{t-1}$	+	+						+
Innovation competence	$Edu.degree_{t-1}$								-
	$Collaboration_{t-1}$	+		+		+			

3.4.2.1 R&D cost in explaining innovation persistence

First, the effect of R&D cost on the persistence of innovations is assessed. R&D cost is only significant in the models of the persistence of product and process innovation. For persistence in product innovation, the coefficient of R&D cost is not significant in Model (1) (0.056, $p > 0.05$) but is significant in Model (2) (0.067, ($p < 0.1$). Since the coefficient of R&D cost in Model (2) is only significant at the 10% level, H1 (a) is weakly supported. Regarding persistence in process innovation, the coefficient of R&D cost is significant and positive both during the crisis and after the crisis (Models (3) and (4)), which shows R&D cost has a similar effect on the persistence of process innovation in both periods. H1 (b) is rejected. The coefficients of R&D cost in the models of organisational and marketing innovations are not significant no matter which datasets are analysed. Both H1 (c) and H1 (d) are rejected.

3.4.2.2 Success-breeds-success in explaining innovation persistence

Second, the success-breeds-success perspective is tested by two resource constraint variables as the success in previous innovations can largely eliminate the difficulties preventing firms from doing innovations. These two constraint variables are significant in the models of product innovation and marketing innovation.

Regarding persistence in product innovation, both coefficients of lack of financial resource and demand uncertainty are not significant during the crisis as shown in Model (1), but the coefficients of these two variables turn significant after the crisis as shown in Model (2) (i.e. -0.376, $p < 0.01$; -0.505, $p < 0.05$, respectively). The effects of lack of financial resources and demand uncertainty on persistence in product innovation during the crisis are different from those after the crisis. H2 (a) is supported. Both H2 (b) and H2 (c) are rejected as neither of the constraint

variables are significant in the models of the persistence of process and organisational innovation. Concerning marketing innovation, lack of financial resource has a weakly negative influence on persistence in marketing innovation during the crisis (-0.347, $p < 0.1$) as shown in Model (7), while the coefficient turns insignificant in the model of after the crisis (-0.061, $p > 0.1$). H2 (d) is partially supported because the results show that the determinants of persistence in marketing innovation during the crisis are different from those after the crisis.

3.4.2.3 The appropriation strategy in explaining innovation persistence

Third, the appropriation strategy is investigated. The appropriation strategy variable is significant in the models of product innovation and marketing innovation. Regarding persistence of product innovation, appropriation strategy is positively related to persistence of product innovation both during and after the crisis periods (i.e. 0.178, $p < 0.01$; 0.21, $p < 0.01$). H3 (a) is rejected as there is no evidence showing that the effect of appropriation strategy on persistence in product innovation is different from that after the crisis periods. Both H3 (b) and H3 (c) are rejected as the appropriation strategy is not significant in the models of the persistence of process and organisational innovation. Concerning persistence of marketing innovation, appropriation strategy is not significant in the model of during the crisis (0.065, $p>0.1$) while it is positively related to persistence in marketing innovation after the crisis (0.152, $p<0.01$). H3 (d) is supported because the impact of appropriation strategy on persistence in marketing innovation during the crisis is different from that after the crisis.

3.4.2.4 Innovation competence in explaining innovation persistence

Fourth, the competence-based perspective is tested with the education level of employees and collaboration between firms. The education variable is only

significant in the model of the persistence of marketing innovations, and the collaboration variable is significant in all the models except for the model of the persistence of marketing innovation.

Regarding persistence in product innovation, a collaboration between firms has a positive impact on persistence in product innovation during the crisis (0.077, $p < 0.05$), but its impact turns insignificant after the crisis (0.03, $p > 0.1$). The results suggest that the impact of firms' competence on the persistence of product innovation during the crisis is different from that after the crisis. H4 (a) is supported. Similar patterns are also observed in the models of the persistence of process and organisational innovation. Collaboration has a positive effect on persistence of process innovation (0.077, $p < 0.05$) during the crisis, but this effect turns insignificant (0.054, $p > 0.1$) after the crisis. H4 (b) is supported. Similarly, collaboration has a positive effect on persistence of organisational innovation (0.061, $p < 0.05$) during the crisis, but the effect turns insignificant (-0.009, $p > 0.1$) after the crisis. H4 (c) is supported. For persistence in marketing innovation, the education variable is not significant during the crisis (-0.005, $p > 0.1$) but it is significant after the crisis (-0.007, $p < 0.05$). H4 (d) is supported. Specifically, the effect of collaboration between firms is only significant in the models during the crisis.

Table 3-5 Estimations of Probit model

	Persistence of product innovation		Persistence of process innovation		Persistence of organisational innovation		Persistence of marketing innovation	
	during	after	during	after	during	after	during	after
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$Log(R\&D)_{t-1}$	0.056	0.067*	0.105***	0.172***	-0.014	0.008	0.022	0.048
	(0.035)	(0.039)	(0.04)	(0.045)	(0.033)	(0.036)	(0.044)	(0.046)
$Lack\ finance_{t-1}$	0.113	-0.376***	0.046	0.04	0.171	-0.022	-0.347*	-0.061
	(0.143)	(0.144)	(0.159)	(0.152)	(0.135)	(0.13)	(0.189)	(0.158)
$Uncertainty_{t-1}$	0.197	-0.505**	-0.155	0.031	-0.215	-0.046	0.357	0.148
	(0.226)	(0.236)	(0.255)	(0.239)	(0.226)	(0.214)	(0.274)	(0.245)
$Appropriation_{t-1}$	0.178***	0.21***	0.02	-0.06	-0.033	-0.029	0.065	0.152**
	(0.068)	(0.071)	(0.071)	(0.072)	(0.066)	(0.064)	(0.079)	(0.074)
$Edu.degree_{t-1}$	0.001	0.003	0.005	-0.002	0.002	-0.003	-0.005	-0.007**
	(0.003)	(0.003)	(0.003)	(0.003)	(0.002)	(0.003)	(0.003)	(0.003)
$Collaboration_{t-1}$	0.077**	0.03	0.077**	0.054	0.061**	-0.009	-0.006	0.015
	(0.032)	(0.038)	(0.036)	(0.04)	(0.031)	(0.036)	(0.04)	(0.043)
$Local\ fund_{t-1}$	0.200	-0.032	0.449**	0.104	0.215	-0.109	-0.143	0.37
	(0.212)	(0.213)	(0.221)	(0.219)	(0.203)	(0.2)	(0.284)	(0.231)
$Central\ fund_{t-1}$	0.52**	0.463*	0.031	-0.177	0.12	0.409*	0.188	-0.274
	(0.248)	(0.262)	(0.245)	(0.251)	(0.226)	(0.237)	(0.283)	(0.282)
$EU\ fund_{t-1}$	0.138	-0.575*	0.184	0.052	0.421	0.33	0.2	-0.736*
	(0.348)	(0.317)	(0.351)	(0.317)	(0.33)	(0.302)	(0.382)	(0.425)
$New\ market_{t-1}$	0.295**	0.41***	0.01	0.001	0.339**	0.05	0.449***	0.293*
	(0.143)	(0.146)	(0.158)	(0.162)	(0.136)	(0.14)	(0.171)	(0.159)
$Market\ share_{t-1}$	0.076	0.363***	0.263*	0.248	-0.193	0.002	0.162	0.527***
	(0.133)	(0.137)	(0.152)	(0.155)	(0.129)	(0.13)	(0.168)	(0.159)
$PDinn_{t-1}$			0.207	0.53***	-0.111	0.059	0.431**	0.118
			(0.161)	(0.171)	(0.132)	(0.135)	(0.186)	(0.172)
$PCinn_{t-1}$	0.187	0.51***			0.233*	0.332**	0.263	0.105

	(0.13)	(0.136)			(0.126)	(0.129)	(0.165)	(0.156)
$ORGinn_{t-1}$	−0.243*	0.044	0.141	0.265*			0.585***	0.494***
	(0.139)	(0.138)	(0.165)	(0.155)			(0.195)	(0.166)
MAR_{t-1}	0.111	0.015	0.139	0.117	0.265**	0.255**		
	(0.137)	(0.143)	(0.154)	(0.155)	(0.128)	(0.129)		
Firm age	0.014**	−0.002	−0.001	0.007	0.006	−0.002	0.015*	−0.004
	(0.006)	(0.007)	(0.007)	(0.008)	(0.006)	(0.006)	(0.008)	(0.008)
Firm size	−0.103	−0.103	0.019	−0.156**	0.102*	0.148**	−0.009	−0.04
	(0.063)	(0.065)	(0.071)	(0.073)	(0.059)	(0.061)	(0.079)	(0.077)
Medium−low tech.	0.19	0.027	−0.486*	−0.164	0.16	0.224	−0.358	−0.163
	(0.245)	(0.252)	(0.287)	(0.263)	(0.238)	(0.238)	(0.358)	(0.337)
Medium−high tech.	0.567**	0.366	0.146	−0.285	0.492**	0.197	0.23	0.192
	(0.235)	(0.244)	(0.244)	(0.247)	(0.224)	(0.228)	(0.295)	(0.289)
High tech.	0.684	0.168	−0.152	−0.663	0.422	0.086	(omitted)	0.814*
	(0.493)	(0.449)	(0.46)	(0.435)	(0.427)	(0.377)		(0.421)
Service	0.035	−0.423**	−0.289	−0.219	−0.014	−0.008	0.416*	0.62**
	(0.169)	(0.174)	(0.188)	(0.191)	(0.161)	(0.167)	(0.217)	(0.223)
_cons	−1.107***	−0.482	−2.219***	−1.749***	−1.456***	−1.257***	−2.849***	−2.101***
	(0.395)	(0.407)	(0.455)	(0.469)	(0.381)	(0.393)	(0.529)	(0.504)
Number of firms	515	486	515	486	515	486	504	486
LR chi2(20)	111.68	132.4	67.88	56.74	46.09	31.34	56.17	60.35
Prob > chi2	0	0	0	0	0.0008	0.0509	0	0
Pseudo R2	0.17	0.2	0.14	0.12	0.07	0.05	0.14	0.13
Log likelihood	−281.02	−261.52	−216.68	−217.3	−318.6	−315.54	−173.16	−199.71

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

3.5 Discussion

The primary goal of this study is to investigate the effectiveness of the four theoretical explanations of innovation persistence. In contrast to previous work, this study directly examines the effect of four commonly seen explanations for innovation persistence. Moreover, this study also looks into whether or not the effects of the four determinants change if the economic environment in which the firms operate is characterised by the 2008 global financial crisis. In times of the global financial crisis, the economic situation is full of considerable uncertainties about the demand condition and market opportunities. The incentives for firms to persist in innovation may change due to the changes in the economic conditions. In brief, the statistical analyses in this study suggest that the four theoretical explanations are effective in explaining innovation persistence and effects of the four determinants of innovation persistence change with the changing circumstances of financial environment.

R&D cost has a positive influence on the persistence of technological innovation (i.e. product and process innovations) but has no influence on the persistence of non-technological innovation (i.e. organisational and marketing innovations). Although this study does not find strong evidence that the effect of R&D cost is different in the context of distinct economic environments, results of this study suggest that effect of R&D costs on the persistence of product innovation during the crisis is different from that after the crisis. In times of the financial crisis, firms are forced to delay or abandon their ongoing innovation projects (Campello et al., 2010; Filippetti and Archibugi, 2011; Paunov, 2012). The attribute of sunk cost of R&D investment may not be strong enough to encourage the firms to continue to invest in innovations. Conversely, this study finds that the R&D investment made in times of crisis has a positive impact on the persistence of product innovation in the following period. This study argues that firms that

continue to invest in R&D are determined to innovate because those firms manage to allocate financial resources to innovative projects while facing the challenge of the global financial crisis.

The research data used in this study cover the period of the global financial crisis which creates severe financial difficulties which hamper the development of innovations (Archibugi et al., 2013; Campello et al., 2010). These financial difficulties are likely to cancel out the positive effect of success-breeds-success on innovation persistence. Results of this study suggest that both lack of finance and demand uncertainty have a negative impact on innovation persistence, particularly in the case of persistence in product innovation. It is interesting that these two factors are not significant in the during-crisis model (Model (1)) but they turn significant in the after-crisis model (Model (2)). One possible explanation is that innovative firms often encounter these two difficulties in developing innovations and the firms may have developed a systematic approach to deal with challenges. This is probably the reason for why lack of finance and demand uncertainty prior to the crisis period does not have a significant influence on the persistence of product innovation. However, in times of financial crisis, these difficulties become severe, and firms' strategies to handle such problems are impeded. Therefore, these two difficulties in times of the global financial crisis are found to have a negative impact on the persistence of product innovation. Findings of this study align with Campello et al.'s (2010) research; they find that in times of the global financial crisis innovative firms are not only forced to cancel their investment in innovation because of the tight credit markets but also have to sell assets to obtain cash.

Appropriation strategy is found to have a positive and significant influence in persistence in product and marketing innovations. In the case of product innovation, as opposed to other forms of innovation, it is typical to protect

products via intellectual property rights. Appropriation strategy prevents the firms' innovations from imitation and helps the firms appropriate the value created by the innovations (Leiponen and Byma, 2009; Wang and Chen, 2010). The existing appropriation practices preserve the returns from past innovations and enable the firms to invest their money in future innovations. Therefore, the appropriation strategy is found to have a positive effect on the persistence in product innovation both during and after the crisis. With regard to the relationship between appropriation strategy and persistence in marketing innovation, significant influence is only found in the after-crisis model. Applications of appropriation such as patent, industry design, and copyright usually come after the completion of new products, and appropriation practices such as patent are expensive to apply. The resource constraints arising from the financial crisis may stop firms from developing new products; instead, they may decide to dedicate their limited resource to projects which are nearly complete. When firms still incur expenditure on the application of appropriation practices in times of crisis, this may imply that they may be near to the launch of new products. In the following period (after the crisis), firms may consider implementing marketing innovation to help bring new products to market.

Concerning the effect of innovation competence on innovation persistence, findings of this study reveal that the collaboration between firms has a positive increase the probability of persistence in the product, process, and organisational innovations, but these positive relationships between collaboration and innovation persistence mainly exist in the models measuring innovation persistence during the crisis period. In other words, these results suggest that the established external collaborative relationships encourage firms to continue to innovate in times of global financial crisis. The collaboration between firms lightens the burden of innovation through sharing the cost and/or reducing the risk of innovation, so firms are able to continue to innovate during the crisis.

Besides, it is costly to find suitable partners to collaborate with. Firms might continue the collaborative projects under strategic consideration in order to maintain those collaborative relationships.

In the following paragraph, this study looks at control variables which have a significant influence on innovation persistence. First, the effects of firms' ambitions such as entering new markets and increasing market share are assessed. Firms aiming to enter new markets are more likely to persist in developing product and marketing innovations regardless of the condition of the economy. When firms wish to enter new markets, they first need to adapt their existing products or to develop new products, which leads to product innovation. Firms also need to adjust their marketing practices in order to sell their products and services.

Second, concerning the effect of increasing market share, it has a positive relationship to persistence in product innovation after the crisis, but the relationship is not significant in the during-crisis model. One possible explanation is that firms may be more cautious about product innovation which is usually capital-intensive. Therefore, firms may delay or abandon product innovation during the crisis. The impacts of increasing market share on persistence in marketing innovation are similar to those on product innovation. Its influence is significant for persistence in marketing innovation after the crisis.

Lastly, we see the effect of various types of innovation on innovation persistence. Previous product innovation has a positive impact on persistence in process innovation after the crisis, and vice versa, but this relationship is not observed during the crisis. One possible explanation is that in an unstable business environment past innovations do not necessarily impact present ones, which implies that the phenomenon of persistence in innovation changes at times of crisis. Previous organisational innovation positively influences persistence in

marketing innovation both during and after the crisis, and vice versa. The findings suggest that there is a steady complementary relationship between organisational and marketing innovations.

3.6 Conclusions

Although the phenomenon of innovation persistence has been confirmed by many recent studies (Antonelli et al., 2013; Ganter and Hecker, 2013; Suárez, 2014; Tavassoli and Karlsson, 2015), none of them systematically investigated why some firms persistently innovate. This study seeks to understand the underlying causes of persistence in four different types of innovation – product, process, organisational and marketing innovations. The existing innovation persistence literature has proposed several theoretical explanations; for instance, R&D cost, success-breeds-success (alleviate the resource constraints on innovations) appropriation mechanism, and firms' innovation competence. This paper contributes to the persistence literature by examining the effectiveness of the four theoretical explanations of innovation persistence. Findings of the present study show that R&D cost, appropriation and innovation competence encourage firms to persist in developing innovation while the innovation-constraining factors such as lack of finance and demand uncertainty prevent innovating firms from continuing to innovate. Overall, the four causes are more capable of explaining the presence of persistence in product innovation. This to some extent echoes Tavassoli and Karlsson's (2015) view, that the underlying theoretical causes of innovation persistence are mostly biased towards technological innovations, while non-technological innovations are not well understood.

In addition, this study carried out two analyses by using two sets of cross-sectional data. The first set of data is characterised by the 2008 global financial crisis, and the other set of data is after the global financial crisis. The outcomes

from the analyses of these two datasets enable this study to further looks at whether the explanatory power of the four explanations changes with the changing circumstances of financial environment. The results suggest that the reasoning behind innovation persistence do change as the circumstance of the financial environment change. In normal times, R&D cost and constraints on innovation activities are not important to persistence in product innovation; nevertheless, the same factors at times of the financial crisis become decisive factors in persistence in product innovation. R&D cost is an important determinant of persistence in process innovation both during and after the global financial crisis, while this factor has no impact on firms' persistent behaviour in organisational and marketing innovations. The appropriation mechanism is also influential in persistence in product innovation both during and after the crisis period, but it is less useful in explaining the persistence in the process and organisational innovations. Regarding the reasoning of innovation competence, established collaboration relationships with other firms has a positive influence on innovation persistence for all types of innovation except for marketing innovation at times of the financial crisis, while the effect of collaboration goes away after the financial crisis.

As mentioned in previous the paragraph the reasoning behind non-technological innovation is poorly understood. The current theoretical explanations of innovation persistence primarily focus on the persistence of technological innovation, particularly for the persistence of product innovation. There have been relatively few studies that look into innovation persistence for non-technological innovation such as organisational innovation and marketing innovation, the exceptions being the works of Ganter and Hecker (2013) and Tavassoli and Karlsson (2015). However, findings of these two studies are contradictory. Ganter and Hecker (2013) find that there is no persistence in organisational innovation while Tavassoli and Karlsson (2015) show that previous

organisational innovation has a significant effect on future organisational innovation, which confirms the persistence of organisational innovation. The heterogeneity of results signifies the need of further explorative research to accumulate a body of empirical evidence to serve as the basis for a proper and consistent understanding of innovation persistence.

It is widely agreed that innovation is an important driver of firms' growth which then contributes to the economic growth of a country. Innovative firms are expected to deliver superior performance, particularly those firms that are able to produce a continuous stream of innovations (Martínez-Ros and Labeaga, 2009; Tavassoli and Karlsson, 2015). The identification of the drivers of innovation persistence enables the policy makers to develop the appropriate policy to encourage firms to engage in innovation persistently. Understanding the determinants of innovation persistence will help with the design of policies that have more far-reaching effects because they affect firms' innovation decisions both in the current period and in future periods. For instance, findings of this research suggest that established connections with other firms or external partners have a profound effect on the continuity of innovations particularly for the product, process and organisational innovations. Policy makers may consider providing a fine platform for the network of interaction.

Chapter 4: The Role of Openness in Explaining Innovation Persistence

Abstract

Both innovation persistence and openness are important concepts in the innovation literature. The persistence literature stresses that prior innovations have a decisive influence on the development of future innovations, and the open innovation literature emphasises that the firms' external linkages improve the success rate of innovations. These two schools of thought focus on contributing factors to future innovations; however, only limited studies link these two research areas. The present study intends to bridge this gap by investigating the effect of openness in terms of firms' search breadth and search depth strategies on firms' propensity to persist in innovations. Results of this study reveal that search breadth only has an impact on product innovation but has no influence on the process, organisational, and marketing innovations. Firms that search broadly are more likely to conduct product innovation and also to persist in product innovation. The search depth strategy is found to have no influence on one-off innovations including product, process, organisational, and marketing innovations, but conversely, it has a positive impact on the persistence of product innovation and on the persistence of marketing innovation. This means that firms that draw deeply from the external sources or search channels have a higher probability to constantly carry out product and market innovations.

4.1 Introduction

The existence of persistence of innovation is corroborated in the innovation persistence literature. The existence of past innovation encourages firms to persist in developing more innovations. Several studies have found persistence of innovation in product innovation and process innovation (Clausen et al., 2011; Ganter and Hecker, 2013; Martínez-Ros and Labeaga, 2009), in organisational innovation (Tavassoli and Karlsson, 2015), across different countries (Cefis, 2003), and on the basis of patent data (Cefis, 2003; Geroski et al., 1997; Malerba and Orsenigo, 1999; Raymond et al., 2010) and survey data (Antonelli et al., 2012; Clausen et al., 2011; Ganter and Hecker, 2013; Martínez-Ros and Labeaga, 2009; Tavassoli and Karlsson, 2015; Triguero and Córcoles, 2013).

The importance of openness of the innovation process has been highlighted in the innovation literature. A great number of empirical studies have examined the relationship between the level of openness to a diversity of external sources and firms' innovation performance (Chiang and Hung, 2010; Hung and Chou, 2013; Kesidou and Snijders, 2012; Leiponen and Helfat, 2010; Nieto and Santamaría, 2007; Tsai, 2009). Most of the current literature focuses on the effect of openness on innovation performance which is a quantitative measurement of firms' sales from innovations. Only the study of Leiponen and Helfat (2010) examines the impact of openness on a qualitative decision to engage (or not) in innovation. Frenz and Ietto-Gillies (2009) state that the quantitative measures such as the degree of innovation performance, and qualitative measures such as a decision to engage in innovation, tend to be explained by different factors. Specifically, openness may play a different role in explaining innovation performance and the introduction of innovation. Although Leiponen and Helfat (2010) suggests that openness to external sources of knowledge increases the

probability of introducing innovation(2010), little is known about the effect of openness on the probability of innovation persistence.

The present study bridges the gaps between the two schools of thought by examining the effect of openness on the persistence in four different types of innovation, which are a product, process, organisational and marketing innovations. Following Laursen and Salter's (2006) study, openness is characterised as the breadth and the depth of a firm's search strategy. This study examines the relationship between the two search strategies and innovation persistence referring to the constant engagement in innovation. The empirical analysis draws on a panel dataset constructed from three waves of the UK CIS covering 2006-2012 (i.e. CIS 6, CIS 7 and CIS 8), which is analysed using random effects probit modelling. Results of this study show that both search breadth and search depth encourage firms to persist in product innovation, and search depth also has a positive impact on the persistence of marketing innovation.

Following this introduction, the literature section briefly reviews empirical studies on innovation persistence, and also the role of openness in the innovation literature. Based on reviews of the extant studies, this study gradually builds up hypotheses. The methodology section presents the research data and econometric model used to test the study hypotheses. Results are then presented and discussed, and conclusions are drawn in the following section.

4.2 Literature review

4.2.1 Persistence of innovation

Persistence of innovation is a concept characterising the relationship between the past and present innovation. Some scholars argue that firms that have innovated once are more likely to innovate again in subsequent periods than those that have

never innovated. This phenomenon is termed 'innovation persistence' (Clausen et al., 2011). The importance of innovation persistence emerges from the permanence of highly skewed performance among innovative firms. This heterogeneity among firms' performance may result from the difference in the patterns of firms' involvement in innovative activities. Roberts (2001) states that firms sustain superior performance by persisting in innovation. He explains that it is unrealistic to expect an individual innovation to generate permanent, superior profit because the profit derived from a single innovation would reduce when rivals imitate the particular innovation. New innovations would help firms move away from imitative competition and, furthermore, the succeeding innovations would help firms to build up distinguishing characteristics and also lead to performance growth (Knott, 2003).

Martínez-Ros and Labeaga (2009, p. 65) understand innovation persistence as a "capacity of the firm to accumulate and assimilate knowledge in engaging the same innovation type". They believe that the capabilities to produce a constant stream of innovations help firms to sustain competitive advantage and outperform their rival firms. From this point of view, it is critical to developing capacities that enable firms to bring out innovations constantly. In the second research of this thesis, the analysis reveals that established collaboration has a positive effect on innovation persistence for product innovation, process innovation, and organisational innovation (Section 3.4.2). A body of literature has shown that collaboration with external parties is positively related to firms' innovation performance (Du et al., 2014; Leiponen, 2005; Tsai and Wang, 2009). It seems that tapping into external sources of knowledge is not only helpful to enhance firms' innovation performance but also impactful to increase the chance of persistence of innovation. The following section details the concept of 'openness' of innovation.

4.2.2 Openness of the innovation process

The importance of openness of the innovation process has drawn considerable attention from both academia and business. The underlying idea of openness is that "firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as the firms look to advance their technology" (Chesbrough, 2006, p. xxiv). Chesbrough (2006) argues that firms that devote too much attention to their internal activities are prone to miss opportunities because many opportunities will fall outside the organisation's present business models or will need to be combined with external technologies to unlock their potential.

Over the last few decades, a growing number of studies have investigated the relationship between openness and innovations: strategies of acquiring externally developed technology (Frenz and Ietto-Gillies, 2009; Tsai and Wang, 2009), collaboration with different types of partners (Du et al., 2014; Tsai, 2009), risk of the open innovation process (Laursen and Salter, 2014; Leiponen and Byma, 2009), and the effect of the level of openness (Garriga et al., 2013; Laursen and Salter, 2006; Love et al., 2014).

Considerable effort has been devoted to the effect of openness on firms' innovation performance in terms of pecuniary benefit. The extant studies on the openness-performance relationship produce mixed results: some researchers find a positive relationship (Du et al., 2014; Leiponen, 2005; Mansury and Love, 2008) while others find no relationship, or a negative relationship (Lhuillery and Pfister, 2009; Un et al., 2010). The mixed results may be partly attributed to the issues of leaving an appropriate lag for the effect of openness to impact on innovation performance (Belderbos et al., 2004). Some more recent works indicate that the inconsistent results from the moderating effect of a firm's absorptive capacity and environmental turbulence in the forms of technological

turbulence (i.e. the current technologies become out-of-date and new ones need to be developed) and market turbulence (i.e. the degree of uncertainty as to customers' demands and preferences) (Hung and Chou, 2013; Tsai and Wang, 2009).

Using the Dutch Community Innovation survey, Belderbos et al. (2004) assess how firms' innovation performance is affected by the cooperation with four types of R&D partner – these are competitors, suppliers, customers, and universities and research institutes. They find that the cooperation with suppliers and competitors has a positive influence on labour productivity growth and the cooperation with universities and research institutes positively affects the sales of the products that are new to the market. Sofka and Grimpe (2010) investigate the effect of firms' search strategies for external knowledge on innovation performance in five European countries. First, they apply an exploratory principal component factor analysis to identify a firm's search strategy. Three search strategies are identified: science-driven, market-driven, and supply-driven. The results reveal that both science-driven and supply-driven search strategies enhance a firm's innovation performance while the market-driven search strategy exerts its influence on performance when the market-driven search strategy interacts with the firm's R&D investments.

Studies on open innovation attempt to understand the mixed results by investigating whether there are factors that moderate the openness-performance relationship. Some studies propose that the inconsistent findings are due to ignorance about the firm's absorptive capacity (Hung and Chou, 2013; Tsai, 2009). Absorptive capacity is a firm's ability to recognise, assimilate, transform and exploit external knowledge based on its existing knowledge (Cohen and Levinthal, 1990; Todorova and Durisin, 2007; Zahra and George, 2002). A certain degree of absorptive capacity is required while a firm decides to take advantage

of external knowledge. Without sufficient absorptive capacity, a firm may not be able to identify valuable ideas or, even worse, may use unsuited ones, which would inhibit innovation performance. Tasi (2009) studies the contingent role of absorptive capacity on the relationship between the performance of product innovation and the four types of partners –suppliers, clients, competitors, and research organisations. He finds that collaboration with different partners has no influence on product innovation performance if the analysis does not take into account the effect of absorptive capacity. A related study by Hung and Chou (2013) reveals that external technology acquisition (ETA) has a positive influence on a firm's performance whereas external technology exploitation (ETE) does not. However, both ETA and ETA positively affect a firm's performance if the firm develops high absorptive capacity.

4.2.3 Level of openness: open search strategy

In addition to focusing on the effects of specific sources of knowledge on innovation performance, other studies look into how the degrees of openness affect innovation performance. Prior research has largely focused on the dimension of openness in terms of a firm's search strategies for external sources of knowledge such as exploration and exploitation (Jansen et al., 2006; March, 1991), number of partners a firm collaborates with (Belderbos et al., 2004), and the search strategy for stimulating innovations (Katila and Ahuja, 2002; Laursen and Salter, 2006).

The idea of search strategy emphasises the quantity of the channels available for information exchange. By doing so, the focus of interest is shifted to a firm's search activity. Katila and Ahuja (2002, p. 1184) explain that a firm's external knowledge search includes an "organisation's problem-solving activities that involve the creation and recombination of technological ideas", which significantly influence the firm's innovation performance. Larusen and Salter (2006) classify a

firm's search strategy according to their breadth and depth. Search breadth "is defined as the number of external sources or search channels that firms rely upon in their innovative activities", and "search depth is defined in terms of the extent to which firms draw deeply from the external sources or search channels" (Laursen and Salter, 2006, pp. 134–135). Both dimensions characterise a firm's openness to external knowledge.

Laursen and Salter (2006) show that firms which are more open to external sources or search channels realise better performance than those which are not. Searching widely and deeply across a variety of search channels enables firms to access a wide variety of ideas and resources which assist firms in the development of innovation. Moreover, they find that the more radical the innovation, the greater influence the search depth strategy has on innovation performance; conversely, the less radical the innovation, the less the effective search breadth will affect innovation performance. In a similar research by Katila and Ahuja (2002), they study how search scope and depth affect firms in the creation of new products. Search *scope* refers to how widely the firm explores new knowledge and search *depth* refers to the frequency with which firms reuse their existing knowledge. The former concept matches the idea of search breadth from Laursen and Salter's study, while the latter is more about the exploitation of knowledge that firms already possess. The concept of search depth in the two studies is totally different. Katila and Ahuja find that both search scope and search depth (the levels of exploitation of existing knowledge) are positively related to innovations. Moreover, search scope and depth complement each other, yielding a combined positive effect on product innovation.

Since the seminal study of Laursen and Salter (2006), an increasing number of studies have examined the association between firms' search strategy for external knowledge and innovation performance (Chiang and Hung, 2010; Cruz-

González et al., 2015; Garriga et al., 2013; Leiponen and Helfat, 2010; Love et al., 2014). Using the data on electronic product manufacturing firms in Taiwan, Chiang and Huang (2010) examine the effect of a firm's search activities. They find that search breadth is closely related to the performance of radical innovation while search depth is closely related to the performance of incremental innovation. It is worth noting that Chiang and Huan's findings are contradictory to those of Laursen and Salter's (2006). One possible explanation is that these two studies adopt different approaches to measure innovation performance. Leiponen and Helfat (2010) complement the existing studies of the effect of firms' search strategy on innovation performance by extending the concept of search strategy to the success rate of introducing innovation. They understand open search strategy from the aspect of statistical sampling. They explain that the payoff from any given external linkages is unknown in advance; therefore, the potential for innovation can be understood as a distribution of values of innovation outcomes. The likelihood of achieving innovation success from any linkage in a given distribution of innovation success increases when the number of external linkages increases. In this sense, innovative firms could improve the chance of innovation success by increasing linkages to external sources of knowledge. Results of Leiponen and Helfat's study reveal that open search strategy not only has a positive impact on innovation performance but also increases the success rate of introduction of innovation.

Love et al. (Love et al., 2014) study the effect of open search strategies using the theory of learning effects, and they indicate that openness to external sources of knowledge involves activities such as identifying and selecting appropriate partners, developing routines to interact with them and constructing management systems to manage the relationship. These activities "are subject to a learning process, as firms discover through time which knowledge sources and linkages are most useful to their particular needs, which partnerships are most

effective in delivering innovation performance, and how best to manage them" (Love et al., 2014, p. 1704). They suggest that there may be a temporal dimension to the relationship between openness and innovation performance. Their study shows that the establishment of considerable experience of external collaborations in the past enhances innovation performance from openness in the present.

Garriga et al. (2013) extend Laursen and Salter's study by taking firm context into account. Previous studies point out that the needs to search for knowledge outside of a firm's boundaries are shaped by the availability of resources and the constraints on the application of these resources within its boundaries (Dyer and Singh, 1998; Zhang et al., 2010). Moreover, a firm's absorptive capacity also influences the firm's search for external sources of knowledge (Hung and Chou, 2013; Tsai, 2009). Garriga et al. extend Laursen and Salter's model by including two aspects; first, the abundance of external knowledge and second, constraints on the application of firm resources. They assess how these two aspects affect innovation performance and firms' search activities. Overall, their results echo Laursen and Salter's findings that both search breadth and search depth have a significant influence on innovation performance. Moreover, the results reveal that the abundance of external knowledge has a U-shaped relationship with both search breadth and depth strategies. Given the above-average abundance of external knowledge, firms tend to search more broadly and deeply. Firms' search activities are also shaped by the constraints on applying resources. Fewer constraints enable a deeper search strategy; conversely, more constraints lead to a broader search for external knowledge.

In sum, prior studies have found that innovation performance is strongly influenced by a firm's search strategies and this causal relationship between performance (Katila and Ahuja, 2002; Laursen and Salter, 2006; Leiponen and

Helfat, 2010) and search activity is subject to learning effects (Love et al., 2014). In addition, a firm's search strategies are affected by firm context (Garriga et al., 2013). Both, the abundance of external knowledge and constraints on applying firm resources, have a direct impact on innovation performance and a firm's search strategies.

4.2.4 A gap between openness and innovation persistence

A considerable body of literature shows that openness to external sources of knowledge is helpful to enhance innovation performance (Laursen and Salter, 2006; Leiponen, 2005) and companies are increasingly recognising the necessity of regularly developing innovations in order to sustain their competitive advantage and performance (Tsai, 2009). As mentioned in the first sub-study of this thesis (see section 2.2.4), a constant engagement in innovations helps firms sustain competitive advantage and in turn achieve superior performance (Antonelli et al., 2015; Damanpour et al., 2009; Deschryvere, 2014). However, it seems that only limited studies link innovation persistence to the idea of openness. This scant attention to the relationship between openness and innovation persistence may in part be due to the fact that most studies of openness in innovation use cross-sectional data, which does not afford the capacity to study firms' innovation behaviour through time (Chiang and Hung, 2010; Laursen and Salter, 2006; Leiponen and Helfat, 2010).

Most current empirical research is based on cross-sectional data, which implies that these analyses implicitly assume that the effect of external sources of knowledge on innovation performance is contemporary. Nevertheless, there may be a temporal dimension in the relationship between openness to external knowledge and innovation. Rosenkopf and Nerkar (2001) find that exploration which spans organisational boundaries consistently has a higher impact on subsequent innovation than exploration that is internally focused has. In other

words, openness to external knowledge stimulates the development of future innovation. Love et al. (2014) argue that there is a learning process involved in managing the relationships with external search channels. In the process of searching external sources of knowledge, firms learn how to identify more suitable knowledge providers, to develop routines to interact with them and to manage relationships with them. Although some researchers have started to look at the effect of search activities on contemporaneous innovations and also on future innovations, no study extends the concept of open search strategy to innovation persistence. Therefore, this thesis aims to fill the gap between openness and innovation persistence by examining how open search strategy affect firms' propensity to persist in innovation.

According to the innovation persistence literature, success-breeds-success is recognised as an important determinant of innovation persistence because the knowledge and resources that accumulate through previous innovations help cultivate future innovations. As innovations are often capital-intensive and resource-demanding, firms have to manage to secure sufficient support for innovation activities. The profit or knowledge accumulated from previous innovations help firms alleviate the resource problem in developing future innovations. In a similar vein to success-breeds-success, the use of external knowledge improves internal resources and the innovation process (Cruz-González et al., 2015; Huizingh, 2011). A broad search strategy helps reduce a firm's risk from unpredictable development as the specific expertise needed has been proven in other applications (Garriga et al., 2013; Sofka and Grimpe, 2010).

Furthermore, a search with greater breadth enriches the knowledge pool by adding numerous novel ideas. The more knowledge a firm possesses, the more it could recombine the different components of knowledge in order to develop new innovations. The innovation persistence literature also highlights the importance

of a firm's knowledge stock in explaining the presence of innovation persistence. Since the process of developing innovation is also a process of learning and knowledge production, this learning-by-doing effect increases a firm's knowledge stock and innovation capability, which then encourages future innovations (Clausen et al., 2011; Ganter and Hecker, 2013).

The learning-by-doing effect is also often used to explain the underlying reason for the presence of innovation persistence, which is detailed in the second sub-study of this thesis (please see section 3.2.2.4, p. 35). The learning-by-doing effect increases firms' knowledge stock and innovation capability, which then encourages future innovation. The innovation persistence literature emphasises that the stock of knowledge accumulated through previous innovation, however, is not the only way to acquire knowledge for innovation. Other inputs include access to external sources of knowledge in the forms of cooperation, alliances, and licensing. By searching broadly, the firm increases the probability of gaining knowledge that will lead to successful innovations (Leiponen and Helfat, 2010; Love et al., 2014). Given the importance of knowledge –internal or external – to a firm's continuous involvement in innovation, the present study attempts to understand how search breadth strategy affects innovation persistence by testing the following hypotheses:

Hypothesis 1(a): External search breadth increases the probability for innovative firms to persist in product innovation

Hypothesis 1(b): External search breadth increases the probability for innovative firms to persist in process innovation

Hypothesis 1(c): External search breadth increases the probability for innovative firms to persist in organisational innovation

Hypothesis 1(d): External search breadth increases the probability for innovative firms to persist in marketing innovation

A broader set of external knowledge sources may not always be beneficial to innovations. Several studies have found that the search activity is subject to diminishing returns (Katila and Ahuja, 2002; Laursen and Salter, 2006). The attention-based theory acknowledges that managerial attention is the most precious resource so managers "need to concentrate their energy, effort, and mindfulness on a limited number of issue" (Ocasio, 1997, p. 203). Once the search activity is beyond a certain level the benefit of the increased breadth of search become negative because of the increased complexity of managing both the variety of knowledge and the relationships needed to maintain access to these sources (Leiponen and Helfat, 2010). Chiang and Hung (2010) suggest that firms should maintain strong and close contacts with a limited number of external search channels to access new knowledge.

Recall that search breadth is about the quantity of different search channels that a firm draws upon, while search depth is about the number of external knowledge sources that a firm draws on *deeply* or *intensely*. The key difference is intensity. Katila and Ahuja (2002) attribute the high frequency of using a given set of knowledge to deepening the understanding of these components of knowledge, which enables firms to better identify important knowledge elements, to develop connections among them, to combine them in many different ways, and to realise the potential value. All these may not be easy to carry out for Firms that are unfamiliar with those given sets of knowledge may not find this easy. Several studies find that search depth strategy is more influential in radical innovation than search breadth strategy (Garriga et al., 2013; Laursen and Salter, 2006). The potential benefits of radical innovations are expected to be higher than those of incremental innovations. As search depth is more likely to help realise to potential benefits of radical innovations, the search depth strategy might motivate firms to persist in innovation. Therefore, this study proposes the following hypotheses:

Hypothesis 2(b): External search depth increases the probability for innovative firms to persist in product innovation

Hypothesis 2(b): External search depth increases the probability for innovative firms to persist in process innovation

Hypothesis 2(c): External search depth increases the probability for innovative firms to persist in organisational innovation

Hypothesis 2(d): External search depth increases the probability for innovative firms to persist in marketing innovation

4.3 Methodology

4.3.1 Data and sample

This empirical setting involves innovative firms in both manufacturing and service sectors in the UK. The data come from the UK Community Innovation Survey (CIS). The CIS is conducted every two years, and it has a wide sectoral coverage. The CIS survey collects information about a wide variety of innovation-related subjects, including whether or not the firm introduced any types of innovation and questions about R&D activity, knowledge sources related to innovation activities, and factors constraining innovation activities.

This study constructed a panel dataset from the three waves of CIS surveys. The respondent firms of the CIS survey are a stratified sample drawn from the ONS Inter-Departmental Business Register (IDBS). Every firm has its own unique IDBR reference number, and this unique reference number allows the present study to construct a panel dataset. Data used in this study are drawn from the sixth, the seventh and the eighth waves of CIS surveys. Each wave of CIS covers a three-year period. The CIS 6 covers the years 2006-2008. The CIS 7 covers the years 2008-2010, the period when firms went through the 2008 global financial crisis. The CIS 8 covers the years 2010-2012. Besides, this study added firms' age data from the UK Business Structure Database in order to obtain an additional control

variable. This study focuses on the continuity of introduction of innovation between different waves of CISs; therefore only firms that participate in the three waves of CIS and contain no missing values are included in this study. Under these rules, the sample is confined to 868 observations corresponding to 633 firms.

4.3.2 Econometric Model

The random effect probit model is applied in this study to examine whether the level of openness affects the probability of persistence of innovation. The use of panel data allows us to directly identify the patterns of firms' innovation behaviour. For instance, innovation persistence appears when a firm reported introducing innovations continuously during two sub-periods. Furthermore, the panel dataset enables us to apply a time-lagged research design. The random effect probit model is used in the present study for three reasons: first, the dependent variable, innovation persistence, is constructed as a binary variable to indicate if a firm is continuously involved in innovations. Second, the analysis is undertaken from a panel dataset from three waves of CIS that share overlapping firms which are surveyed. The random effect probit model takes into account the existence of multiple observations of each firm in different periods of time (Un et al., 2010). Third, the random effect probit model is widely used in most of the innovation persistence studies (Ganter and Hecker, 2013; Martínez-Ros and Labeaga, 2009; Peters, 2007; Tavassoli and Karlsson, 2015; Triguero and Córcoles, 2013)

Most current published research findings are based on cross-sectional data, which implies that these studies assume to some extent that the effect of open search strategy on innovation performance is contemporaneous. Love et al. (2014) argued that there may be a temporal dimension affecting the process. Specifically, firms' search processes are rooted in their previous experience because past

success tends to shape future behaviour. Therefore, previous experience will shape how they organise the search for and the development of innovation, as well as the relationship between the breadth and depth of external linkages and innovation outputs (Laursen and Salter, 2006; Love et al., 2014). Considering this temporal dimension, proxies for openness and most of the independent variables are from earlier waves of CISs while the dependent variables are from later waves of the CISs. The advantage of the use of time-lagged research design is that it may help strengthen the causality implications of the findings in the present study.

$$
\begin{aligned}
Persistence_{i,t} = {} & \beta_0 + \beta_1 * search\ breadth_{i,t-1} + \beta_2 * search\ depth_{i,t-1} + \beta_3 \\
& * cost\ constraint_{i,t-1} + \beta_4 * know.constraint_{i,t-1} + \beta_5 \\
& * market\ constraint_{i,t-1} + \beta_6 * regulation\ constraint_{t-1} + \beta_7 \\
& * local\ fund_{t-1} + \beta_8 * central\ fund_{t-1} + \beta_9 * EU\ fund_{t-1} + \beta_{10} \\
& * local\ fund_{t-1} + \beta_{11} * \log(Inn.exp.)_{t-1} + \beta_{12} * edu.degree_{t-1} + \beta_{13} \\
& * PD_{t-1} + \beta_{14} * PC_{t-1} + \beta_{15} * ORG_{t-1} + \beta_{16} * MAR_{t-1} + \beta_{17} * age + \beta_{18} \\
& * size + \beta_{19} * crisis + \beta_j * industry_j
\end{aligned}
$$

4.3.3 Variables

4.3.3.1 Dependent variables

The dependent variable in this study is innovation persistence. This study is interested in how openness affects persistence of 1) product innovation, 2) process innovation, 3) organisational innovation, and 4) marketing innovation. There are four dependent variables in this research, each of which is used in a separate regression. As mentioned above, the panel is made up of three periods, so innovation persistence is determined according to the firms' status of innovation activities from *t-2* to *t-1* and from *t-1* to *t.* A persistence variable takes the value 1 if a firm reported introducing innovations continuously during

two sub-periods, otherwise 0. For instance, if a firm reported that it introduced product innovation in both *t-2* and *t-1* or in both *t-1* and *t*, the variables of the persistence of product innovation are coded 1. The same logic is applied to the other three types of persistence variable: persistence of process, organisational, and marketing innovations.

4.3.3.2 Independent variables

The major explanatory variables in this study are the openness of a firm's innovation process. Following Laursen and Salter's (2006) approach, the degree of openness is measured by the breadth and depth of a firm's external searching activities.

Search breadth is constructed as a combination of the 10 external sources of information listed in Table 4-2. As a starting point, each of the 10 sources is coded as a binary variable. The variable is coded 1 if a respondent reported using a given knowledge source. Then these 10 binary variables are added up so that each firm gets a score ranging from 0 to 10. This score represents the number of external knowledge sources a firm used in its innovation. The higher the score is, the more open a firm is to search breadth.

Search depth represents the extent to which a firm drew intensively from external search channels. Search depth is constructed similarly to the way in which search breadth is constructed. Each of the 10 knowledge sources is coded as a binary variable. The variable is coded 1 if a firm reported that a given knowledge source is highly important to its innovation, otherwise 0. Subsequently, these 10 sources are added up so that each firm has a score representing how many knowledge sources are highly important.

4.3.3.3 Control variables

Given that the panel dataset used in this study is characterised by the turbulent times of the 2008 global financial crisis, this study includes two sets of variables – constraints and public funding – to manifest the difficulties a firm might go through. Due to the risky and uncertain nature of innovation, innovation activities are prone to all kinds of difficulties such as excessive economic risk, lack of qualified personnel, or uncertain demand, among others. These difficulties may become even more serious during a time of crisis as firms may not have sufficient resources to deal with problems constraining the development of innovations. All the respondent firms are asked if they ran into any trouble that constrained their innovation activities. These constraining factors are classified into four categories: cost constraints, knowledge constraints, market constraints and regulation constraints. A constraint variable is coded 1 if a firm reported encountering a problem in that category.

Regarding public funding, the CIS asked firms if they receive external funding from the local government, central government, or the European Union institution or programmes. In the times of financial crisis, firms tend to suffer from a severe shortage of financial resources. Access to external financial resources allows firms to continue with the development of their innovations (Paunov, 2012). A funding variable is coded 1 if a firm reported receiving any public financial support for its innovation activities.

Absorptive capacity is essential for innovative firms that wish to take advantage of the openness of the innovation process. Absorptive capacity help firms "to recognise the value of new information, assimilate it, and apply it to commercial ends" (Cohen and Levinthal, 1990, p. 128). Firms' internal research and development (R&D) acts as a solid foundation on which to develop absorptive capacity. A firm's absorptive capacity is measured by a firm's investment in

innovation and the education level of its employees. Another important reason to include the absorptive capacity as a control variable in the regression models is the potential endogeneity problem which may lead to biased estimation of regression coefficients. An endogeneity problem will occur if an uncontrolled variable influences both the dependent variable and independent variables. As shown in Table 4-5, there is positive correlation between the absorptive capacity and the openness, and the correlation between the absorptive capacity and the innovation persistence is also mostly positive. Since absorptive capacity affects the openness (the independent variable) and the innovation persistence at the same time, the variables of the absorptive capacity are controlled to avoid the endogeneity problem. The following section provides the details of other control variables and the reason why these control variables are included in this study.

Besides, this study also includes some commonly seen control variables such as firm size, firm age, and industries. Table 4-1 provides a description of all the variables used in this study.

Table 4-1 Description of variables

	Variables	Description
1	Persistence of product innovation	Binary variable (0, 1). If the firm introduced product innovation in two successive waves of CIS surveys, the variable is coded 1.
2	Persistence of process innovation	Binary variable (0, 1). If the firm introduced process innovation in two successive waves of CIS surveys, the variable is coded 1.
3	Persistence of organisational innovation	Binary variable (0, 1). If the firm introduced organisational innovation in two successive waves of CIS surveys, the variable is coded 1.
4	Persistence of marketing innovation	Binary variable (0, 1). If the firm introduced marketing innovation in two successive waves of CIS surveys, the variable is coded 1.
5	Search breadth$_{t-1}$	Numbers of knowledge sources that firms utilised in their innovation activities.
6	Search depth$_{t-1}$	Numbers of important knowledge sources that firms utilised in their innovation activities.
7	Cost constraints$_{t-1}$	Binary variable (0, 1). If the firm reported that it faced cost constraints on innovation activities, the variable is coded 1.
8	Knowledge constraints$_{t-1}$	Binary variable (0, 1). If the firm reported that it faced knowledge constraints on innovation activities, the variable is coded 1.
9	Market constraints$_{t-1}$	Binary variable (0, 1). If the firm reported that it faced market constraints on innovation activities, the variable is coded 1.
10	Regulation constraints$_{t-1}$	Binary variable (0, 1). If the firm reported that it faced regulation constraints on innovation activities, the variable is coded 1.
11	Local funding$_{t-1}$	Binary variable (0, 1). If the firm received public financial support for innovation activities from UK local or regional authorities, the variable is coded 1.
12	Central funding$_{t-1}$	Binary variable (0, 1). If the firm received public financial support for innovation activities from UK central government, the variable is coded 1.

13	EU funding$_{t-1}$	Binary variable (0, 1). If the firm received public financial support for innovation activities from EU institutions or programmers, the variable is coded 1.
14	Innovation investment$_{t-1}$	Logarithm innovation investment.
15	Education degree$_{t-1}$	Percentage of employees who have a college or higher degree.
16	Product innovation$_{t-1}$	Binary variable (0, 1). If the firm introduced product innovation, the variable is coded 1.
17	Process innovation$_{t-1}$	Binary variable (0, 1). If the firm introduced process innovation, the variable is coded 1.
18	Organisational innovation$_{t-1}$	Binary variable (0, 1). If the firm introduced organisational innovation, the variable is coded 1.
19	Marketing innovation$_{t-1}$	Binary variable (0, 1). If the firm introduced marketing innovation, the variable is coded 1.
20	Firm age	Firm's age.
21	Firm size	Logarithm number of employees.
22	CIS7 (crisis time, 2008-2010)	Time dummy variable.
23	Mining and quarrying	Industry dummy variable at the two-digit classification code level.
24	Manufacturing	Industry dummy variable at the two-digit classification code level.
25	Electricity, gas, steam and air conditioning supply	Industry dummy variable at the two-digit classification code level.
26	Water supply, sewerage, waste management and remediation activities	Industry dummy variable at the two-digit classification code level.
27	Construction	Industry dummy variable at the two-digit classification code level.
28	Wholesale and retail trade; repair of motor vehicles and motorcycles	Industry dummy variable at the two-digit classification code level.
29	Transportation and storage	Industry dummy variable at the two-digit classification code level.

30	Accommodation and food service activities	Industry dummy variable at the two-digit classification code level.
31	Information and communication	Industry dummy variable at the two-digit classification code level.
32	Financial and insurance activities	Industry dummy variable at the two-digit classification code level.
33	Real estate activities	Industry dummy variable at the two-digit classification code level.
34	Professional, scientific and technical activities	Industry dummy variable at the two-digit classification code level.
35	Administrative and support service activities	Industry dummy variable at the two-digit classification code level.

4.4 Results

4.4.1 Preliminary analysis

Table 4-2 gives the descriptive analysis of the 10 external sources of information listed in the CIS survey. Each firm was asked to indicate the importance of each source to its innovation activities. Information from clients, customers or end user is considered the most important, followed by suppliers and competitors. It appears that information sources from the marketplace such as supplier, clients and competitors are more important than other sources. The results differ slightly from Laursen and Salter's (2006) findings in which information from suppliers is found to be the most important external source, closely followed by clients and customers. Although results of this study also show that suppliers and clients are important sources of information, this study finds that information from clients is clearly more important than that from suppliers. Around 60% of respondent firms reported that information from clients is highly important while the corresponding figure for suppliers dropped to 30%. One possible explanation for this difference may be that the innovation is being democratised, which means that not only firms but also individual customers are more capable of innovating for themselves (von Hippel, 2005). Besides, the rapid advances in information and communication technology make it much easier for firms to interact directly with clients, customers or end users via social media.

Table 4-2 Sources of information related to innovation activities in UK firms

		Before financial crisis (2006-2008) (N=449) Percentage				During financial crisis (2008-2010) (N=419) Percentage			
	Information sources	Not used	Low	Medium	High	Not used	Low	Medium	High
1	Suppliers of equipment, materials, services or software	5.79	23.83	40.31	29.40	11.22	23.15	36.52	27.92
2	Clients, customers or end user	5.12	8.46	24.72	61.47	6.92	6.92	25.78	60.14
3	Competitors or other businesses in your industry	8.24	25.84	43.21	22.27	13.37	24.34	40.33	21.24
4	Consultants, commercial labs, or private R&D institutes	26.06	41.65	23.39	8.46	27.68	38.42	24.58	8.11
5	Universities or other higher education institutes	41.20	39.42	14.25	4.68	47.49	33.13	14.80	3.82
6	Government or public research institutes	41.20	38.75	14.92	4.90	47.02	35.32	13.37	3.34
7	Conference, trade fairs, exhibitions	22.27	38.53	30.96	8.02	26.25	37.71	27.45	7.88
8	Professional and industry associations	19.60	31.63	36.75	11.58	26.01	33.65	30.31	9.31
9	Technical, industry, or service standards	17.15	30.07	36.08	16.04	27.21	25.54	32.46	14.08
10	Scientific journals	29.18	41.87	23.16	4.90	40.33	33.41	18.85	6.68

Table 4-3 shows the openness level of external search breadth and depth across industrial sectors and also the percentage of persistence for the four types of innovation in each industry. On average, firms cited six external sources of information for their innovation. Manufacturing, information and communication, and professional, scientific and technical activities industries show the highest level of external search breadth, which means that manufacturing firms and firms engaging in scientific and technological activity tend to search more broadly than firms in other industries do. Regarding external search depth, most of the firms incorporate only one external source of information deeply in their innovation. Firms in water supply, sewerage, and remediation-related activity industries exhibit the highest level of search depth, while firms in the energy utility industry show the lowest level of search depth.

Regarding innovation persistence, overall, the majority of respondent firms across industries continuously engaged in product and organisational innovations, while the continuation of process and marketing innovations is less desired. On average, one-third of the firms continued to introduce product innovation and only one-fifth of them persisted in process innovation. The percentages of firms that keep developing organisational innovation and marketing innovation are 45% and 19%, respectively.

Although there is no clear one-to-one relationship between openness and persistence of innovation, it is worth noting that the level of persistence of product innovation is highest in industries with a high level of external search breadth. For instance, the manufacturing industry has the highest external search breadth and the greatest percentage of the persistence of product innovation.

Similar situations can be seen in the information and communication industry, and professional, scientific and technical activities industry.

Table 4-3 Openness and persistence of innovation across industry

Industry	No. of firms	Breadth mean	Depth mean	Percentage of firms that persist in			
				Product innovation	Process innovation	Organisational innovation	Marketing innovation
Mining and quarrying	11	6.89	1.04	*	*	*	*
Manufacturing	299	8.08	1.55	63.21	28.43	51.17	16.39
Electricity, gas, steam and air conditioning supply	*	6	0.58	*	*	*	*
Water supply, sewerage, waste management and remediation activities	10	7.3	2.27	*	*	*	*
Construction	32	7.09	1.16	34.38	31.25	65.63	3.13
Wholesale and retail trade; repair of motor vehicles and motorcycles	115	6.74	1.02	24.35	16.52	40.00	20.87
Transportation and storage	52	6	0.83	32.69	26.92	34.62	15.38
Accommodation and food service activities	53	5.77	0.9	26.42	3.77	30.19	39.62
Information and communication	44	7.73	1.67	59.09	29.55	45.45	15.91
Financial and insurance activities	24	6.58	1.26	*	*	*	*
Real estate activities	17	6.62	1.06	*	*	*	*
Professional, scientific and technical activities	127	7.89	1.9	48.03	27.56	44.88	17.32
Administrative and support service	80	6.63	1.16	22.50	6.25	56.25	17.50

activities						
Average	6.87	1.26	35.51	20.56	45.06	19.50

* Denotes the frequency of the cell below 10 and is not allowed to be displayed.

Table 4-4 Descriptive statistics (N=868)

Variable	Mean	Std. Dev.
Introduction of product innovation	0.5380	0.4988
Introduction of process innovation	0.3479	0.4766
Introduction of organisational innovation	0.5853	0.4930
Introduction of marketing innovation	0.3065	0.4613
Persistence of product innovation	0.4412	0.4968
Persistence of process innovation	0.2293	0.4206
Persistence of organisational innovation	0.4666	0.4992
Persistence of marketing innovation	0.1820	0.3861
Search breadth$_{t-1}$	7.5011	2.9698
Search depth$_{t-1}$	1.6728	1.7039
Cost constraints$_{t-1}$	0.3502	0.4773
Knowledge constraints$_{t-1}$	0.1106	0.3138
Market constraints$_{t-1}$	0.1313	0.3380
Regulation constraints$_{t-1}$	0.0922	0.2894
Local funding$_{t-1}$	0.1152	0.3195
Central funding$_{t-1}$	0.0991	0.2989
EU funding$_{t-1}$	0.0472	0.2123
Innovation investment$_{t-1}$	5.4429	2.1858
Education degree$_{t-1}$	21.0691	26.8156
Firm age	27.6555	10.3135
Firm size	5.6600	1.1247

Table 4-5 Correlation table (N=868)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
1	1.00																																		
2	0.32*	1.00																																	
3	0.13*	0.24*	1.00																																
4	0.14*	0.11*	0.22*	1.00																															
5	0.23*	0.13*	0.06	0.05	1.00																														
6	0.15*	0.15*	0.09*	0.12*	0.37*	1.00																													
7	0.03	0.05	0.06	-0.01	0.06	0.16*	1.00																												
8	0.11*	0.09*	0.07*	0.02	0.07*	0.13*	0.14*	1.00																											
9	0.05	0.02	0.03	0.03	0.02	0.12*	0.24*	0.12*	1.00																										
10	0.01	0.04	-0.02	0.03	0.06	0.11*	0.18*	0.13*	0.15*	1.00																									
11	0.08*	0.1*	0.06	0.01	0.15*	0.04	0.09*	0.01	0.08*	0.07*	1.00																								
12	0.22*	0.11*	0.08*	0.02	0.18*	0.13*	0.07*	0.08*	0.04	0.03	0.22*	1.00																							
13	0.08*	0.1*	0.06	0.01	0.13*	0.07*	0.02	0.08*	0.04	-0.03	0.29*	0.33*	1.00																						
14	0.26*	0.25*	0.1*	0.08*	0.3*	0.23*	0.05	0.05	0.09*	0.01	0.08*	0.31*	0.2*	1.00																					
15	0.14*	0.13*	0.01	-0.01	0.18*	0.23*	0.04	0.11*	0.04	0.03	0.12*	0.22*	0.18*	0.26*	1.00																				

16	0.66*	0.18*	0.08*	0.13*	0.2*	0.14*	0.05	0.09*	0.05	0.09*	0.09*	0.19*	0.07*	0.15*	0.09*	1.00														
17	0.23*	0.65*	0.15*	0.13*	0.18*	0.16*	0.03	0.06	−0.01	0.02	0.12*	0.11*	0.08*	0.18*	0.08*	0.22*	1.00													
18	−0.01	0.1*	0.62*	0.13*	0.02	0.06	0.08*	0.1*	0.01	−0.02	0.03	0.02	0.03	0.03	0.01	−0.02	0.08*	1.00												
19	0.04	0.05	0.11*	0.59*	0.03	0.09*	0.03	0.07*	0.04	0.04	−0.02	−0.01	0.00	−0.05	0.00	0.11*	0.12*	0.16*	1.00											
20	0.05	0.01	0.04	0.02	0.08*	0.01	0.00	0.00	0.04	0.05	−0.14*	−0.01	−0.09*	0.18*	−0.05	0.01	−0.02	0.01	0.00	1.00										
21	−0.04	0.04	0.1*	0.07*	0.06	0.06	−0.09*	−0.09*	−0.02	0.04	−0.13*	−0.03	−0.09*	0.26*	−0.19*	−0.03	0.02	0.09*	0.04	0.25*	1.00									
22	−0.07	−0.02	−0.05	−0.07*	0.1*	0.03	−0.05	−0.02	0.00	0.00	−0.01	−0.02	−0.02	−0.01	0.00	−0.04	0.04	0.07*	−0.01	−0.11*	0.02	1.00								
23	−0.06	−0.01	0.00	0.00	−0.01	−0.01	0.00	−0.01	0.11*	0.00	−0.01	0.00	−0.03	0.06	0.04	−0.05	−0.01	−0.02	−0.01	−0.01	−0.1*	−0.03	1.00							
24	0.28*	0.09*	0.07	−0.03	0.19*	0.03	0.05	0.01	0.11*	0.00	0.1*	0.12*	0.00	0.26*	−0.21*	0.17*	0.06	−0.01	−0.14*	0.14*	0.01	−0.02	−0.08*	1.00						
25	0.01	−0.04	0.00	0.06	−0.03	−0.03	−0.05	−0.02	−0.03	−0.02	−0.02	−0.02	−0.02	0.01	−0.03	0.01	−0.06	0.01	0.05	−0.09*	−0.01	0.03	−0.01	−0.05	1.00					
26	−0.05	0.02	−0.06	−0.02	−0.04	0.08*	0.06	0.00	0.02	0.04	0.03	0.07*	−0.02	0.00	−0.04	−0.06	0.02	−0.05	−0.02	−0.04	−0.08*	0.06	−0.01	−0.08*	−0.01	1.00				
27	−0.04	0.04	0.07*	−0.08*	−0.04	−0.01	−0.04	−0.05	−0.06	−0.04	−0.05	−0.04	−0.01	−0.02	−0.02	−0.06	−0.01	0.09*	−0.07*	0.05	0.13*	−0.02	−0.02	−0.14*	−0.01	−0.02	1.00			
28	−0.16	−0.06	−0.05	0.03	−0.07*	−0.06	−0.04	−0.03	−0.02	−0.03	−0.12*	−0.13*	−0.06	−0.03	−0.14	−0.13*	−0.09*	−0.01	0.04	0.17*	0.14*	−0.01	−0.04	−0.28*	−0.03	−0.04	−0.08*	1.00		
29	−0.06	0.02	−0.06	−0.02	−0.14*	−0.08*	−0.02	−0.03	−0.03	0.02	−0.03	−0.07*	−0.06	−0.08*	−0.14*	0.01	0.08*	−0.05	0.06	0.04	−0.01	0.01	−0.03	−0.18*	−0.02	−0.03	−0.05	−0.1*	1.00	
3	–	0.12*	–	0.14*	–	−0.05	−0.01	–	–	0.04	−0.03	–	−0.01	–	–	−0.03	–	–	0.15*	–	0.05	–	−0.03	–	–	–	−0.05	−0.1*	−0.06	1.00

0	0.09*		0.08*		0.11*			0.07*	0.06			0.07*		0.16*	0.12*		0.12*	0.07*		0.09*		0.04		0.18*	0.02	0.03											
31	0.07*	0.04	−0.01	−0.01	0.00	0.01	−0.03	0.02	−0.03	−0.06	−0.03	0.1*	0.07*	0.09*	0.24*	0.05	0.02	0.01	0.04	−0.07*	−0.09*	0.00	−0.03	−0.17*	−0.02	−0.02	−0.05	−0.09*	−0.06	−0.06	1.00						
32	−0.04	0.03	−0.03	0.05	−0.04	−0.04	−0.05	−0.01	0.00	0.02	−0.06	−0.06	−0.04	0.02	0.02	−0.01	0.02	−0.03	0.01	−0.06	0.05	0.01	−0.02	−0.12*	−0.01	−0.02	−0.03	−0.07	−0.04	−0.04	−0.04	1.00					
33	−0.04	0.00	0.05	−0.07*	−0.03	−0.02	0.02	−0.02	−0.01	−0.02	0.08*	−0.02	0.01	−0.05	−0.03	0.00	−0.02	0.07*	−0.06	−0.05	−0.03	0.04	−0.02	−0.1*	−0.01	−0.02	−0.03	−0.06	−0.04	−0.04	−0.03	−0.02	1.00				
34	0.03	0.05	−0.01	−0.01	0.08*	0.11*	0.02	0.15*	−0.03	−0.06	0.09*	0.11*	0.15*	0.04	0.54*	0.00	0.07*	0.00	0.00	−0.1*	−0.25*	0.03	−0.05	−0.3*	−0.03	−0.04	−0.08*	−0.16*	−0.1*	−0.11*	−0.1*	−0.07*	−0.06	1.00			
35	−0.14*	−0.13*	0.06	−0.01	−0.04	0.00	0.02	−0.04	−0.03	0.13*	−0.03	−0.11*	−0.07*	−0.31*	−0.11*	−0.07*	−0.05	0.07*	0.05	−0.16*	0.12*	0.00	−0.04	−0.23*	−0.02	−0.03	−0.06	−0.12*	−0.08*	−0.08*	−0.07*	−0.05	−0.05	−0.13*	1.00		

* Denotes significance at the 5% level

4.4.2 Econometric analysis

Before examining the hypotheses about openness contributing to innovation persistence (continuous involvement in innovation), this study first runs a test on how openness affects innovation (one-off involvement in innovation) to provide a basic understanding of the relationship between openness and innovation. Overall, the results suggest that the effect of openness is contingent on the types of innovation. Search breadth strategy is found to be positively related to product innovation but has no influence on the process, organisational, and marketing innovations. The results are similar to the findings of Leiponen and Helfat's (2010) research in which search breadth is positively associated with technological innovation (product as well as process).Search depth strategy has no influence on all four types of innovation – product, process, organisational, and marketing innovations. Details of the results are shown in Table 4-6. Then, this study continues to examine the hypotheses to see whether openness affects innovation persistence (continuous involvement in innovation).

Table 4-6 Openness and innovation

	(1)	(2)	(3)	(4)
	Product innovation	Process innovation	Organisational innovation	Marketing innovation
Search breadth$_{t-1}$	0.0552**	-0.00108	-0.0180	-0.0178
	(0.0249)	(0.0259)	(0.0262)	(0.0267)
Search depth$_{t-1}$	0.0303	0.0549	0.0418	0.0743
	(0.0436)	(0.0450)	(0.0474)	(0.0461)
Cost constraints$_{t-1}$	-0.0220	0.129	-0.0344	-0.190
	(0.143)	(0.148)	(0.153)	(0.155)
Knowledge constraints$_{t-1}$	0.532**	0.0137	0.113	-0.248
	(0.224)	(0.214)	(0.225)	(0.228)
Market constraints$_{t-1}$	0.135	-0.0426	0.113	0.0362
	(0.209)	(0.207)	(0.217)	(0.215)
Regulation constraints$_{t-1}$	-0.0659	0.146	-0.0211	0.448*
	(0.233)	(0.246)	(0.255)	(0.246)
Local funding$_{t-1}$	0.0724	0.220	0.275	-0.111
	(0.222)	(0.219)	(0.244)	(0.238)
Central funding$_{t-1}$	0.371	-0.221	0.508*	0.184
	(0.267)	(0.240)	(0.279)	(0.247)
EU funding$_{t-1}$	-0.326	0.135	0.0741	-0.0246
	(0.339)	(0.341)	(0.372)	(0.360)
Innovation investment$_{t-1}$	0.129***	0.124***	0.0407	0.117**
	(0.0411)	(0.0423)	(0.0426)	(0.0462)
Education degree$_{t-1}$	0.00432	0.00247	-0.00158	-0.00377
	(0.00337)	(0.00346)	(0.00363)	(0.00367)
Product innovation$_{t-1}$		0.381**	0.0746	0.319**
		(0.151)	(0.152)	(0.157)

Process innovation$_{t-1}$	0.562***		0.325**	0.343**
	(0.142)		(0.149)	(0.148)
Organisational innovation$_{t-1}$	-0.0697	0.356**		0.424***
	(0.143)	(0.152)		(0.154)
Marketing innovation$_{t-1}$	-0.0263	0.153	0.225	
	(0.138)	(0.142)	(0.146)	
Firm age	0.00511	-0.00301	-0.00352	0.00770
	(0.00725)	(0.00775)	(0.00803)	(0.00805)
Firm size	-0.0889	0.0764	0.138*	-0.108
	(0.0717)	(0.0774)	(0.0805)	(0.0795)
Crisis time (2008-2010)	-0.117	-0.103	-0.194	0.0118
	(0.119)	(0.120)	(0.123)	(0.127)
Industry dummies	Included	Included	Included	Included
Constant	-2.976***	-1.913**	-0.403	-1.508*
	(0.864)	(0.770)	(0.801)	(0.781)
lnsig2u	-0.0685	0.0965	0.383	0.206
	(0.395)	(0.329)	(0.340)	(0.363)
Wald chi2	73.43	56.58	36.52	43.70
Prob > chi2	0.0000	0.0016	0.1588	0.0391
Observations	868	868	868	868
Number of firms	633	633	633	633

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Analyses of the effect of openness in terms of search breadth and search depth on innovation persistence are shown in Table 4-7. Regarding the first set of hypotheses about the effect of search breadth on innovation persistence, only the

coefficient of search breadth in the model of persistence of product innovation is significant (0.0816, $p<0.05$), which means that the wider the search breadth, the higher the chance is that firms persist in product innovation. Only Hypothesis 1(a) is supported while hypotheses 1(b), 1(c), and 1(d) are rejected.

Concerning the second set of hypotheses about the influence of search depth on innovation persistence, the coefficient of search depth is significant in the model of the persistence of product innovation (0.12, $p<0.1$) and it is also significant in the model of the persistence of marketing innovation (0.0978, $p<0.1$). Hypotheses 2(a) and 2(d) are supported while 2(b) and 2(c) are rejected. In sum, the results indicate that search breadth has a positive influence on the persistence of product innovation while it has no influence on the persistence of process, organisational, and marketing innovation. Search depth is found to have a positive impact on the persistence of product innovation and also the persistence of marketing innovation. It is noticeable that both persistence of process innovation and persistence of organisational innovation are not affected by openness, regardless of search breadth or search depth.

Next, this study looks at the control variables. First, the four constraint variables, the knowledge constraint variable has a significant influence on the persistence of product innovation (0.621, $p<0.05$) but it has no impact on the persistence of the other three types of innovation. It is somewhat counter-intuitive that the result shows that firms facing knowledge constraints are more likely to persist in product innovation. None of the cost, market, and regulation constraint variables has any effect on the persistence of product, process, organisational and marketing innovations. Looking at the funding variables, funding from the UK central government has a positive impact on the persistence of product innovation (0.621, $p<0.1$). Funding from UK local government and EU institutions have no significant influence on the persistence of innovation, regardless of whether the innovation is in the product, process, organisational, or marketing

areas. Regarding the variable of innovation investment as a proxy for firm's absorptive capacity, it has a positive impact on the persistence of product innovation (0.146, $p<0.05$) and persistence of progress innovation (0.219, $p<0.01$) while it shows no influence on the persistence of organisational innovation or persistence of marketing innovation. With regard to the education variable, none of these coefficients in the four persistence models is significant. In addition, this study also takes into account the complementary effect between various types of innovation activities. The presence of product innovation in the previous period is positively related to persistence of progress innovation (0.847, $p<0.01$) and to the persistence of marketing innovation (0.613, $p<0.01$). The presence of progress innovation in previous period has a positive impact on the persistence of product innovation (0.727, $p< 0.01$), the persistence of organisational innovation (0.443, $p<0.01$), and persistence of marketing innovation (0.516, $p<0.01$). The presence of organisational innovation in the previous period is positively associated with persistence of marketing (0.692, $p<0.01$); and vice versa (0.384, $p<0.01$). Firm size has a positive effect on persistence of organisational innovation (0.145, $p<0.1$). Crisis time, a dummy variable, is found to have a negative and significant relationship with persistence of marketing innovation (-0.33, $p<0.05$), which suggests that innovative firms tended to stop undertaking marketing innovation in the time of the 2008 global financial crisis.

Table 4-7 Openness and persistence of innovation

	(1)	(2)	(3)	(4)
	Persistence of product innovation	Persistence of process innovation	Persistence of organisational innovation	Persistence of marketing innovation
Search breadth$_{t-1}$	0.0816**	0.0435	-0.0225	0.00454

	(0.0381)	(0.0478)	(0.0281)	(0.0325)
Search depth$_{t-1}$	0.120*	0.0568	0.0480	0.0978*
	(0.0664)	(0.0747)	(0.0500)	(0.0529)
Cost constraints$_{t-1}$	-0.201	0.228	0.0485	-0.181
	(0.208)	(0.252)	(0.167)	(0.181)
Knowledge constraints$_{t-1}$	0.621**	0.333	0.267	-0.0201
	(0.311)	(0.350)	(0.237)	(0.258)
Market constraints$_{t-1}$	0.0205	-0.453	-0.0597	0.229
	(0.295)	(0.362)	(0.229)	(0.249)
Regulation constraints$_{t-1}$	0.0219	0.195	-0.180	-0.00603
	(0.336)	(0.429)	(0.270)	(0.284)
Local funding$_{t-1}$	0.131	0.601	0.179	0.00598
	(0.300)	(0.370)	(0.251)	(0.281)
Central funding$_{t-1}$	0.621*	0.0850	0.283	-0.0814
	(0.358)	(0.379)	(0.277)	(0.295)
EU funding$_{t-1}$	-0.120	0.0871	0.287	0.106
	(0.493)	(0.563)	(0.392)	(0.423)
Innovation investment$_{t-1}$	0.146**	0.219***	0.0494	0.0828
	(0.0622)	(0.0758)	(0.0466)	(0.0535)
Education degree$_{t-1}$	0.00813	0.00880	0.00114	-0.00490
	(0.00501)	(0.00600)	(0.00393)	(0.00445)
Product innovation$_{t-1}$		0.847***	0.0627	0.613***
		(0.279)	(0.163)	(0.207)
Process innovation$_{t-1}$	0.727***		0.443***	0.516***
	(0.199)		(0.160)	(0.179)
Organisational innovation$_{t-1}$	-0.301	0.296		0.692***
	(0.207)	(0.249)		(0.198)
Marketing innovation$_{t-1}$	0.328	0.253	0.384**	

	(0.203)	(0.234)	(0.155)	
Firm age	0.00306	-0.0156	0.00604	0.00709
	(0.0113)	(0.0146)	(0.00882)	(0.00956)
Firm size	-0.131	0.189	0.145*	0.0255
	(0.112)	(0.143)	(0.0874)	(0.0930)
Crisis time (2008-2010)	-0.252	-0.105	-0.155	-0.330**
	(0.157)	(0.184)	(0.129)	(0.148)
Industry dummies	Included	Included	Included	Included
Constant	-4.119***	-5.668***	-1.619*	-3.382***
	(1.332)	(1.620)	(0.863)	(1.031)
lnsig2u	1.190***	1.492***	0.628*	0.270
	(0.327)	(0.336)	(0.323)	(0.403)
Wald chi2	57.88	39.87	44.49	46.69
Prob > chi2	0.0011	0.0680	0.0330	0.0148
Observations	868	864	868	851
Number of firms	633	630	633	620

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

4.5 Discussions

First, this study looks at the effect of search breadth on innovation and persistence of innovation. The outcomes show that search breadth only has an impact on product innovation but has no influence on the process, organisational, and marketing innovations. A similar pattern is found in the analysis of innovation persistence. Search breadth has a significant influence on the persistence of product innovation only. It is not totally unexpected to see this similar pattern because the persistence of innovation is continuous involvement in innovation. While search breadth increases the probability of involvement in product innovation, it also increases the probability of persistence of product innovation. According to the definition of search breadth, it focuses more on the quantity of external sources of knowledge rather than the quality of the knowledge; thus it is suggested that knowledge acquired from the search breadth strategy should be understood as shallow in nature. This superficial character implies that knowledge acquired through the search breadth strategy does not deviate too much from the firms' core knowledge (Cruz-González et al., 2015). Thus, it would be relatively easy to incorporate such knowledge into the firms' existing knowledge, which leads to innovations. A great variety of external knowledge enables the firms to introduce a continuous stream of innovations which is also characterised as the persistence of product innovation.

Turning to the effect of search depth on innovation and persistence of innovation, there is no evidence showing that search depth has an impact on any of the four type of innovation – product, process, organisational, and marketing innovations. However, the analysis of innovation persistence reveals a different story about the search depth. Search depth has a positive impact on the persistence of product innovation and on the persistence of marketing innovation. It is interesting that search depth is not influential in the introduction of product innovation, but it is

in the persistence of product innovation. One possible explanation may be that external knowledge obtained from a deep search is quite complicated. Therefore, the importance of search depth cannot be reflected in a one-time innovation. Cruz-González et al. (2015) state that external search depth tends to lead more to the exploration of new knowledge in distant fields, which makes it difficult for firms to understand and apply it. Thus, only firms that continuously dedicate themselves to innovation can benefit from search depth.

Similarly, search depth has no significant impact on marketing innovation, but it does have a positive influence on the persistence of marketing innovation. According to the argument of market orientation, firms should not confuse their customers with changes in their marketing method such as pricing, promotions, and channels of distribution of the same product (Tavassoli and Karlsson, 2015). This is probably the reason why neither search depth or search breadth has a significant impact on marketing innovation. Nevertheless, in the analysis of openness and persistence of marketing innovation, search depth is found to have a positive effect on the persistence of marketing innovation. Although there are a few studies examining the effect of openness on non-technological innovations or innovation persistence, this study attempts to provide a possible explanation. Satisfying market needs is key to market success. A few of the openness studies have found that search depth is closely related to exploration of new knowledge (Belderbos et al., 2010; Cruz-González et al., 2015), which leads to novel and radical innovations. In order to successfully introduce the innovations to the market, firms need to tailor their marketing plans for those innovations. However, search depth is resource-consuming as the firms not only need to maintain a strong and close relationship with particular search channels but also need to devote considerable resources to assimilate and apply knowledge from those channels. If the knowledge gained can only be used in a one-off innovation, the firms may not be willing to search deeply among a limited number of external

partners. This study argues that the knowledge gained form search depth should enable the firms to introduce at least a stream of innovations.

Next, this study looks at the impacts of various constraints on innovation activities which seem to be contingent on the types of innovation, and some of the constraining factors are positively associated with certain types of innovation activity. Although the hampering effect of financial constraints for innovation has been extensively dealt with in the innovation literature (Hewitt-Dundas, 2006; Mancusi and Vezzulli, 2010; Paunov, 2012; Savignac, 2008, 2006; Tiwari and Buse, 2007), little is known about the effect of financial constraints on the persistence of innovation. It is plausible to expect that financial constraints would have a negative impact on the persistence of innovation; however, results of this study do not find support for this casual relationship between financial constraints and persistence of innovation.

Regarding the effect of knowledge constraints, the findings of this study suggest that knowledge constraints are associated with persistence of product innovation. The positive effects of knowledge and regulation constraints on innovations are somewhat counter-intuitive. The results suggest that firms that suffer from knowledge constraints are more likely to persist in product innovation. Mohnen et al. (2008) explain that innovating firms are more likely to perceive obstacles than non-innovating firms because innovating firms are embarking on an adventure in their quest for innovations and are more likely to try/attempt things that they are less skilled at. Galia and Legros (2004) postulate that "it is plausible that certain problems are not effectively encountered until firms face them. […] innovative firms face problems and more innovative firms have more problems (p. 1189)". This suggests that the perception of obstacles may slow innovation down, but it certainly will not prevent firms from innovating.

Only the funding from the central government has a positive impact on the persistence of product innovation while funding from the local government or EU institution have no profound influence on any types of the persistence of innovation. This study argues that funding from the central government is highly likely to be more substantial than that from the local government. In a time of global financial crisis, small amounts of funding may be insufficient for innovative firms to complete their innovations.

It is not surprising that R&D investment is positively related to the introduction of innovation as it has long been recognised as useful for developing innovation. R&D investment has a significant and positive effect on all types of innovation except for organisational innovation. Previous studies have indicated that there is a complementary relationship between various types of innovation: this study also finds a complementary relationship. Established and large firms are expected to be more active in innovation even in a time of financial crisis. A number of studies indicated that constraints on innovation decrease with firm size and established firms tend to possess slack resource saving from their previous profit. However, this study only finds that larger firms are more likely to embark on organisational innovation than smaller firms are. Regarding the time dummy variable indicating the time of the 2008 financial crisis, findings confirm that firms are less likely to persist in marketing innovation. One possible explanation may be that, unlike technological innovation, marketing innovation is not characterised by sunk cost; therefore temporary interruption will not cause many worries about future innovation.

4.6 Conclusions

This study contributes to the rapidly emerging literature on innovation studies by bridging the gaps between the innovation persistence literature and the open

innovation literature. This study investigates how openness in terms of a firm's search strategy affects a firm's propensity to persist in innovation. Following Laursen and Salter's (2006) work, openness is defined as a firm's search breadth and search depth. Search breadth concerns the *variety* of external sources of knowledge that a firm used for its innovations, and search depth focuses on the number of external knowledge sources that a firm draws on *deeply*. The present thesis deviates from the existing literature on open innovation in the sense that it is not primarily interested in how openness improves a firm's innovation performance measured by profit from innovations. Instead, this study strives to investigate whether openness encourages a firm to continually engage in innovations.

The results reveal that search breadth has a positive influence on the introduction of product innovation only, and it also has a positive effect on the persistence of product innovation. These findings suggest that firms that aim to succeed in product innovation should integrate a broad set of external knowledge into their developing process of product innovation. This result is consistent with Leiponen and Helfat's (2010) findings suggesting that broader horizons with respect to external knowledge sources are associated with successful innovation in terms of both the introduction of new innovations and returns from them. Regarding the effect of search depth strategy, it is interesting that search depth has no influence on the *introduction* of product innovation, but it is positively related to the *persistence* of product innovation. Cruz-González et al. (2015) indicate that external knowledge obtained from a deep search is more complicated than that acquired from a broad search. Therefore the influence of external knowledge from search depth cannot be reflected in a one-time innovation. Instead, only firms that continuously dedicate themselves to innovation can successfully apply these sets of knowledge and benefit from search depth.

Chapter 5: Conclusion

5.1 Summary of research questions and findings

This thesis has developed several research questions based on the identification of research gaps in the relevant literature in the field of innovation persistence. This thesis has addressed theses gaps by answering the following research questions in three researches:

In the first research (Chapter 2), this thesis investigates 1) whether or not firms continue to innovate in both technological (i.e. product and process innovations) and non-technological (i.e. organisational and marketing innovations) types of innovation activity amid the turbulence of the 2008 global financial crisis, and 2) how the complementarities emerging from the joint adoption of different types of innovation affect innovation persistence.

Innovation persistence is recognised in both technological and non-technological innovations in times of global financial crisis. The preliminary analysis of the Transition Probability Model showed that there is strong persistence in product, process, organisational and marketing innovations, but that the level of persistence differs among different types of innovation. The level of persistence is highest in organisational innovation followed by product innovation and process innovation, and the level of persistence is lowest in marketing innovation. One possible explanation for the highest level of persistence in organisational innovation may be due to the 2008 global financial crisis. The literature on economic crisis has highlighted the need for better management (Champion, 1999; Naidoo, 2010). Campello et al. (2010) indicate that during the crisis period, firms were facing dramatic changes in various aspects such as employment, marketing and technology spending. Therefore, firms need to adapt the ways

they used to manage and run their businesses. This finding highlights the importance of organisational innovation because innovating firms need to quickly adapt their management methods in response to any changes internal or external to the firms. Regarding the level of persistence in marketing innovation, it is not totally unexpected that the level of persistence in marketing is low as the cost of delay or abandonment of marketing innovation is relatively small (Tavassoli and Karlsson, 2015). Therefore, Wooldridge's (2005) random effect probit model is applied to test the state dependence between future and past innovations. Findings of the first sub-study are consistent with what has been found in the literature that there is persistence in product and process innovations. In line with prior studies (Ganter and Hecker, 2013; Martínez-Ros and Labeaga, 2009; Tavassoli and Karlsson, 2015), findings of the first sub-study confirmed the presence of innovation persistence in technological innovation such as product and process innovations. Moreover, this thesis supplements the extant persistence literature with the discovery of persistence in non-technological innovation such as organisational and marketing innovations.

Regarding the effect of complementarities among different types of innovation, the joint adoption of complementary innovations increases firms' propensity to persist in innovation. However, the positive effect of complementarities among innovations is contingent on the combination of different types of innovation. The joint adoption of product and process innovations and the joint adoption of product and organisational innovations increase the probability that firms will persist in process innovation and organisational innovation, respectively. In other words, firms that simultaneously adopted both product and process innovations show a higher propensity to conduct process innovation constantly, and firms that adopted both product and organisational innovations at the same time are more likely to persist in organisational innovation. The level of persistence in the process and organisational innovations is strengthened by the joint adoption of

product innovation. This finding suggests that product innovation may trigger follow-up innovations in the production process of new products (i.e. process innovation) or innovations in business practices for organising work responsibility and administrative procedures (i.e. organisational innovation). This finding conveys a message to firms' managers that the achievement of product innovation requires corresponding flexibility and changes in their production process and management practices, instead of concentrating on a single type of innovation activity. In other words, it is necessary for innovating firms to have a comprehensive plan for their innovation projects, such as the compatibility between different types of innovation and the chronological sequence of these innovations.

In the second research (Chapter 3), the focus of interest is to understand the underlying reasoning behind innovation persistence by examining the theoretical explanations which can be widely found in the relevant literature (Clausen et al., 2011; Ganter and Hecker, 2013; Peters, 2007; Suárez, 2014; Tavassoli and Karlsson, 2015). The literature on innovation persistence has proposed four theoretical explanations for the presence of innovation persistence: 1) **R&D sunk cost.** Firms that can afford to invest in R&D have a greater chance to succeed in innovation (Amara et al., 2008; Raymond and St-Pierre, 2010; Romijn and Albaladejo, 2002). 2) **Success-breeds-success.** Returns from previous successful innovation can be used to finance future innovation (Clausen et al., 2011; Peters, 2007; Suárez, 2014; Tavassoli and Karlsson, 2015). 3) **Appropriation strategy.** Appropriation practices such as patent, copyright and trademark help firms to avoid losses incurred from rivals' imitation, and the economic value appropriated from the firms' innovation can be reinvested in current or future innovations (Cohen et al., 2000; Leiponen and Byma, 2009; Tavassoli and Karlsson, 2015; Wang and Chen, 2010). 4) **Innovation competence.** Innovation is an accomplishment of accumulated competencies. Firms with experience in

innovation have developed the necessary skills for innovation, which grants such firms a more advantageous position from which to continue to innovate (Clausen et al., 2011; Ganter and Hecker, 2013; Peters, 2007). Based on these theoretical explanations this thesis constructed four sets of corresponding factors and investigates which factors drive firms to innovate persistently. Unlike the extant literature which used the lagged innovation to measure innovation persistence, this thesis introduces a new measure as a proxy for innovation persistence. When a firm reported having carried out innovation during two successive CIS survey periods, the firms are deemed to innovate persistently. The use of innovation persistence *per se* as the dependent variable allows this thesis to more directly explore the relationship between innovation persistence and its potential drivers.

This thesis conducted two cross-sectional analyses to explore innovation persistence during different time periods. Since the research data used in this thesis cover the period of the 2008 global financial crisis, the author is able to explore 1) what drives innovative firms to continue to innovate in times of the 2008 global financial crisis and 2) what drives innovation firms to persist in innovation after the global financial crisis. Overall, this thesis finds that the four theoretical explanations are more capable of interpreting the underlying causes of persistence in product innovation than the persistence in the other three types of innovations – process, organisational and marketing. First, the proxy for R&D sunk cost is firms' investment in research and development. Firms that continued to invest in R&D during the global financial crisis were found to persist in product innovation. Both the R&D sets of expenses incurred before and during the global financial crisis have a positive effect on the persistence in process innovation. Second, the theoretical explanation of success-breeds-success is proxied by two innovation-constraining factors based on the consideration that the financial difficulties caused by the global financial crisis are likely to cancel out the positive effect of success-breeds-success. The issues of lack of finance and demand

uncertainty during the time of crisis prevented firms from persisting in product innovation. Third, the appropriation strategy is measured by the amount of protection practices in place for innovation. Appropriation strategy encourages firms to continue to innovate with products during and after the global financial crisis. Lastly, the innovation competence is proxied by the level of education of employee and firms' ability to collaborate with external organisations. The established collaborative relationship with other firms increases the probability of persistence in the product, process and organisational innovations. It is worth noting that firms that have established a collaborative relationship with external entities are more likely to persist in all types of innovation except for marketing innovation in times of the global financial crisis. This finding implies that external linkages are influential in firms' decisions on whether or not to continue to innovate, which leads this thesis to further explore the relationship between openness (i.e. external linkages) and innovation persistence.

In the third research (Chapter 4), this thesis bridges the research gaps between the literature on innovation persistence and the research field of open innovation. In the second research of this thesis, external linkages (i.e. collaboration with external parties) are found to be positively related to innovation persistence, which motivated this thesis to explore further how firms' openness affects innovation persistence. Following Laursen and Salter's (2006) study, the openness of firms is measured by the firms' external search strategies such as search breadth and search depth. Search breadth focuses on the volume of external sources of knowledge firms used for their innovation, and search depth is more about how many important external sources of knowledge are incorporated into firms' innovation. In other words, search breadth cares about the *diversity* of the knowledge, and search depth focuses on the *quality* of the knowledge. Before investigating the relationship between openness and innovation persistence, this thesis followed Leiponen and Helfat's (2010) study which examines how

openness influences the success rate of technological innovation. Since this thesis considered innovation persistence as an accumulation of one-off innovations, the analysis of the impact of openness on innovation could provide a basic understanding of how firms' external search strategies influence their innovations. Then, the author further explored how external search strategies affect innovation persistence, a new measure which is constructed by firms' continuous involvement in innovation during two successive survey periods.

The external search strategies are found to influential in both one-off involvement and the persistence in product innovation, but the effects of external strategies are less profound in the other three types of innovation, regardless of one-off involvement or the persistence in innovation. Search breadth strategy has a positive impact on both product innovation (one-off involvement) and the persistence in product innovation (continuous involvement). The diversity of knowledge acquired from the search breadth strategy assists firms to introduce a constant stream of product innovation. Search depth strategy does not influence all four types of innovation (one-off involvement); however, search depth strategy has a positive impact on the persistence in product and marketing innovations. Prior studies have pointed out that knowledge gained from search *depth* strategy is more complicated than that acquired from search *breadth* strategy (Belderbos et al., 2010; Cruz-González et al., 2015), and therefore it takes more time and resources for firms to understand and apply this knowledge to their innovative activities. The benefit of search depth strategy can only be reaped by firms that continuously dedicated themselves to innovation.

5.2 Summary of contributions

The contributions of this thesis are reflected in the three sub-studies. In the first research, this thesis advances current research on the innovation persistence in

three respects. First, this research is one of the few research endeavours that investigates innovation persistence in the context of an economic crisis, the 2008 global financial crisis. The findings of the first research show that there is strong persistence in all four types of innovation and that innovating firms continue to innovate even in a changing economic environment. Findings of this thesis suggest that the persistence in innovations is not due to inertia which is a concept that characterises innovation persistence as a matter of routine (Winter, 2003). Conversely, the results support the theory predicting that persistent innovation is not likely without a clear strategy backed up by the relevant capabilities (Clausen et al., 2011). In times of global financial crisis, a number of firms are forced to delay or abandon their innovations (Filippetti and Archibugi, 2010; Paunov, 2012; Suárez, 2014) or even to sell assets to obtain cash (Campello et al., 2010). This thesis suggests that the presence of innovation persistence should be understood as an outcome of strategic planning and is key to overcoming the global financial crisis (Hausman and Johnston, 2014). Second, beyond investigating persistence through the lagged dependent variable, this sub-study examines the moderating impact of complementarities between different types of innovation on persistence in innovation. Third, this thesis contributes to innovation persistence by providing more empirical evidence in the presence of innovation persistence in the non-technological types of innovation such as the persistence in organisational and marketing innovations.

In the second research, this thesis contributes to the literature by examining the underlying causes of innovation persistence. The second research introduces a new measure of innovation persistence and directly investigates the effect of the potential drivers of innovation persistence. Results reveal that the determinants of innovation persistence determinants would change with the changes in the macro-economic environment, which means that what drives firms to persist in innovation in times of global financial crisis becomes ineffective in encouraging

firms to continue to innovate, and vice versa. In addition, this thesis contributes to the body of research on the determinants of innovation persistence by discovering that the theoretical explanations of innovation persistence are only capable of explaining the persistence in technological innovation, particularly the persistence in product innovation. Little is known about the *reasoning* behind the persistence in non-technological innovation (i.e. organisational and marketing innovations).

In the third research, this thesis contributes to the literature in that it is one of the few research endeavours which links the innovation persistence and open innovation literature. This study offers new insights into the innovation persistence literature by exploring the effect of firms' external search strategies on firms' propensity to continue to innovate. This study highlights the role of openness in terms of firms' external search strategies such as search breadth and search depth on innovation persistence. Findings of the third research indicate that the effect of firms' external search strategies is mainly shown on the persistence in product innovation. In addition, this study advances the knowledge of the open innovation literature in that the effect of openness tends to last a certain period. (e.g., this thesis examines the effect of openness on the dynamics of firms' innovation behaviour during two periods). This study applies a time-lagged design to investigate the relationship between persistence and openness because it takes time for firms to identify, assimilate, and then integrate external knowledge into firms' innovation process. This time-lagged approach takes into account the temporal dimension and would strengthen the causality implication of this research. Moreover, findings of this study support Love et al.'s (2014) proposition that openness to external sources of knowledge is subject to a learning process because firms learn through time which knowledge sources are most useful to their needs and how to effectively and efficiently manage the partnership with external knowledge providers. The benefit of openness to

innovation in any period will be affected by the lessons learned from firms' previous experience of external partnering. Therefore, firms that adopted external search strategies have a higher probability to continue to innovation based on capabilities learned from experience.

5.3 Implications

Several managerial and policy implications arise based on the findings of this thesis. First, the presence of innovation persistence means that innovation is a self-sustaining process that could be expected to reproduce itself over time; this, in turn, infers that past/present innovation has far-reaching effects on future innovation. From a strategic management perspective, innovation persistence signifies that past innovation supplies a fundamental building block for gaining and sustaining competitive advantage. From a policy perspective, innovation policy programmes are expected to bring long-term benefits to the economy. Despite the efforts to encourage innovative firms to persist in innovation, it is crucial to help non-innovators to commit themselves to innovation. Once the policy programmes succeed in encouraging innovation, a virtuous cycle would be created. Policy makers might need to tailor policy programmes to suit the needs of both innovators and non-innovators. Furthermore, the joint adoption of complementary innovation strengthens firms' propensity for innovation persistence. Managers may consider taking advantage of the complementarities to retain the continuous loop of innovation, which may help the firms to surpass their competitors.

Second, the identification of determinants of innovation persistence provides managers with useful information on the key factors in the continuity of innovative projects. In consideration of innovation policy, the identification of important drivers of innovation persistence directs policy makers regarding the

supportive programme for innovation. For instance, the financial constraints are one of the primary causes of discontinuation of product innovation (Campello et al., 2010). Nevertheless, findings of this thesis suggest that public funding from the central government would encourage firms to persist in innovation, particularly in the time of the 2008 global financial crisis. It is important for policy makers to help to innovate firms to access public funding to satisfy the need for financial resources. In times of the global financial crisis, firms became more risk-averse, and their R&D activities were likely to be re-oriented towards short-term, low-risk innovations, while long-term, high-risk innovations were cut first. The growth and decline of the long-term and/or short-term innovations may lead to a temporary recovery from the crisis but may damage the drivers of long-term growth in the process (Guellec and Wunsch-Vincent, 2009). The long-term innovations are declining because the funding for them contracts in downturns. In order to ensure the recovery is durable, it is important for governments to remedy such deficiencies in low investment in long-term, high-risk innovations.

Third, findings on the positive effect of collaborative arrangement on innovation persistence convey to firms' managers that collaboration with external firms stimulates the development of innovation. Smith and Tushman (2005) point out that a constant stream of innovation requires increased collaborative interaction between members of the team. Firms aiming to introduce a regular stream of innovation could direct their efforts towards establishing and maintaining a strong relationship with their partners. The government could consider implementing a programme that helps innovative firms to connect with each other. Moreover, the government could consider building public-private partnerships with innovating firms and, through this approach, the government could pledge public support to promising research and innovation affected by the

crisis. The establishment of public-private partnerships could be done through adjusting the balance of public and private funding.

5.4 Limitations and Future Research

Critical consideration of these results must bear in mind some limitations of this thesis. First, the analysis presented here is limited by the data and the statistical models. The results are confined to the UK, and it will be important to see whether the findings of this thesis can be generalised to different contexts such as other developed countries and also developing countries because the challenges faced by firms in different countries may differ significantly. In addition, the thesis restricts the research sample to firms that had responded to three waves of the innovation survey (i.e. CIS 6, CIS 7 and CIS 8). The time frame for the three surveys ranges from 2006 to 2012, covering the period of the 2008 global financial crisis. The selected samples in this thesis are somewhat biased toward survival firms which may possess special characteristics that influence their decisions on innovation persistence. Moreover, there is a one-year overlap between two consecutive waves of the UK CIS. Hence, the overlap of survey periods could lead to biased results which show persistence in innovation. Another limitation of this thesis is the assumption about the time that needs to elapse before past innovations could exert influence in terms of feedback and the accumulation effect that lead to new innovations. As Suárez (2014) said, in the innovation persistence literature the estimated time-lag seems to be explained more by the availability of the research data than by a theoretical consideration of the time lag required for the existing innovations to exert effects on the succeeding innovations. However, it is better to have no delay at all. Only the increase in the length of the longitudinal data will allow researchers to employ a different setting to investigate the impact of past innovations on current ones.

Lastly, this thesis concludes by suggesting some directions for future research. First, based on the findings of a proven persistence of innovation in this thesis, the author suggests future studies may carry out empirical research on how innovation persistence is related to the asymmetric performance of innovation across firms. Second, although this thesis has identified some of the reasoning behind persistence in product innovation, the causes of innovation persistence in the other three types of innovation activity (i.e. process, organisational and marketing innovations) are still not well understood. More research is needed into the determinants of innovation persistence in these three types of innovation. Third, as mentioned earlier, innovation can be considered as a self-efficient process that is expected to reproduce itself over time, which implies that when innovating firms decide to stop or abandon their innovation they must have strong reasons to give up their innovation. Future research may try to understand better why firms innovate in one period but not in the subsequent period. Finally, this thesis studies the importance of breadth and depth of external search to innovation persistence, but the analytical approach used does not allow for the analysis of the importance of the channel of the individual source of knowledge. Future studies may advance this line of research by investigating the effects of certain sources of knowledge on innovation persistence.

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