Intangibles strategy, appropriability regimes and firm innovation performance

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Declaration

I hereby declare that except where duly acknowledged, this thesis is entirely my own work and has not been submitted for another degree in any other university.

Abstract

This thesis is positioned in light of the increasing importance of intangible assets to firms in today's economies. The emergence of the knowledge-based economy has led to a shift towards the creation and management of knowledge assets; assets which are now widely acknowledged as a key driver of firm innovation and growth. Accordingly, there is an increasing need for firms to become concerned with strategies relating to intangible assets.

Based upon firm-level data taken from the UK Community Innovation Surveys and the Business Structure Database, this thesis is comprised of three empirical chapters. Each of these chapters uses quantitative analysis which is econometric in nature to examine firms' intangibles strategies from different perspectives.

Using a series of probit and ordered-probit models, the first study examines a firm's intangibles investment and protection behaviour, exploring how the industry appropriability regime and other elements of industry structure influence firm decisions. The study contributes to knowledge by seeking to identify whether the industry appropriability regime or some other element of industry structure drives a firm's intangibles strategy. In addition, the analysis explores whether the effects are consistent across the different components of a firm's intangibles strategy. Results suggest that both the industry appropriability regime and industry structure influence a firm's intangibles investment behaviour and the *importance* a firm attaches to different knowledge-protection mechanisms. In contrast, industry structure is less important for a firm's *actual* protection decisions, and a stronger appropriability regime is found to have a positive effect on a firm's use of easier-to-implement protection mechanisms.

The second study uses Tobit-model regressions to examine how the strength of the industry appropriability regime influences the complexity and variability of firms' knowledge-protection strategies within an industry. The analysis adds to existing knowledge by taking a holistic view of knowledge protection and examining how the strength of the industry appropriability regime impacts upon firms' knowledge-protection choices *within* an industry. Results suggest that both the complexity and variability of firms' knowledge-protection strategies increase when the knowledge-protection dimension of the industry appropriability regime strengthens. Moreover, results further suggest that the magnitude of the effect on complexity and variability varies across different industries.

In the third study, an innovation production function is estimated using a fractional-response model to investigate the relationship between a firm's innovation performance and its orientation towards the use of formal and informal knowledge-protection mechanisms. The analysis builds upon the existing knowledge-protection literature by using data on firms' *actual use* of formal and informal knowledge-protection mechanisms. In addition, the study contributes towards existing knowledge by exploring the effects of both formal and informal knowledge-protection strategies on the returns to innovation in firms of different sizes, firms with different technologies, firms in different sectors and firms innovating with different degrees of novelty. Results suggest that in general, both formal and informal knowledge-protection strategies are important for firms' innovation returns. Furthermore, industrial context, firm size and the degree of novelty of an innovation are all found to affect the magnitude of the impact upon a firm's innovation returns.

List of abbreviations

BSD	Business Structure Database
CAT	Computerised Axial Tomography
CIS	Community Innovation Survey
CR5	Concentration Ratio, Five-firm
DVD	Digital Versatile Disc
EMI	Electrical Musical Instruments
EU	European Union
FKP	Formal Knowledge Protection
FSB	Federation of Small Businesses
GDP	Gross Domestic Product
GLM	Generalised Linear Model
HHI	Herfindahl-Hirschman Index
ICT	Information and Communications Technology
IDBR	Inter-departmental Business Register
IKP	Informal Knowledge Protection
IO	Industrial Organisation
IP	Intellectual Property
IPO	Intellectual Property Office

IT	Information Technology
MCP	Marginal Cost of Protection
MVP	Marginal Value of Protection
OECD	Organisation for Economic Co-operation and Development
OLS	Ordinary Least Squares
ONS	Office for National Statistics
PAYE	Pay As You Earn
QMLE	Quasi-Maximum Likelihood Estimation
R&D	Research and Development
RBV	Resource-based View
SIC	Standard Industrial Classification
SME	Small and Medium-sized Enterprise
UK	United Kingdom
US	United States
VAT	Value Added Tax
VIF	Variance Inflation Factor
VRIN	Valuable, Rare, Inimitable, Non-substitutable
VRIO	Valuable, Rare, Inimitable, Organised

Chapter 1

Introduction

1.1 Research background

In recent years, the emergence of the knowledge-based economy has resulted in a significant shift in the origins of most companies' value and sources of revenue; for most firms, intangible assets have overtaken tangible assets as the dominant driver of value creation. It is now widely acknowledged that intangible assets are a key driver of innovation and organisational value in research and development (R&D) organisations (Del Canto and Gonzalez, 1999; Bounfour, 2003), generating more value for firms than physical assets (Thurow, 1997). The recognition that intangible assets are a key driver of growth (Montresor et al., 2014) and that innovation stems from knowledge (Roper et al., 2016a) has led to a shift within firms towards the creation and management of knowledge assets. As a result, many advanced national economies driven by tangible assets have been transformed towards more knowledge-based economies based on investment in intangible assets.

Intangible assets are assets that do not have a physical or financial embodiment. They have a difficult to codify 'tacit dimension' (Teece, 1981) – knowledge or competences are embedded in processes, procedures, routines and structures. Intangible assets include intellectual property, such as trademarks and patents, as well as brand and company reputation, company networks and databases (Hall, 1992). Also referred to as knowledge assets or intellectual assets, these assets are generally classified into three groups (OECD, 2011): computerised information (for example, software and databases); innovative property (for example, R&D, copyrights, designs, trademarks); and economic competencies (for example, brand equity, firm-specific human capital, networks joining people and institutions, organisational know-how that increases enterprise efficiency and aspects of advertising and marketing). Together, these groups form part of a firm's intellectual capital[1]. Interpreted broadly, 'intangibles' can be related to brands, process or product innovations, advertising, managerial skill, human capital in the workforce, and other aspects of the firm. Although balance-sheet data do, at times, contain a book (accounting) value for intangible assets, there is widespread agreement that this vastly underestimates the true stock of intangible assets of most firms.

The value of intangible assets lies in their ability to generate revenue for a firm. For example, goodwill (the value of a business in excess of its owner's equity – for example, favourable location and community awareness) and brand recognition are intangible assets which allow people to remember a company and want to buy its products. Superior profits stem from intangible assets such as know-how, customer relationships, brands and superior business processes (Teece, 1998), and by combining intangible assets with complementary intangible and tangible assets, a firm can gain further value. Thus, the ownership and/or control of complementary assets helps promote competitive success (Teece, 1986).

The competitive advantage of a firm lies in its ability to create, transfer, assemble, integrate, exploit and protect difficult-to-imitate non-tradable assets, of which knowledge assets are the most important (Teece, 1998, 2000a). Knowledge is fundamental to competitive advantage (Thurow, 1997; Blumentritt and Johnston, 1999) and intangible assets are fundamental to sustained competitiveness and performance (Seeman et. al., 2000). Aaker (1989) identifies the route to sustainable competitive advantage as being a process of managing assets and skills. A firm's strategies, including those of intangibles, are developed with the long-term aim of achieving a competitive advantage. The fundamental shift which has taken place in the basis for competitive advantage has immense implications for firm strategy, organisation, and management education (Teece, 2011).

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[1] Intellectual capital is comprised of human, structural and social capital (Edvinsson, 1997; Edvinsson and Malone, 1997). Human capital is the knowledge, skills and experiences that individual employees possess. Structural capital is everything that remains in a firm once its employees are removed. It includes the explicit, rule-based knowledge embedded in the firm's work processes and systems, or encoded in written policies, training documentation, or shared data bases of "best practices." It also includes intellectual property, protected by patents and copyrights. Social capital is reflected in the ability of groups to collaborate and work together and is a function of trust. Effective networks of relationships characterised by high levels of trust are a valuable resource in the creation and use of knowledge.

Given the recognised link which exists between intangible assets and firm growth, the strategic management of intangible assets – and in particular the management of knowledge (Blumentritt and Johnston, 1999) – is of vital importance. A firm's intangible assets are shaped when they undertake investment and protect knowledge embedded within their innovations. Investment into intangible assets is increasingly becoming the largest form of firm investment due to its contribution to growth (OECD, 2013). During recent times, the growth of investment into intangibles has exceeded that of tangibles. In the United Kingdom (UK) for example, the growth of investment into intangibles more than doubled as a share of market-sector gross value added during the 1970 to 2004 period (OECD, 2011). Today, many knowledge-based companies possess little tangible capital; their asset base consists almost entirely of intangible assets, assets which are increasingly being regarded as 'a new source of growth' (OECD, 2011).

In light of the increasing importance of intangible assets, there is a need for firms to fully recognise the importance of such assets and to be increasingly concerned with the strategy relating to them, "What must matter most to businesses is the fact that, globally speaking, over 65 per cent of most companies' value, sources of revenue and building blocks for future growth, sustainability and profitability evolves directly from intangible assets." (Maguire and Moberly, 2013, p. 86).

1.2 Existing literature

The existing literature surrounding intangible assets largely focuses upon their effect on economic performance. Some authors examine how intangible-asset investment affects organisational performance (for example, Ballot et al., 2001; De and Dutta, 2007; Marrocu et al., 2011), while others examine the performance effects of protecting intangible assets (for example, Falvey et al., 2006; Andries and Faems, 2013; Hu and Png, 2013). Contributions concerning those factors which influence a firm's intangibles strategy and the links between intangibles, innovation and performance are less common. Of the studies which do provide evidence of the link between intangible assets, innovation and growth, some show skills and talents (leadership and people management, for example), attributes that constitute intangible assets, to be enablers of innovation and exporting (Leiponen, 2005 and

Freel, 2005, for example), while others provide evidence on the link between design investment and innovative activity (Cereda et al., 2005, for example), and the increasing design intensity of a wide range of products has strengthened this link (Verganti, 2009). In addition, leadership and leadership style have been identified as important factors which shape innovation (Vaccaro et al., 2012). In another study, Andrews and de Serres (2012) find that intangible assets such as employee skills, databases, design, organisational know-how, brands and various forms of intellectual property form the basis for innovation-based growth.

Innovation – the application of knowledge to change or create more effective processes, products and ideas – is translated into economic growth through a greater variety of better-quality products and more effective processes. In the long term, the majority of economic growth is due to innovation (Innovation Report, 2014). Innovation involves risk; it is expensive and time consuming to develop new ideas and translate these ideas into a product or process. In addition, the probability of failure is high. Innovating firms are faced with a risk of imitation by both existing competitors and new competitors attracted into the market by the existence of high returns (Hurmelinna-Laukkanen, 2009). In the face of imitation, an innovating firm's competitive advantage may be eroded, and without an expectation of profiting from an innovation and a monopolistic power over an innovation, firms will be discouraged from investing in innovative activities – there will be no incentive to innovate (Schumpeter, 1942). This appropriability problem (Arrow, 1962) has implications for both firm performance and survival (Ceccagnoli and Rothaermel, 2008), so that firms face the key strategic challenge of protecting returns to innovation. Through the use of protection mechanisms, firms increase their chances of securing a return on their investment. Protecting the returns to innovation helps firms sustain any competitive advantage which exists and, in turn, may stimulate further innovation. Knowledge protection adds value to business and gives firms a greater chance of surviving and flourishing. In support of this viewpoint, evidence shows that industries with an above-average use of intellectual property protection generated over a quarter of UK employment and almost 40 per cent of UK Gross Domestic Product (GDP) in 2010 (EPO/ OHIM, 2013).

1.2.1 Intangibles strategy

A firm's management of its knowledge assets – its intangibles strategy – is an important determinant of whether or not the firm is able to successfully appropriate the returns to its innovation. An intangibles strategy includes the formulation and execution of strategies relating to the *investment into* and the creation of intangible assets, and the *protection of* intangible assets in order to protect any income streams which flow from them. A firm makes decisions on the investment into and the protection of its intangible assets, and the combination of these decisions represents its intangibles strategy.

The most common way for a firm to develop intangible assets is to invest in R&D (Teece, 2011). The majority of the literature identifying the determinants of R&D, one significant form of intangibles investment, focuses on two types of factors (Barge-Gil and Lopez, 2014). The first adopts a Schumpeterian view, focusing on the effects of firm size and market power. The second includes more fundamental, industry-specific determinants of inter-industry R&D investment such as demand pull, technological opportunities and appropriability. In addition to investing in R&D, a firm may develop intangible assets by investing in other areas of the business, such as training and computer software, for example.

Many authors identify factors which affect a firm's strategy relating to the protection of intangibles. Protection strategy differs across product and process innovations (Levin et al., 1987; Granstrand, 1999), industrial sectors (Levin et al., 1987; Harabi, 1995), the stage of innovation i.e. where in the innovation value chain the firm is located (Thomas, 2003), firm size (Kitching and Blackburn, 2003), the level of R&D intensity (Leiponen and Byma, 2009), the availability, strength and efficiency of appropriability mechanisms (Hurmelinna-Laukkanen and Puumalainen, 2007a) and the degree of innovativeness (Thoma and Bizer, 2013). In one study, Olander et al. (2014) identify the availability of protection, the safety or manageability of collaboration and the inconvenience of protection as factors affecting a firm's knowledge-protection decisions, and Cassiman and Veugelers (2002) find that industry-level patterns determine a firm's legal appropriability rather than firm managers who have limited opportunity to do so.

1.3 Research aims and objectives

Following this brief introductory chapter, this thesis is divided into three empirical chapters to provide an investigation into firms' intangibles strategies and the implications for innovation performance. The thesis asks:

- How a firm's intangibles strategy (the investment into and the protection of intangible assets) is influenced by the industry appropriability regime and industry structure
- How the complexity and variability of firms' knowledge-protection strategies within an industry are influenced by the industry appropriability regime
- How a firm's returns to innovation are influenced by its knowledge-protection strategy

The thesis aims to contribute towards the understanding of the relationship between particular aspects of the industry environment and a firm's intangibles strategy at both the firm level and the industry level, and in addition, it aims to contribute towards the understanding of the relationship between a firm's intangibles-protection strategy and the returns to innovation.

1.3.1 Methodology

The three empirical chapters address the research questions using quantitative analysis which is econometric in nature. The Econometrics Society defines econometrics as 'economic theory in its relation to statistics and mathematics' and its object as the 'unification of the theoretical-quantitative and the empirical-quantitative approach to economic problems' (cited by Frisch, 1933). The statistical analysis undertaken in the three empirical chapters of this thesis attempts to link variables and test theories or hypotheses. A central question in the philosophy of science concerns the relationship between empirical evidence and theoretical understanding; econometrics belongs to the evidence side of this relationship. Econometricians are positivists attempting to find the source of knowledge in either logical deductions or in empirical observation (Hoover, 2005).

The quantitative analysis undertaken in the three empirical chapters is based upon five waves of the UK Community Innovation Survey (CIS) covering the period 2002 to 2012 (CIS 4 to CIS 8) and data from the Business Structure Database (BSD) covering the period 1997 to 2012.

The first data source, the CIS, is the main source of innovation data in the UK and Europe. Background information and motivation for the survey can be found in the Organisation for Economic Co-operation and Development's (OECD) Oslo Manual (OECD, 2005). CIS-type data are widely used in academic papers concerned with explaining firms' innovation activities and performances (for example, Frenza and Ietto-Gillies, 2009; Battisti and Stoneman, 2010; Becker et al., 2016). The UK CIS, the UK counterpart of the European Union (EU) Community Innovation Survey, is conducted every two years by means of a postal questionnaire and follow-up telephone interviews. The surveys are non-compulsory and, for the waves analysed here, achieved a response rate ranging between 51 per cent in 2012 (CIS 8) and 58 per cent in 2004 (CIS 4)[2]. The UK surveys provide detailed information on firms' innovation activity, an indication of the objectives of firms' innovation activity and their external innovation connections. Questions relating to firm size and structure, customer base, firm product and process innovation activity, the sources of innovation, perceived barriers to innovation, the levels of public support and basic economic information about the firm are included. The surveys contain up to 16,000 firms (approximately), each having 10 or more employees. The firms included are statistically representative of the 12 regions of the UK, most industrial sectors and all sizes of firms (with 10 or more employees). The sampling frame is taken from the Inter-departmental Business Register (IDBR), a UK-Government compiled register of all UK businesses based on tax and payroll records.

The second data source used in the quantitative analysis is the BSD. This is derived primarily from the IDBR, which is a live register of data collected by Her Majesty's Revenue and Customs via Value Added Tax (VAT) and Pay As You Earn (PAYE) records. In 2004, it was estimated that businesses listed on the IDBR accounted for almost 99 per cent of economic activity in the UK. Only very small businesses, such as the self-employed, are not listed. The BSD represents the IDBR at one particular

[2] See: https://www.gov.uk/government/collections/community-innovation-survey

moment in time and provides a version of the IDBR for research use. The reporting period is the financial year, and there are up to approximately 5.5 million firms included. The dataset contains a small number of variables for almost all UK firms, and these include employment, turnover, foreign ownership, Standard Industrial Classification (SIC) codes, start-up dates and termination dates.

An advantage of using survey research as the strategy of enquiry (Creswell, 2009) is that it is efficient at providing large amounts of data. The research generalises from a sample to a population (Babbie, 1990), and allows inferences to be made about the characteristics and behaviour of firms.

The empirical approaches adopted in each study reflect the nature of the dependent variables being investigated. Regression methods are used to test the hypotheses in all three empirical chapters. In Chapter 2, two different types of model are estimated. The first – a probit model – is used to analyse firms' intangibles investment and protection, and the second – an ordered-probit model – is used to analyse managerial attitudes towards intangibles protection. The ordered-probit estimation method is a generalisation of the probit analysis to the case where more than two outcomes of an ordinal dependent variable exist. In Chapter 3, a series of Tobit models (censored-regression models) are estimated to examine the complexity and variability of firms' knowledge-protection strategies within an industry, and in Chapter 4, generalised linear models are used to estimate an innovation-production function with the proportion of innovative sales as the dependent variable.

1.3.2 Empirical chapters

i. *The industry appropriability regime, industry structure and a firm's intangibles strategy*

Chapter 2 links a firm's intangibles-investment and intangibles-protection decisions to the industry environment within which the firm operates. The motivation for this firm-level study originates from the increasing importance of intangible assets in today's economies and the industrial organisation (IO) viewpoint that a firm's appropriate strategy decisions depend strongly on the environment of the industry in which the firm operates (Scott, 1982).

The emergence of the knowledge-based economy has led to an increase in intangible investment, such that, in recent years, intangible investment has risen above that of tangibles (Haskel et al., 2011). Intangible assets reflect value in a firm, and the strategy relating to them has important implications for competitive advantage. Creating a competitive advantage based upon knowledge is a challenging prospect for firms as the benefits of producing new knowledge spill over to competitors and create an appropriability problem (Arrow, 1962). As a solution to this problem, a firm's intangibles strategy not only includes investment into intangible assets but also includes the protection of knowledge and creative outputs through the use of knowledge-protection mechanisms.

In Chapter 2, the source of a firm's competitive advantage is assumed to lie within the industry environment (Burns and Stalker, 1961; Lawrence and Lorsch, 1967; Thompson, 1967), so that a firm's appropriate strategy decisions depend strongly on the market environment in which the firm operates (Scott, 1982). In light of this, the empirical analysis undertaken in this study investigates how the industry environment influences a firm's strategy in relation to its intangible assets. In particular, this study seeks to explore whether a firm's intangibles strategy is contingent upon the appropriability regime of the industry within which the firm operates or some other element of industry structure.

Chapter 2 advances existing research by examining how the industry appropriability regime and other elements of industry structure influence the investment and protection components of a firm's intangibles strategy. The study contributes to knowledge by seeking to identify whether the industry appropriability regime or some other element of industry structure drives a firm's intangibles strategy. In addition, the study contributes to knowledge by identifying whether the industry-appropriability-regime effects and the industry-structure effects are consistent across a firm's intangibles investment and protection strategies.

ii. Appropriability regimes and the complexity and variability of knowledge-protection strategies within industries

In Chapter 2 it is proposed that elements of the industry environment – common to all firms within a particular industry – affect firms' intangibles investment and protection strategies. Indeed, existing literature identifies that firms' knowledge-protection strategies differ markedly across industrial sectors. For example, Arundel and Kabla (1998) find that the effectiveness of patents in preventing imitation varies across industries, Brouwer and Kleinknecht (1999) find that firms in high-technology industries are more likely to use patents and Miles and Boden (2000) make a distinction between the service and manufacturing industries. Leading on from this, Chapter 3 provides an in-depth analysis of firms' knowledge-protection strategies within industries. All firms within a given industry operate subject to the same industry environment, yet firms within an industry make different knowledge-protection choices. Firms are characterised by their resources and capabilities, and it is the heterogeneous nature of firm-specific resources and capabilities which gives rise to the variation in firms' knowledge-protection choices within industries.

Given the heterogeneous nature of resources and capabilities across firms within an industry, the analysis in Chapter 3 examines how the distribution of knowledge-protection strategies within industries is influenced by the industry appropriability regime. Chapter 3 advances the existing field by examining firms' knowledge-protection strategies *within* industries. It investigates how firms' knowledge-protection strategies within industries respond to changing appropriability conditions. In order to examine intra-industry knowledge-protection strategies, the study adopts a novel (to my knowledge) approach. It examines how the strength of the industry appropriability regime affects the distribution characteristics of firms' knowledge-protection strategies within industries: it examines how a change in the strength of the industry appropriability regime affects the complexity (or average intensity) of firms' knowledge-protection strategies and the variability of firms' knowledge-protection strategies within industries. In addition, the analysis is further extended to compare the effects across different industries, in particular high-technology/knowledge-intensive industries and low-technology/less knowledge-intensive industries.

iii. Formal versus informal knowledge protection: which matters most for innovation returns?

Following on from Chapter 3 which examines firms' knowledge-protection strategies within industries, Chapter 4 examines firms' knowledge-protection strategies in more detail and explores how firms' formal and informal strategies help capture the returns to firm innovation. Formal knowledge-protection mechanisms, for example patents, are those implemented through regulation. They become effective by legally excluding imitators (Hall, 1992). Informal knowledge-protection mechanisms, for example secrecy, are not based upon structures and statutory-enforcement possibilities (Hurmelinna-Laukkanen, 2014).

Chapter 4 contributes to existing knowledge by examining how formal knowledge-protection strategies and informal knowledge-protection strategies affect firms' innovation returns. In this firm-level study, an innovation production function is estimated to investigate the relationship between a firm's orientation towards formal knowledge-protection, and its orientation towards informal knowledge-protection, and innovation performance. A comprehensive analysis is carried out: first, all innovating firms are examined, second, different industries, technologies and sizebands are compared, and third, firms undertaking new-to-the-market, new-to-the-firm and both new-to-the-market-and-firm innovations are compared with one another. As an extension to the analysis, firms undertaking new-to-the-market innovation are further explored. The effects of formal and informal knowledge-protection strategies on the returns to innovation of firms of different sizes, firms with different technologies and firms in different sectors within this sub-group of innovators are examined. Initially, an exploratory factor analysis of knowledge-protection data identifies two factors – one loaded more heavily with formal knowledge-protection mechanisms and another loaded more heavily with informal knowledge-protection mechanisms. The two identified factors are used in the analysis to represent formal and informal knowledge-protection strategies.

The final chapter of the thesis – Chapter 5 – provides some discussion and conclusions. It summarises the key research findings from the three individual empirical chapters, highlights important contributions to knowledge and discusses the main policy implications which arise as a result of this research.

Chapter 2

The industry appropriability regime, industry structure and a firm's intangibles strategy

2.1 Introduction

Until recently, measured investments were all tangible; assets were thought to be things that could be touched (Haskel and Westlake, 2018). However, present-day economies rely more and more upon other non-physical, intangible assets containing knowledge and ideas – they are unable to survive on tangible investment alone.

Since the early 2000s, investment into intangible assets in the United Kingdom (UK) has been greater than that for tangible assets (Haskel et al., 2011). In 2008, intangible investment was £137 billion compared with £104 billion for tangible investment. Of this intangible investment, training accounted for £27 billion, organisational capital £31 billion, design £23 billion, software £22 billion and research and development (R&D) £16 billion (Haskel et al., 2011).

The reasons for the transition towards intangible investment provide policymakers with an improved understanding of firm innovation and growth (Haskel and Westlake, 2018). Intangible assets such as design, software and R&D are more labour dependent than tangible assets – designers and software developers have to be paid, as do scientists. The new technologies that have emerged during recent years – for example, information technology (IT) technologies – have increased firms' opportunities to invest in intangible assets so that intangible investment has risen above that of tangibles. Changes in industrial structure have also contributed towards the growth in firms' intangible investment. Both the services and manufacturing sectors have become more intangible intensive, for example, leading to an increase in intangible investment (Haskel and Westlake, 2018).

Firms continually create and use intangible assets – for example, the creation of a firm name or the design of the physical attributes of a product. As intangible assets can be used to reflect value in a firm, the strategy relating to such assets requires a firm's careful thought and attention.

Creating and maintaining a competitive advantage based upon knowledge is a challenging prospect for firms as the benefits of producing new knowledge spill over to competitors and create an appropriability problem (Arrow, 1962). As a solution to this problem, a firm's intangibles strategy not only includes investment into intangible assets but also includes the protection of knowledge and creative outputs through the use of knowledge-protection mechanisms. Intangibles strategy – the formulation and execution of strategies relating to the investment into and the creation of intangible assets (for example, through R&D activities), and the protection of intangible assets (for example, through the use of patents), is the focus of this study.

In the pursuit of a competitive-advantage attaining intangibles strategy, a firm is required to know the *source* of the competitive advantage. Within the literature, two prominent views have emerged relating to this source – industrial organisation (IO) theory and the resource-based view (RBV) theory. The first – IO theory – identifies the industry environment (structural forces and the competitive environment, for example) as a potential source (Burns and Stalker, 1961; Lawrence and Lorsch, 1967; Thompson, 1967), and the second – the RBV theory of strategic management – identifies a firm's internal resources and capabilities as a potential source of competitive advantage (Penrose, 1959; Rumelt, 1984; Wernerfelt, 1984).

The focus of the present study lies with the IO viewpoint assuming that a firm's appropriate strategy decisions depend strongly on the market environment in which the firm operates (Scott, 1982). The empirical analysis undertaken here investigates how the industry environment influences a firm's strategy in relation to its intangible assets. In particular, this study seeks to explore whether a firm's intangibles strategy is contingent upon the appropriability regime of the industry within which the firm operates or some other element of industry structure.

The industry appropriability regime is the environmental factors a firm faces (excluding firm and industry structure) which govern its ability to capture profits from an innovation (Teece, 1986). The most important dimensions of the appropriability regime are the nature of the industry's technology and the effective and available means of intellectual property (IP) protection within the industry to protect both the innovations themselves and any increased rents that flow from them (Teece, 1986, 1998, 2000a; Levin et al., 1987; Teece and Pisano, 1998). As the expected returns to innovation are high when appropriability is strong, the empirical analysis explores whether innovative activity (investment into R&D, for example) within firms is more likely in the presence of a strong industry appropriability regime. In addition, the analysis investigates how a firm's intangibles-protection strategy responds when the industry appropriability regime changes in strength.

Industry structure also plays a central part in determining strategy and the strategies available to firms (Teece et al., 1997). The empirical analysis here draws upon the IO viewpoint (Porter, 1980) identifying the state of competition within a firm's environment as being an important determinant of a firm's value-creating intangibles strategy. The empirical analysis investigates how a change in industry competition affects a firm's intangibles investment and protection decisions.

The existing literature surrounding intangible assets largely focuses upon the impact they have on economic performance. Some authors examine the link between a firm's investment into intangible assets and firm performance (for example, Ballot et al., 2001; De and Dutta, 2007; Marrocu et al., 2011), while others examine the performance effects of protecting intangible assets (for example, Falvey et al., 2006; Andries and Faems, 2013; Hu and Png, 2013). Contributions concerning the industry environment and its impact on the different elements of a firm's intangibles strategy are less prominent.

The present study advances existing research by examining how the industry appropriability regime and other elements of industry structure influence the investment and protection elements of a firm's intangibles strategy. This study adds to previous work by seeking to identify whether it is the industry appropriability regime or some other element of industry structure which drives a firm's intangibles strategy. In addition, the study adds to existing research by identifying whether the effects of the industry appropriability regime and other elements of industry structure are consistent across the two different aspects of a firm's intangibles strategy – investment and protection.

The remainder of this chapter is organised as follows. Section 2.2 outlines the conceptual framework. Firstly, two prominent views on the source of a firm's competitive advantage are discussed. The first – IO theory – identifies the environment (i.e. the structural forces that exist within an industry and the competitive environment) as the potential source of competitive advantage. The second – the RBV theory of strategic management – identifies a firm's internal resources and capabilities as the potential source. Secondly, the appropriability regime and the structural factors which exist within an industry's environment – both the focus of this study – are discussed in more detail. Finally in this section, intangibles strategy and the issues surrounding intangibles strategy are discussed. Section 2.3 details the conceptual model and develops a number of hypotheses, Section 2.4 profiles the data used and the empirical approach adopted, Section 2.5 describes the main empirical results, and Section 2.6 includes discussion and conclusions.

2.2 Conceptual framework

2.2.1 Competitive advantage

Competitive advantage is considered to be the basis for superior firm performance (Omalaja and Eruola, 2011). A firm is able to gain a competitive advantage by implementing a value-creating strategy not being simultaneously implemented by any current or potential competitor (Barney, 1991). If a firm's competitive advantage remains in place following unsuccessful imitation by competitors, the advantage is considered to be *sustained* (Lippman and Rumelt, 1982). A firm with a competitive advantage is able to achieve a superior performance relative to other competing firms within the same industry group or relative to the industry average. The competitive advantage arises when the firm is able to offer consumers greater value than other firms. It can do this by either charging lower prices than other firms or by providing consumers with a greater benefit than other firms, justifying higher prices. Porter (1985) identified that a "Competitive advantage grows fundamentally from the value a firm is able to create ... Value is what buyers are willing to pay, and superior value stems from offering lower prices than competitors for equivalent benefits or providing unique benefits that more than offset higher prices," (Porter, 1985, p 3).

Firms aim to make decisions and implement strategies which allow them to develop and sustain a competitive advantage (Hill and Jones, 2013); they aim to implement value-creating strategies. However, in order to succeed in this, firms require an understanding of the causes of competitive advantage or the source of the advantage upon which its strategies are to be based. The organisational processes by which firm strategies are developed provide an insight into firms' understanding of competitive advantage and into where they believe the true source of the advantage lies. Within the literature, two prominent views regarding the source of competitive advantage have emerged. The first – IO theory – identifies the industry environment or the structural forces and competitive environment within the industry as the potential source. Porter (1991) highlights four elements of a firm's immediate environment that have the strongest influence upon firms' competitive advantage: factor conditions (available labour and capital, for example), demand conditions (the size and nature of the customer base), related and supporting industries (upstream and downstream industries), and firm strategy, structure and rivalry (competition forces firms to find new ways to increase production). The second – the RBV theory – identifies a firm's internal resources and capabilities as the potential source. The RBV theory emphasises strategic choice, with firm managers identifying, developing and positioning key resources in order to maximise returns (Fahy, 2000).

2.2.1.1 The source of competitive advantage

i. Industrial organisation (IO) theory

IO theory identifies the industry environment as a potential source of a firm's competitive advantage. In their seminal work, Burns and Stalker (1961) were the first to introduce the idea that a firm is an open system and affected by its environment; they uncover the environment's impact upon a firm's internal structure. Their study examines firms that, following the war, are faced with having to adapt their business strategies to changes in technologies and markets. Some firms are able to adapt, others fail. Two distinct groups of firms emerge from their results; firms that adapt successfully and are innovative and firms that are unsuccessful in adapting to new conditions. Those firms that successfully adapt and are able to operate in a dynamic and uncertain environment show a more ‘organic’ organisational structure (for example, individual tasks within the firm are adjusted and continually re-defined through interaction with others). It is this ‘organic’ system which Burns and Stalker (1961) find to be closely linked to success in innovative activity. Those firms that are unable to adapt, preferring a more stable environment, exhibit a more ‘mechanistic’ organisational structure (for example, individual tasks within the firm are defined and coordinated by a formal hierarchy of superiors) (Meadows, 1977).

Following on from Burns and Stalker (1961), Thompson (1967) views firms as being open systems that are faced with technologies and environments of varying levels of uncertainty, and it is these uncertainties which limit a firm’s ability to plan and execute strategies in order to achieve a desired outcome. Observed firm behaviour therefore reflects a firm’s efforts to resolve the tension between uncertainty and firm rationality (Davis and Powell, 1992). Through their work, Lawrence and Lorsch (1967) measure a ‘formality of structure’ variable and find a positive correlation between environmental uncertainty and the formality of structure in the management of firms’ departments. They suggest that different styles of organisation are observed across different departments within a firm (for example, R&D and manufacturing departments), and that these different styles depend upon the characteristics of the environment with which they are associated.

These three studies combined (Burns and Stalker, 1961; Thompson, 1967; Lawrence and Lorsch, 1967) provide the foundations of contingency theory. Contingency theory recognises the need for firms to thoroughly investigate their external environment when formulating internal structures (Nilsson and Rapp, 2005) so that observed firm structures match contingent environmental conditions (Burns and Stalker, 1961). In light of this, a change in a firm’s external environment (for example, a new technology), may cause the firm to act differently so that best practices depend upon the contingencies of the situation. The essence of contingency theory is that firm performance is linked to the firm’s ability to ‘fit’ the characteristics of its structure to the contingencies that it faces (Burns and Stalker, 1961), and it is this link with performance which motivates firms to adjust to changing environmental conditions. As the degree of 'fit' between strategy and the environment (Hofer, 1975; Prescott, 1986), or strategy and structure (Chandler, 1962; Rumelt, 1974), has significant implications for performance, contingency has emerged as an important concept in both strategic management and organisational research (Venkatraman and Prescott, 1990). Hofer (1975) develops a contingency theory of firm strategy in which strategically-significant environmental and organisational variables include economic conditions, demographic trends, political and legal factors, industry structure variables and competitor variables. Operationally, firms are required to find a match between the environment and their strategies.

Strategic management researchers draw upon contingency theory, conceptualising the environment as a key variable for understanding organisational behaviour and performance. The structure-conduct-performance paradigm of IO (Mason, 1949; Bain, 1959) is one approach to modelling the environment. It emphasises the influence industry structure has, or the environment (contingency variable) has, upon firm strategy (conduct). The theory makes the simplifying assumption that firms' strategically-relevant resources are identical (Scherer, 1980; Porter, 1981; Rumelt, 1984), and also assumes that resources are mobile so that any resource heterogeneity present is short lived (Barney, 1986).

Porter (1980) bases his five-forces framework on the structure-conduct-performance paradigm in industrial organisational economics. Porter (1980) identifies five competitive forces which exist within industry structure that may affect firm strategy: the threat of new entrants into the industry, the intensity of rivalry among existing competitors, the pressure from producers of substitute products or services, the bargaining power of buyers of the industry's outputs and the bargaining power of suppliers to the industry's companies. Within an industry, firms aim to position themselves in such a way so as to defend themselves against these competitive forces (Porter, 1979); they find ways to sustain their existence within the industry and to increase their own competitiveness. The firm most successfully matching its strategy with the competitive forces that are present is most likely to achieve a competitive advantage. Therefore, a strategy aligned with market and industry conditions is the source of the competitive advantage. This so-called 'competitive forces' theory was the dominant approach to achieving competitive advantage during the 1980s.

Porter's (1980) five-forces framework – a framework which draws upon the structure-conduct-performance approach to firm strategy – has both advantages and limitations. An advantage of the five-forces framework is that it goes beyond the more simplistic focus on relative market growth rates as a way of determining industry attractiveness (Grundy, 2006). Firm managers are encouraged to focus on the external environment in order to understand the foundations of competition and the root causes of profitability (Porter, 2008). In addition, analysing the five competitive forces allows the complex interactions of competitors to be evaluated in a structured way. In terms of limitations, firms within an industry are assumed to be able to make a judgement about an industry's attractiveness and profitability (Johnson et al., 2008) based upon an assessment of the five competitive forces as defined by the model. In identifying a firm's strengths and weaknesses in this way, it is assumed that a strategy can be implemented which will strengthen the firm's position within the industry. In reality, firm managers may not have the ability to assimilate and assess the competitive forces which exist. Furthermore, the competitive forces approach includes an over-simplification of micro-economic theory by only considering five competitive forces, and Porter (1980) provides no justification to prove the validity of his choice of five forces (Speed, 1989). Moreover, the five-forces model is static, taking no account of time (Grant, 1995). This makes it difficult to analyse dynamic markets which change quickly. In addition, Porter's model allows no role for the effects of digitalisation and globalisation – important factors affecting industry structures during recent years. Furthermore, although Porter's contingency-theory approach suggests that key strategic requirements vary depending upon environmental conditions, it does not provide any guidance for predicting the form or strength of the strategy-environment relationship (Prescott, 1986). Open questions therefore remain in relation to the effects different aspects of the industry environment have upon firm strategy as well as to the relative strength of these effects, something the present study aims to address.

ii. Resource-based view (RBV) theory

One criticism of Porter's five-forces model is that it provides no role for firms' resources and capabilities. In contrast, the RBV theory focuses upon the firm and its individual attributes rather than the wider industry environment to locate the source of competitive advantage. The origins of the RBV theory lie with Penrose (1959), where firm-specific resources allow for diversification. Penrose (1959) describes the firm as a collection of resources, and it is the heterogeneity of these resources across different firms which make a firm unique. In addition, different firms are able to draw different services from the same type of resources (Foss, 2012). These firm resources, or firm specific assets, enable the firm to create a cost or differentiation advantage. In contrast to the competitive forces theory, firm resources in the RBV theory are assumed to be immobile assets – both tangible and intangible – and are thus tied to the firm (Wernerfelt, 1984). It is upon these heterogeneous, immobile resources that the theory of competitive advantage is based (Penrose, 1959; Rumelt, 1984; Wernerfelt, 1984).

Barney (1991) defines firm resources as "all assets, capabilities, organisational processes, firm attributes, information, knowledge, etc. controlled by a firm that enable the firm to conceive of and implement strategies that improve its efficiency and effectiveness" (Barney, 1991, p.101). A firm's capabilities are its ability to utilise its resources effectively. Capabilities allow a firm to make better use of its resources as mere possession of resources is not sufficient (Penrose, 1959). A firm's internal resources and capabilities are the source of firm profitability as they enable the firm to achieve a cost or differentiation advantage and, in turn, a competitive advantage. The heterogeneous and immobile resources are an essential requirement for a competitive advantage to be achieved, and in order for a competitive advantage to be sustained, firm resources are required to possess four attributes: resources are required to be valuable (V), rare (R), costly to imitate or inimitable (I) – embedding capabilities within firm routines makes them difficult for competitors to replicate – and non-substitutable (N). Collectively, these attributes are known as VRIN (Barney, 1991). Barney (1995) later extended VRIN to become VRIO by include resources that are organised (O) in such a way so as to capture value.

Teece et al. (1997) draw on and extend the RBV theory in their dynamic capabilities approach. It is assumed that firms constantly adapt, renew, reconfigure and re-create their resources and capabilities in line with the competitive environment which they face. In a highly dynamic business environment, the original RBV theory proposition is viewed as being static and neglects the influence of market dynamism, something the dynamic capabilities approach aims to address (Eisenhardt and Martin, 2000).

In reality, the RBV has limitations as a theory due to its limited value in generating managerial prescriptions (Lockett et al., 2009). The RBV theory of the firm supports the view that a valuable resource can act as a source of competitive advantage for the firm. In doing so, the theory assumes that firm managers are able to evaluate the potential resources that may provide more benefit to the firm and enable success for the firm in the emerging markets (Kozlenkova et al., 2014). Some firm managers may not have the ability to do this. VRIO has been proposed as a framework for understanding which resources are valuable to a firm and what makes them so, how vulnerable they are to imitation, and how the firm can exploit and manage them sustainably (Barney and Hesterly, 2009). This proves problematic for firm managers; they find it difficult to identify the relevant resources that satisfy VRIO criteria (Arend and Lévesque, 2010). It is also difficult for firm managers to determine how much to invest in specific resource characteristics to maintain performance in these criteria. Previous literature identifies that many of the least imitable resources, such as competence embedded in the firm, for example, are difficult to identify effectively, and once identified are hard to manipulate (Teece et al., 1997; Priem and Butler, 2001). In addition, embedded resources, identified by VRIO, tend to lose value quickly in high-velocity environments and hold firms back from strategic change (Jarzabkowski and Wilson, 2006). Another limitation of the RBV approach is its managerial influence. The framework implies that if any firm can acquire or develop resources at a cost advantage then those resources will be imitable and only a source of competitive parity. The theory therefore suggests that managers have a limited ability to create a sustained competitive advantage (Barney, 2007). Furthermore, RBV perceives a firm to be a bundle of resources, and gaining access to such intra-organisational data is extremely difficult. To carry out a complete investigation of the firm (i.e. to identify resources), resources are required to be accessible (Barney, 2007).

2.2.2 Structural factors

The impact of industrial structure on firm performance was first exposed by Bain in 1959 with the development of the IO structure-conduct-performance paradigm. The paradigm relates industry structure (for example, the number of competing firms, homogeneity of products, costs of entry and exit) to firm conduct (i.e. strategies to gain competitive advantage – for example, price taking, product differentiation, tacit collusion, and exploitation of market power) and performance (for example, firm growth, national output and employment growth). The range of options available to a firm and the constraints it faces are defined by industry attributes, and as a result of this, a firm's conduct and performance are very much linked to industry structure. Porter (1980) draws upon this IO viewpoint to derive his own five-competitive-forces model. The model identifies the state of competition within a firm's environment as being an important determinant of the firm's value-creating strategy. Analysing an industry's underlying structure in terms of Porter's five competitive forces provides a method by which industry competition and profitability can be assessed and understood. A firm can identify its strengths and weaknesses relative to the industry and implement offensive or defensive strategies in order to strengthen its position in relation to the five competitive forces (Porter, 1980).

2.2.2.1 Competitive forces framework

Porter (1980) identifies that competition within an industry depends upon five basic forces: the threat of new entrants, rivalry among existing competitors, the threat of substitute products or services, the bargaining power of buyers and the bargaining power of suppliers. A firm's "Knowledge of these underlying sources of competitive pressure provides the groundwork for a strategic agenda of action," (Porter, 1979, p.138). Firms plan for and respond to competitive forces so that their strategies take advantage of any opportunities and address any threats which exist within the industry environment. As the collective strength of any competitive forces differs across industries, systematic differences result in the nature of competitive strategies available to individual firms (Kaniovski and Peneder, 2002).

The five competitive forces framework identifies the five most common threats firms face in their competitive environments and the conditions under which these threats are likely to be present (Barney and Hesterly, 2009). Three competitive forces arise from horizontal competition (the threat of new entrants, the threat of substitute products or services and the threat of established rivals) and two come from vertical competition (the bargaining power of suppliers and the bargaining power of customers) (Porter, 1980).

i. Threat of entry

The first environmental threat identified is the threat of new entrants. New entrants are firms who have recently started operating within an industry or are due to begin operating soon. Any economic rents being earned by incumbent firms attract new firms into the industry. Upon entry, the level of competition increases, and any economic rents and competitive advantages are eroded away. New firms continue to enter the industry until competitive parity is reached (Barney and Hesterly, 2009).

The ease with which new competing firms enter an industry is determined by the barriers to entry which exist. In the absence of barriers to entry, competition is maximised, and any competitive advantages within an industry are quickly eroded. If barriers to entry are high, firms are deterred from entering the industry, and incumbents sustain any economic rents and competitive advantage (Barney and Hesterly, 2009). Both structural and strategic barriers to entry exist, often referred to as economic and behavioural barriers to entry. Structural barriers to entry come from basic industry characteristics such as technology, costs and demand. The broadest definition of structural factors (Bain, 1956) suggests that barriers to entry arise from product differentiation, absolute cost advantages and economies of scale. Strategic barriers to entry exist due to the behaviour of incumbents. Incumbents may choose to increase structural barriers or to make credible threats to potential new entrants. For example, an incumbent might over-invest in capacity in order to threaten new entrants with a price war, or they might implement product differentiation strategies in the form of increased advertising, branding and superior customer services as an effective way of creating entry barriers.

Porter (1979) identifies six major sources of barriers to entry:

- Existing economies of scale (incumbents' costs are falling as a function of production volume) – new entrants are forced to enter on a large scale or at a cost disadvantage
- The need for new entrants to differentiate products – new entrants are forced to spend heavily in order to overcome customer loyalty
- Large capital requirements – new entrants are forced to invest large financial resources in order to compete
- Cost advantages for incumbents – entrants incur higher unit costs at every rate of output
- Difficulties accessing product distribution channels – new entrants must create a new product/service-distribution channel
- Government policy – new entrants require licenses and must operate according to regulation and standards

ii. Threat of rivalry

The second environmental threat in the five-competitive-forces framework is the extent of firm rivalry among existing firms within the industry. Rivalry threatens firms by reducing economic rents (Barney and Hesterly, 2009), and for many industries, the intensity of competition among direct competitors is a major determinant of overall competitiveness. Rivalry is more intense in industries where there are a large number of competing firms that are similar in size and power, where industry growth is slow, where there is a lack of product differentiation and where capacity is added in large increments (Porter, 1979). A high level of rivalry within an industry is often indicated by frequent price cutting as customers switching from competitors are believed to be the only source of growth (Barney and Hesterly, 2009).

iii. Threat of substitutes

The ease with which a firm's product or service can be substituted by another firm's product or service reflects the third threat in the five-competitive-forces framework. The availability of substitutes within an industry places a ceiling on the prices firms can charge and upon the economic rents they can earn (Barney and Hesterly, 2009).

The threat of substitutes is high if the cost of switching is low, and in the extreme case where a substitute is viewed as being superior to the product or service, the product or service will be completely replaced, for example, video tapes have been replaced by digital versatile discs (DVDs). Factors affecting the threat of substitutes include a buyer's propensity to substitute, the relative price performance of substitutes, buyer-switching costs, a perceived level of product differentiation, fad and fashion, technology change and product innovation.

iv. Threat of powerful customers

The fourth threat in the competitive-forces framework is the bargaining power of customers, or the amount of pressure a customer is able to exert upon a firm. Powerful customers act in such a way so as to lower a firm's revenues (Barney and Hesterly, 2009). Customers do this by forcing down prices, demanding a higher quality or more service and playing one firm off against another (Porter, 1979). If a customer impacts upon a firm so as to affect its margins and volumes, it holds a substantial amount of power. Such customer power may exist when the number of buyers is small, customers purchase large volumes, switching to another (competitive) product is simple, customers can do without the good or service for a period of time or customers are price sensitive (Barney and Hesterly, 2009). A firm is able to reduce customers' bargaining power by partnering, improving its supply-chain management, increasing customer incentives or increasing loyalty benefits, for example.

v. Threat of powerful suppliers

The fifth and final threat in the competitive-forces framework is the bargaining power of suppliers. Suppliers can threaten a firm's economic rents by increasing the price of their supplies or reducing their quality (Barney and Hesterly, 2009). The more pressure a supplier can place on a firm, in terms of being able to affect its margins and volumes, the more power it has. The number of potential suppliers within an industry determines the relative power of each seller. Suppliers are powerful if very few exist for a particular product, there are no substitutes for that product or the product is extremely important to the buyer and they cannot do without it (Barney and Hesterly, 2009). The bargaining power of suppliers can be reduced by a firm entering into a partnership, a firm taking over a supplier, a firm improving its supply-chain management (for example, through training) or a firm increasing its knowledge about a supplier (for example, by gaining knowledge about supplier costs and methods) so that the supplier becomes more dependent upon the firm.

2.2.2.2 Competitive forces and industry type

When the collective forces within an industry are strong, there is a high level of competition, and the industry becomes relatively unattractive to new entrants. Entry to the industry is very easy, and overall profitability is driven down to a level resembling that of the economist's perfectly competitive market (Porter, 1979). In a *perfectly competitive* industry, there are a large number of competing firms, products are homogeneous with respect to cost and product attributes, and costs of entry and exit are low i.e. there are low entry barriers. Firms are price takers and respond to changes in industry supply or demand by adjusting price rather than attempting to influence the level of supply or demand themselves. Price-taking firms can only expect to gain competitive parity (Barney, 2007). Firms in such an industry have very few options and face many constraints; firms generate returns that just cover their cost of capital in the long run. In such a situation, industry structure completely determines both firm conduct and long-run firm performance (Barney and Hesterly, 2009).

When the collective forces within an industry are at their weakest, competition approaches the economist's monopoly market (Barney, 2007). *Monopoly* industries consist of a single firm, and entry into this type of industry is very costly (Barney, 2007). There are few examples of monopoly industries, although the personal computer operating systems industry, almost completely dominated by Microsoft, comes close. Firms are able to use their market power to set prices and generate competitive advantages and significant economic rents (Barney, 2007).

Two other types of competition within an industry that lie between perfect competition and monopoly have been identified by economists – oligopoly and monopolistic competition. In both cases, the collective forces are moderately high (Barney, 2007). *Oligopoly* is an industry characterised by a small number of competing firms. Products are either homogeneous or heterogeneous, and costs of entry and exit are high. Firms face a variety of conduct options, and significant competitive advantages and economic rents can be earned (Barney, 2007).

In *monopolistically competitive* industries, there are a large number of competing firms and low-cost entry and exit into and out of the industry exists, but unlike the case of perfect competition, products in these industries are not homogeneous with respect to costs or product attributes. Firms successfully implement product differentiation strategies and are able to act as quasi-monopolists. However, these monopoly positions are always threatened by the competitive actions of other firms within the industry. Examples of monopolistically competitive industries include the tea and car industries. Firms have a variety of conduct options and are able to gain competitive advantages (Barney, 2007).

The underlying economic and technological conditions within an industry determine the strength of Porter's five competitive forces and the overall level of competition within the industry. The intensity of competition determines the degree to which investment inflows drive returns. The competitive forces are strong in industries where no firm earns outstanding returns and weak in industries where high returns are common (Porter, 1980). Across industries, the strongest competitive forces originate from different sources. For example, foreign-competitor rivalry and competition from substitute materials are prominent within the steel industry. In order for a firm to prosper within an industry, it assesses the overall strength of the competitive forces within its environment prior to positioning itself and shaping its strategy. When shaping its strategy, a firm is required to position itself so that its capabilities provide the best defence against any competitive forces present. In positioning itself, a firm takes the industry's structure as given and matches its strengths and weaknesses accordingly. A firm can build defences against the competitive forces, or it can position itself where the forces are weakest. Through strategic moves, a firm is able to influence the balance of the competitive forces, and by anticipating shifts in the factors which underlie the forces, it can respond to them appropriately (Porter, 1979).

Alongside the competitive forces which exist within an industry's environment, lies the industry appropriability regime – the environmental factors a firm faces (excluding firm and industry structure) which govern its ability to capture profits from an innovation (Teece, 1986).

2.2.3 Appropriability

Appropriability is a firm's capacity to retain any added value it creates for its own benefit. More specifically, here it represents the extent to which a firm can capture profits generated through innovation (Teece, 1986; Levin et al., 1987). It is often the case that firms fail to appropriate the returns to their innovations (Ceccagnoli and Rothaermel, 2008). Innovating firms are faced with a risk of imitation by both existing competitors and new competitors attracted into the market by the existence of high returns (Hurmelinna-Laukkanen, 2009). It is possible that a fast second entrant into the market or even a slow third can outperform the innovator (Teece, 2012). This appropriability problem (Arrow, 1962) has implications for both firm performance and survival (Ceccagnoli and Rothaermel, 2008), so that firms face the key strategic challenge of protecting any returns to their innovation.

Firms that successfully innovate are able to exploit their competitive advantage and monopolise the market (Aghion and Howitt, 1996). When an innovating firm is faced with imitation, its competitive advantage may be eroded. Without an expectation of profiting from an innovation and a monopolistic power over an innovation, firms will be discouraged from investing in innovative activities – there will be no incentive to innovate (Schumpeter, 1942). Protecting the returns to innovation stimulates further innovation and helps firms sustain any competitive advantage which exists.

Two essential components of appropriability have been identified (Teece, 1986*), the appropriability regime* and *specialised complimentary assets.* A firm's ability to profit from innovation – or appropriate returns to innovation – depends upon both components (Pisano, 2006).

2.2.3.1 The appropriability regime

The first essential component of appropriability is the *appropriability regime* – the environmental factors a firm faces (excluding firm and industry structure) which govern its ability to capture profits from an innovation (Teece, 1986). The most important dimensions of the appropriability regime are the nature of the technology within the industry (for example, whether it is a product or a process technology or whether knowledge is tacit or codified in nature) and the available and effective methods of IP protection within the industry to protect both the innovations themselves and any increased rents which flow from them (Teece, 1986, 1998, 2000a; Levin et al., 1987; Teece and Pisano, 1998).

Assessing the nature of a technology within an industry provides an indication of its ease of imitability (Pisano, 2006) or 'accessibility'. The accessibility of a technology (Jones Day, 2006) determines the likelihood of imitation. Accessibility varies across both products and processes and tacit and codified knowledge. For example, many process technologies are not generally observable and are therefore highly inaccessible. In contrast, new products are easily accessible to many; their technologies are observed and can be re-created through techniques such as reverse engineering. In addition, some technologies are based upon tacit knowledge and are very difficult to understand, making them particularly inaccessible. Other technologies use codified knowledge so that the technology is accessible to everyone. In summary, the less (more) accessible the technology, the less (more) likely it will be subject to imitation and the more (less) likely returns will be appropriated.

The second dimension of the industry appropriability regime is the effective methods of IP protection available to protect innovations and the rents which flow from them. For the purpose of this study, the knowledge-protection dimension of the appropriability regime is assumed to include both formal and informal protection mechanisms. Formal protection mechanisms are legally enforceable protection mechanisms and typically include registered rights such as patents, design rights and trademarks and unregistered rights such as copyright. Informal protection mechanisms are not based directly on regulated structures and statutory enforcement possibilities (Hurmelinna-Laukkanen, 2014); they include secrecy, complexity of design and lead-time on competitors. Within an industry, it is the availability and enforceability of both formal and informal knowledge-protection mechanisms which helps to shape the appropriability regime (Hurmelinna-Laukkanen and Jauhiainen, 2004).

The industry appropriability regime, a combination of the two dimensions discussed above, determines the barriers to imitation which exist within an industry and, in turn, the ease with which competitors can imitate an innovation (Ceccagnoli and Rothaermel, 2008). Appropriability regimes can be strong or weak (Teece, 1986), and their strength varies across industries. An appropriability regime is 'strong' when innovations are easy to protect – knowledge about them is tacit or is well protected through the use of knowledge-protection mechanisms. In this instance, innovations are hard to imitate because knowledge is embedded within firms' routines and capabilities or it is well protected through the use of patents and secrecy, for example. The pharmaceutical and chemical industries are examples where the appropriability regime is strong. It is difficult for competitors to imitate innovations within these industries as patents, on molecules for example, are extremely effective. The software industry is also characterised by a relatively strong appropriability regime as innovations are typically protected by patents and copyrights, and it is technically possible for firms to make imitation extremely difficult.

An appropriability regime is 'weak' when innovations are difficult to protect – knowledge can be easily codified, and knowledge-protection mechanisms are ineffective. When technologies are easily observed and reverse engineering is possible, the scope for patenting is small, imitation is easy, and alternatives can be easily developed. The soft drinks industry, for example, Coca Cola and Pepsi is an example where the appropriability regime is relatively weak. The use of patent protection would be short lived, and imitation would be relatively easy thereafter. The use of secrecy combined with trademarks is more suitable here. Another example where the appropriability regime is weak is the digital economy where firms rely upon branding and quality of services to maintain competitive advantages.

In reality, appropriability regimes form a continuum, some emphasising knowledge-protection mechanisms over the nature of technology and some emphasising the nature of technology over protection (Teece, 1998, 2000). A strong regime can be achieved by different means; some industries may rely upon protection while others may rely upon tacit knowledge embedded deep within firms' structure (Levin et al., 1987). Whatever the chosen combination, firms aim to create a first-mover advantage and earn higher than average returns. Strategically, the strongest appropriability regime is not always best. Rather, a firm aims to maximise the value of its knowledge assets, and this will be achieved by having an efficient appropriability strategy (Shapiro and Varian, 1999), consistent with the industry appropriability regime.

In the original Teece (1986) framework, appropriability regimes are assumed to be exogenously determined by the nature of technology and the means of knowledge protection used to protect innovations and the rents which flow from them. Pisano (2006) suggests that appropriability regimes are increasingly being endogenously influenced by the behaviour and strategies of firms themselves and are the 'product of conscious strategies of firms' (Pisano, 2006, p.1122). In some cases, firms take their complementary asset position as given and shape the appropriability regime to optimise the value of those assets. Evidence of this behaviour can be found in the open-source software industry. Here, the source code for computer programs is made publicly available so that other developers can build upon the code. This behaviour represents a shift in the appropriability regime of the software industry. Traditional software development saw proprietors use a variety of IP protection mechanisms to protect their designs from imitation and illegal use. With open-source software, developers contribute and understand that their contributions can be used by others; a commonly shared base of technology is created (Pisano, 2006). Open-source software clearly represents a weakening of the appropriability regime. Granstrand (1999), Teece (2006) and Pisano and Teece (2007) support this viewpoint suggesting that it is possible for appropriability regimes to be endogenously shaped by firms, governments, and technological change.

2.2.3.2 Specialised complementary assets

The second fundamental component of appropriability is the ownership of *specialised complementary assets* (Teece, 1986). Many innovators are unable to capture the economic rents which flow from their innovations because they lack the specialised complementary assets required to do so. The successful commercialisation of an innovation 'requires that the know-how in question be utilised in conjunction with other capabilities or assets. Services such as marketing, competitive manufacturing, and after-sales support are almost always needed. These services are obtained from complementary assets, which are specialized' (Teece, 1986, p. 288).

Teece (1986) highlights the importance of specialised complementary assets in understanding the performance implications of an innovation. Firms accumulate specialised assets over long periods of time; they are path dependent and idiosyncratic (Teece et al., 1997). Included in a firm's stock of specialised complementary assets are its resources and capabilities that display VRIO characteristics. Consequently, specialised complementary assets are a source of sustainable competitive advantage (Barney, 1991).

The relationship between an innovator and the owner of complimentary assets – if the innovator does not own them – can be described in terms of dependency (Teece, 1986). The degree of dependence between the innovation and the complementary assets needed to produce and/or take the innovation to market affects an innovator's ability to appropriate returns. In his conceptual framework, Teece (1986) distinguishes between the owners of generic, specialised and co-specialised complementary assets. Generic complimentary assets are not specific to an innovation; they are general-purpose assets, for example, general-purpose manufacturing equipment. When complementary assets are generic, no profit-sharing problems exist between an innovator and the owner of such assets (Hurmelinna et al., 2007) – generic complementary assets are readily accessible. The innovator appropriates returns provided that the appropriability regime is strong enough to prevent imitation (Hurmelinna et al., 2007). Specialised complimentary assets exhibit one-way interdependence between themselves and the innovation. If the innovator is dependent upon complementary assets, the complementary assets owner has more bargaining power than the innovator in price negotiations, and they receive more appropriated returns. Co-specialised complementary assets are characterised by a two-way dependence between themselves and the innovation. The success of the relationship depends upon mutual participation of the innovator and the owner of the complementary assets. In this case, bargaining power is balanced between the two parties.

2.2.3.3 The appropriability regime and specialised complementary assets: an interaction

The interaction between appropriability-regime strength and the ownership of specialised complementary assets (i.e. the two components of appropriability), determines the degree to which firms are able to profit from their innovations (Ceccagnoli and Rothaermel, 2008). In the presence of a weak appropriability regime, imitation is relatively easy, and firms require access to specialised complementary assets to enable themselves to gain a competitive advantage and capture the returns from an innovation. In this case, the owners of specialised complementary assets are in a relatively powerful and controlling position. In a weak appropriability regime, firm investment into specialised complementary assets (investment into marketing, sales efforts and customer service, for example) aids the appropriation of innovation returns (Cohen and Levin, 1989). In a strong appropriability regime, imitation is relatively difficult. Firms rely on knowledge-protection mechanisms or tacit knowledge to appropriate the returns from an innovation; access to specialised complementary assets is less important. This Teece (1986) framework suggests that appropriation requires an effective strategy, and that firms are required to choose the best complementary asset position given the strength of the appropriability regime that it faces: firm strategy is contingent upon the appropriability regime (Pisano, 2006).

2.2.4 Intangibles strategy

A firm's management of its knowledge assets is an important determinant of whether or not the firm is able to successfully appropriate returns to innovation (Section 2.2.3 above). The strategic management of knowledge assets, or so-called *intangible assets*, is of growing importance in today's world due to the arrival of the knowledge economy and the recognition that intangible assets are the main value creator for firms; they are a key driver of growth for many developed countries (Montresor et al., 2014). According to Teece (1998), the competitive advantage of a firm lies in its "ability to create, transfer, assemble, integrate, and exploit knowledge assets" (Teece, 1998, p.75). This importance of intangible assets to long-term firm success has meant a shift within firms towards the creation and management of knowledge assets. The centrality of knowledge and IP introduces new managerial challenges to firms; placing a value on intangible assets is difficult, and 'the management of a completely invisible asset' (Soo et. al., 2002, p.130) is demanding – it is difficult to manage something that cannot be measured. In addition, a firm's management of intangible assets is not simply an IP issue which can be delegated to a legal department within the firm; managerial decisions differ according to the firm's underlying demand and cost structures, the appropriability regime within the firm's environment, the nature of the innovation and the characteristics and complexity of the technology facing the firm (Teece, 2000a).

In accordance with the RBV theory of the firm (see Section 2.2.1.1 above) where firm resources and capabilities influence growth and performance (Penrose, 1959; Wernerfelt, 1984), the successful management of intangible assets in order to appropriate innovation returns requires particular entrepreneurial skills and capabilities. A firm's knowledge – represented by know-how, culture, routines and experiences, for example – is characterised by its inimitability. This inimitability generates added value for customers and scarcity for competitors (Barney, 1991): the firm's knowledge is a source of competitive advantage.

A strategy is defined as "a pattern in a stream of decisions" (Mintzberg, 1978, p. 934). In the present study, an intangibles strategy includes the formulation and execution of strategies relating to the *investment into* and the creation of intangible assets, and the *protection of* intangible assets in order to protect any income streams which flow from them. A firm makes decisions on the investment into and the protection of its intangible assets, and the combination of these decisions represents its intangibles strategy.

i. Intangibles investment

When investing in intangible assets, firm managers make a series of quantitative decisions. They decide how much money to spend, the scale of the investment and when the investment will take place. In order to make these decisions, managers are required to understand conceptually what constitutes the firm's intangible assets and to have the ability to apply the leadership skills needed to effectively invest in them. Key strategic questions and decisions surrounding a firm's investment into intangible assets impact upon the firm's innovation streams, and therefore it is important that managerial decisions regarding intangibles investment are informed decisions. For managerial decisions to be informed, information in relation to the investment into intangibles and the benefits which flow from them is required. This way, managers obtain a clear picture of the firm and its performance. If managerial decisions are uninformed, resources may be wasted, and consequently, returns to investment may be low. To be informed, managers require an understanding of core business processes along with the complexity of the decisions that they need to make. Some investment decisions require coordination and alignment with other strategic decisions, and the complexity of these decisions will determine the focus of any intangible-asset investments. It is essential that firm managers are equipped with the knowledge-management tools and techniques required to make these decisions so that the focus of any intangible-asset investment can be determined.

ii. Intangibles protection

As well as being able to generate, acquire, transfer and combine intangible assets to meet customer needs, a firm has to be able to protect its intangible assets (Teece, 2000a). Intangible assets typically entail higher risks than those of a physical or financial nature. Mismanagement, theft and IP crime require firms to actively protect intangible assets, mitigating the risks and preserving their value. The protection of intangible assets limits imitation and, in accordance with the RBV theory of the firm, helps firms to gain a competitive advantage (Teece et al., 1997).

When protecting its intangible assets, a firm typically chooses between formal and informal protection methods. In the case of formal methods, protection is implemented through regulation (for example, patents, trademarks and copyright) (Hall, 1992), while more informal methods such as the complex nature of databases, networks and reputation hinder imitation by competitors in the short run (Fahy and Smithee, 1999).

In some instances, the protection of intangible assets and innovation reveals information that competing firms can make great use of; it can enhance learning. For example, patents and patent applications are often viewed as a source of information enabling different sources and flows of technology to be monitored (Pitkethly, 2001).

Firms' use of knowledge protection may have negative as well as positive effects. For example, protection may lead to a situation where strong appropriability conditions are created before a dominant design has been achieved, constraining firms and locking them into a particular concept (Teece, 1986). The use of tacit knowledge and formal protection mechanisms obstructs the transfer of knowledge and may have a negative impact upon future innovation performance. An overly-strong protection of intangibles may therefore hinder the flow of knowledge and eliminate any benefits associated with imitation.

2.2.4.1 Intangibles protection: Intra- and inter-sector differences

Previous research suggests that a firm's choice of formal and informal knowledge-protection mechanisms differs across sectors and industries (due to the presence of tacit or codified knowledge, product and process technologies and the industry appropriability regime, for example) (Levin et al., 1987; Cohen et al., 2000), and across firms (due to resources and capabilities, for example) (Lopez, 2009; Hall et al., 2014). A firm's choice also depends upon the novelty of the innovation (Hanel, 2005).

i. Industry/technology characteristics

Industry characteristics play an important part in determining whether firms use formal or informal protection methods to protect innovations. Levin et al. (1987) – the Yale I survey – and Cohen et al. (2000) – the Carnegie Mellon survey – examine the extent to which firms in different industries choose formal and informal knowledge-protection methods to appropriate returns. Both studies report broadly consistent findings. For both product and process innovations, secrecy and lead time are viewed as important knowledge-protection mechanisms; a high percentage of firms are found to rely on informal mechanisms in their knowledge-protection strategies. With the exception of the pharmaceutical and chemical industries, patents are found to be much less important. However, patents are identified as being more important for product innovations than for process innovations. One reason for this is that a patented process could easily be invented around once knowledge is disclosed. This is supported by Harabi (1995), who in a study of Swiss firms finds the same result. In this study, firms express concern regarding the disclosure of knowledge because it allows competitors an opportunity to invent around their innovations. Again, patents are identified as being most important to firms in the pharmaceutical, chemical and machinery industries. As in Levin et al. (1987), lead time is found to be the protection mechanism most important for firms' appropriation. Results show that secrecy is also important, more so for process innovations; processes can be effectively retained within the firm and protected with trade secrets. In a survey of one hundred manufacturing firms, Mansfield (1986) finds that in both the pharmaceutical and chemical industries, patent protection is necessary for at least 30 per cent of innovations. Several other industries (petroleum, machinery, and fabricated metals) report patents to be necessary for 10 to 20 per cent of innovations. The remaining industries do not rely on patent use.

Cohen et al. (2000) find that R&D intensive industries, for example pharmaceuticals, report a high effectiveness of almost every protection mechanism. The majority of other industries report a high effectiveness for two or more mechanisms and only a small number of industries report a high effectiveness of only one. Cohen et al. (2000) find that patents are used more often than secrecy in discrete product industries, whereas in complex-product industries it is easier to invent around technologies, and therefore firms rely less on patents and more on informal methods of protection such as lead-time. In their study of small Finnish manufacturing and service firms, Leiponen and Byma (2009) find that R&D intensive firms and science-based firms are more likely to protect knowledge formally. Other firms use speed to market or secrecy as protection methods.

Brouwer and Kleinknecht (1999) examine Dutch manufacturing firms and find that those in high-technology industries are more likely to patent than those in other industries. Their results are consistent with those of Levin et al. (1987) and Harabi (1995) who find patents to be most important within the chemical and pharmaceutical industries. Across all innovating firms, Levin et al. (1987) and Harabi (1995) find around half of firms report patents to be insignificant when protecting their knowledge – lead time and secrecy are reported to be more important.

Some technologies are easier to protect formally than others. For example, in the chemicals and pharmaceuticals sector, a patent is able to protect a specific compound (or a specific chemical formula); it is clear what the patent protects and few disputes arise (Bessen and Meurer, 2008). In other sectors, for example information technology, the range of patents is less precise. The probability of dispute is higher, and patent use is less popular (Hall et al., 2014).

Innovation in services is quite different from innovation in manufacturing, relying less on R&D and more on new information technology-based processes (Hall and Sena, 2017). Contrary to the view that service sector firms may gain no benefit from using formal knowledge-protection mechanisms, Hall and Sena (2017) find formal protection mechanisms to be more important than informal protection mechanisms for service sector productivity. Their results are ambiguous for the manufacturing sector as informal and formal knowledge protection has an equal effect on productivity, although the effect is negative. This negative effect is attributed to there being longer lags between innovative activity and productivity within the manufacturing sector.

Other studies which focus on services (Mairesse and Mohnen, 2004; Hipp and Herstatt, 2006) suggest that most service firms do not use any type of knowledge protection. Those service firms that do protect their knowledge tend to use formal trademarks and copyrights and informal mechanisms such as customer, supplier and employee lock-ins. Mairesse and Mohnen (2004) examine French firms' use of knowledge-protection mechanisms in the manufacturing and service industries. Innovative service firms are found to use protection mechanisms less often than high-tech manufacturing firms but more often than low-tech manufacturing firms. Hipp and Herstatt (2006) find that service-intensive German firms use long-term labour contracts to protect their knowledge. Secrecy, lead time and complexity are also identified as being important protection mechanisms, whereas only 6 per cent of service firms examined use formal protection mechanisms.

Blind et al. (2003) find that the propensity to patent and the number of patent applications is significantly lower in services compared with manufacturing; 7 per cent of service firms applied for patents compared with 25 per cent of firms in the manufacturing industry. Applying formal methods of protection to services is not straightforward (Blind et al., 2003; Maskus, 2008), for example, the tacit knowledge included in services is not eligible for patenting. It is the intangible nature of service innovations that determines the type of protection mechanisms which can be used successfully (Miles and Boden, 2000).

Baldwin et al. (1998) examine the use of knowledge-protection mechanisms in Canadian service industries (for example, communications and financial services) using innovation survey data from 1996. Less than half of innovators report using any of the knowledge-protection mechanisms available to them. Of those used, copyright and trademarks are the most popular – particularly in the financial services industry. Patents are used only by the technical business service industry. Lead time is identified as the most effective knowledge-protection mechanism by all service industries. Of the formal protection mechanisms available, trademarks are identified as being most effective.

Päällysaho and Kuusisto (2006) examine a sample of Finnish and UK firms in three knowledge-intensive service industries (advertising, business and management consultancy, and software consultancy and supply). Trademarks and copyright are the most popular formal knowledge-protection mechanisms whereas patents are rarely used. The most popular protection mechanism used by firms in these service industries is restrictive contracts (for example, non-disclosure agreements). Secrecy is also identified as being important in these industries.

ii. Firm resources and capabilities

Although all knowledge protection represents a cost to the firm, formal protection mechanisms are often viewed by firms as a more expensive option than informal knowledge-protection mechanisms. Applying for a patent, for example, can be a costly process, and a firm will continue to incur costs whilst keeping a patent in force (Hall et al., 2014). Patent enforcement requires firms to actively monitor markets for potential infringement. If an infringement is detected, patent holders require financial resources to enable them to engage in litigation. Informal protection mechanisms, often viewed as the least expensive method of innovation protection, are not without their costs. For example, the use of secrecy by firms is often accompanied by confidentiality agreements (Hall et al., 2014).

As well as incurring costs when protecting innovations, firms face uncertainty when using both formal and informal protection mechanisms. In the case of patents for example, this uncertainty relates to whether a patent will be granted, whether it will be invalidated at a point thereafter, whether any infringements will occur and if so, whether they will be proven. A firm also faces uncertainty when using informal mechanisms, for example when a firm uses secrecy, it is uncertain as to whether the secret will be maintained and whether any breach of confidentiality will be proven, in court or otherwise.

The strength of a firm's formal knowledge protection often depends upon the resources it has available to threaten court action, and if necessary to take court action. Small firms are likely to lack the necessary resources and capabilities to do this (West, 2006; Olander et al., 2009). They are therefore more likely to choose informal mechanisms to protect their knowledge (Kitching and Blackburn, 1998; Leiponen and Byma, 2009).

The costs and complexity associated with formal methods of protection make it more likely that small firms rely upon informal protection methods such as secrecy and speed to market (Arundel, 2001; Thomä and Bizer, 2013). Arundel (2001) examines firms from seven European countries and analyses whether firm size influences the relative importance of particular knowledge-protection mechanisms. The study finds that for firms of all sizes, secrecy is considered more relevant than patents, although in the case of product innovations, the relative importance of secrecy declines with firm size. Regarding R&D intensive firms, all firms believe secrecy to be more effective than patents, but R&D intensive small and medium-sized enterprises (SMEs) attach more importance to patents than other SMEs.

In their study, Coles et al. (2003) examine small firms in the textile-design sector of the UK, Italy and the United States. Following an increase in computer-aided design and communication technologies, an increase in the speed and quality of design copying occurred. This impacted upon some sectors more than others. Coles et al. (2003) find that small firms are unable to increase their use of formal knowledge protection to address the imitation problem because they lack the resources to do so. It is suggested that the small firms that lack resources may have to adapt their protection strategies in an alternative way, for example by frequently changing designs, implementing competitive pricing policies and increasing technical complexity so that designs are difficult to copy.

In a qualitative study, Kitching and Blackburn (2003) examine how 389 small firms from four different sectors (computer software, design, electronics and mechanical engineering) exploit and protect their innovations. They find that many small firms choose not to protect their innovations in any way and that many are unaware that protection mechanisms are available to them. Small firms that do use formal protection methods to protect knowledge are identified as being the more innovative firms.

Larger firms perceive patents to be effective (Combe and Pfister, 2000; Sattler, 2003) and they attach more importance to them than smaller firms (Blind et al., 2006). Leiponen and Byma (2009) conduct an empirical study of small Finnish manufacturing and service firms. They find that patents become more relevant as firm size increases. R&D-intensive small firms and science-based small firms are identified as those firms more likely to use formal methods of knowledge protection. Other small firms use speed to market or secrecy as protection methods. In a study of Canadian firms, Hanel (2005) finds that the use of all formal protection mechanisms increases with firm size.

iii. Innovation novelty

Both the Yale I survey (Levin et al., 1987) and the Carnegie Mellon survey (Cohen et al., 2000) asked firms for the reasons why they did not use patents. One of the most common firm responses was the lack of novelty of innovations (Lopez, 2009). The degree of novelty associated with an innovation reflects the degree to which new skills, knowledge and capabilities need to be developed in order to capture the commercial value of the innovation (Laursen et al., 2013). An extremely novel (radical) innovation is likely to require significant R&D investment (Hewitt-Dundas et al., 2017) and has a significant impact upon a market and upon the economic activity of firms within that market. Such a radical or *new-to-the-market* innovation exhibits possible technological spillovers (Veugelers and Schneider, 2018), more so than less novel, *new-to-the-firm* innovation. It is therefore reasonable to expect knowledge-protection mechanisms to be more extensively used in conjunction with new-to-the-market innovation than new-to-the-firm innovation. It is also reasonable to expect formal knowledge-protection mechanisms to be used for novel, new-to-the-market innovation. The lack of novelty associated with new-to-the-firm innovation suggests that formal protection mechanisms are less likely.

Empirical studies tend to support these expectations. Thomas (2003) interviews 120 small firms in the biotechnology industry about their knowledge-protection practices. Strategies differ according to the firm's stage of innovation. Firms that took a product or service to the marketplace used patents as a protection method, whereas firms that supplied materials or services to other firms typically relied upon trade secrets. Products developed by suppliers are characterised by rapid innovation, and the use of secrecy is deemed to be sufficient in such an environment where rapid changes in knowledge occur.

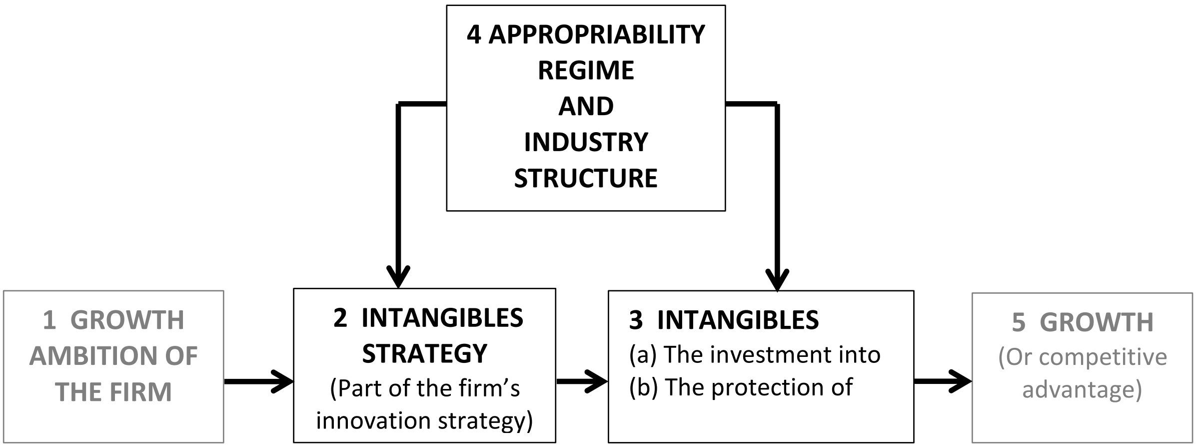
In a study of Canadian manufacturing firms, Hanel (2005) finds that new-to-the-market innovators rely more on formal protection than informal protection, although firms developing new markets are more likely to use trademarks than patents. The stage of development of an innovation may determine which knowledge-protection mechanisms a firm uses. When developing a new technology, firms are likely to use secrecy – they tend to apply for patents when taking a product to market (Hussinger, 2006).

2.3 Conceptual model and hypotheses

2.3.1 Conceptual model

The conceptual model underpinning the analysis carried out here is shown in Figure 2.1. The appropriability regime and industry structure (4) are the arrangements within the industry environment that influence or limit the choices and opportunities available to a firm. The proposed hypotheses are based upon the transmission mechanisms which exist between a firm's intangibles strategy (2 and 3) and the appropriability regime and industry structure (4) within the industry environment. The growth ambition of the firm (1), also a determinant of intangibles strategy, represents the individual firm's capacity to act independently and to make its own free choices.

Figure 2.1 Conceptual model



Innovation is an important means through which firms compete and grow (Mason et al., 2009) with many studies (for example, Geroski and Machin, 1992 and Yasuda, 2005) finding a positive effect of innovation upon growth. Intangible assets are an important strategic factor in this value creation as innovation involves the production of new knowledge through activities such as R&D, for example (Roper et al., 2008). These intangible assets are very much part of the innovation process, and therefore the strategy relating to intangible assets represents part of a firm's innovation strategy (2). From this, it follows that a firm's growth ambition (1) leads to the development of an appropriate intangibles strategy to aid innovation (2) – a strategy which incorporates decisions about the investment into and the protection of intangible assets (3).

The external environment impacts upon the firm at various stages during this growth process. Within the model, the environment – the industry appropriability regime and industry structure – impacts upon a firm's intangibles strategy by affecting firms' decisions on the investment into and the protection of such assets (3).[3] By

[3] Some empirical studies suggest a potential for reverse causation from innovation (or innovation strategy) to industry structure (see for example, Levin and Reiss, 1984, 1988; Farber, 1981). The theoretical basis lies in Schumpeter's notion of "creative destruction", where industry structure is influenced by past and current innovative success and failures. More precisely, the innovation process

building stocks of intangible assets, a firm is able to target those that provide a source of differentiation within the industry in which it operates. The firm can realise the full value of its intangible assets by internally exploiting them, and it is able to preserve their value and mitigate any associated risks by using some form of protection method.

The semi-public good characteristics of knowledge (exclusion is rarely perfect) leads to the appropriability problem (Arrow, 1962), and therefore, unless an innovator is able to protect the knowledge which it creates (3), competitors will be able to imitate an innovation without incurring the high fixed costs of creating knowledge. As a result of this, a firm's expenditure on intangible assets is not only comprised of the investment into such assets (for example, R&D, design investment, training, software development etc.) but also includes the protection of intangible assets through the use of appropriability or knowledge-protection mechanisms (for example, patents, copyrights, lead-time, secrecy etc.).

The analysis presented here investigates how the two separate elements of a firm's intangibles strategy – the investment into and the protection of intangible assets – are affected by a change in the industry appropriability-regime strength and changes in the characteristics of other elements of industry structure. It explores whether or not the two elements of a firm's intangibles strategy are driven by a particular component of the industry environment and, if they are, whether the driver(s) of each element of intangibles strategy is (are) consistent with one another.

2.3.2 Hypotheses

i. Intangibles investment

Much of the variation in intangible asset investment which exists can be explained by industry variables (Villalonga, 2004). The industry environment is the factor most recognised for affecting a firm's investment into intangible assets (Arighetti et al., 2011). For example, both the propensity to innovate within an industry and the

generates transient market power which is in turn eroded by rival innovation and imitation (Pohlmeier, 1992).

appropriability conditions within an industry help determine a firm's incentive to invest in intangible assets (Cockburn and Griliches, 1988).

Firms invest into innovation with the aim of increasing profits – they produce new products and develop more efficient processes of production (Greenhalgh and Rogers, 2007). R&D – one of the many intangible assets that a firm is able to investment into – is long considered an investment into firm knowledge. A sizeable literature exists examining the determinants of R&D investment, the majority of which focuses upon two factors: the first of these factors adopts a Schumpeterian view, focusing on the effects of firm size and market power. Here, large firms within a concentrated industry drive technological progress (Schumpeter, 1942). They exploit economies of scale in R&D and unforeseen innovations better than smaller firms. Often, large firms possess monopoly power, and this allows them to prevent imitations – giving them an incentive to innovate. Furthermore, the process of 'creative destruction' keeps these firms alert to the threat of rival and potential rival innovators. The theory proposes that these large firms use monopoly profits to engage in further productive R&D activities. Since the work of Schumpeter (1942), two suggestions have arisen as to why large firms may drive innovative progress (Symeonidis, 1996): first it is proposed that a positive relationship exists between market power and the incentive to innovate. A large market power increases the certainty that a new product will be successful and generate future profits for the firm. Firm profits in turn provide the finance required for further R&D, bypassing any issues which may be faced in gaining finance for uncertain projects, for example. Second, it is proposed that firm size and innovation are positively correlated with one another. In keeping with the thoughts of Schumpeter (1942), larger firms are viewed as being better equipped to benefit from innovation irrespective of where the innovation occurs in the firm's product range. In addition to this, larger firms are more able to finance the large fixed costs required to implement new research and are also more able to manage any risk associated with their innovations (by diversifying their innovation portfolio, for example).

The second factor which much of the determinants-of-R&D literature focuses upon includes more fundamental, industry-specific determinants of inter-industry R&D investment such as demand pull, technological opportunities and appropriability

(Barge-Gil and Lopez, 2014). The effect of industry appropriability conditions upon a firm's R&D and innovative output is not straight forward (Klevorick et al., 1995). Strong appropriability conditions enhance a firm's incentive to engage in R&D, and weak appropriability conditions lower the cost of research for other firms, effectively increasing their opportunities. When a firm invests in R&D, it is important that the firm is able to appropriate the returns to its investment so that the investment becomes worthwhile (Levin et al., 1987). However, an increased appropriability will not always lead to an increase in innovative effort more generally (Hall and Ziedonis, 2001; Bessen and Maskin, 2009; Lerner, 2009). For example, appropriable innovation may lead to a reduction in future innovation (Nelson, 2006): the higher appropriability leads to fewer spillovers, and consequently, any R&D designed to absorb such spillovers is subsequently reduced (Nelson and Winter, 1982; Cohen and Levinthal, 1989, 1990).

When competition within an industry increases, one may expect investment into R&D to be lower as firms' expected return on any investment is lower. When competition within an industry falls, the presence of market power for some firms allows them to appropriate the returns from their investments, and the higher profit which they earn allows them to finance further investment (Schumpeter, 1942). However, in a competitive environment, Schumpeter (1942) also states that in the case when rival behaviour is predictable, any uncertainty associated with excessive rivalry is reduced, increasing the incentive to invest. In contrast to the Schumpeterian viewpoint, Arrow (1962) suggests that market power is a disincentive to investment because an increase in investment displaces any economic profit that is already being earned. Scherer (1980) and Porter (1990) support the negative relationship between market power and R&D investment arguing that the lack of competitive pressures discourages innovation.

Empirical studies investigating the effects of market concentration or industry structure upon innovative behaviour do not reach a consensus. Some studies support Schumpeter's (1942) view while others, assuming perfect ex-post appropriability, find that a firm's gains from innovation at the margin are larger within an industry that is competitive ex ante rather than under monopoly conditions (Arrow, 1962).

Using an indicator of R&D (the percentage of sales that can be attributed to products developed during the last five years), Kraft (1989) conducts a cross-section analysis for 57 German firms and finds a positive relationship between product innovation and concentration (given by the inverse of the number of competitors within the industry to which the firm belongs). This result is supported by Artés (2009) who finds that market concentration positively affects the long-term decision of investing in R&D. However, market concentration is found to have no effect upon the short-term decision. Farber (1981) finds R&D increases with buyer-market concentration when the sellers' market is concentrated but may decline with buyer-market concentration when the sellers' market is less concentrated. Kathuria (1989) suggests that the effects of seller-market concentration upon R&D may be biased in an upward direction if buyer-market concentration is not controlled for. Cabral (1994) finds that market power is associated with development activities in a static framework, but in later research Cabral extends the analysis to incorporate a dynamic framework using a one-leader one-laggard model (Cabral, 2003). Results from the later research indicate that the optimal choice for leaders is to pursue safer projects and for laggards to pursue riskier projects.

Acs and Audretsch (1987) examine the characteristics of firms and their effects upon innovation in both concentrated and less concentrated industries. They find that large firms are more innovative in concentrated industries with high barriers to entry and that smaller firms are more innovative in less concentrated industries that are less mature. A similar conclusion was reached by Dorfman (1987) in a comparative study of four electronics industries.

Examining firms from two different technological opportunity groups, Rosenberg (1976) finds a weak negative relationship between market share and R&D intensity levels. Aghion et al. (2005) find an inverted relationship between product market competition and innovation. Using panel data, they develop a model where competition discourages those firms progressing slowly and lagging behind others from innovating but encourages those firms racing forward, side by side with one another, to innovate.

It is sometimes the case that measures of industry structure are statistically significant in explaining R&D intensity or innovation, but the magnitude of the effects is economically unimportant. The industry-structure effect often disappears when other industry characteristics are included within the analysis (review in Cohen and Levin, 1989).

The empirical evidence discussed above illustrates mixed findings. Results typically depend upon the underlying assumptions and focus of each study. Much of the empirical evidence fails to standardise R&D type, firm size and the definition of market power, all of which affect the R&D investment which takes place. Another reason as to why the relationship between R&D and market concentration is ambiguous is the reverse-causality relationship concentration has with many variables, for example profits and entry barriers (Kathuria, 1989). Many channels exist through which market concentration can influence R&D, and estimation results reflect the many different connections which occur simultaneously between R&D and market concentration.

Given that no consensus has been reached as to the effects of industry competitiveness upon R&D investment and innovation, it is proposed that:

Hypothesis 1a: A firm's investment into intangible assets increases when industry competitiveness increases

Hypothesis 1b: A firm's investment into intangible assets decreases when industry competitiveness increases

Empirically, evidence on the relationship between appropriability and R&D investment is inconclusive. Some studies find no statistically-significant effect of appropriability upon R&D intensity (for example, Levin et al., 1985), while others find a positive effect for some industries (for example, Mansfield, 1986). Levin et al. (1985) find R&D intensity to be greater in young industries, in those industries with a strong science base and in industries where the government makes a substantial contribution towards technological knowledge. Although statistically insignificant, the sign on the appropriability variable is as expected, and Levin et al. (1985) conclude that inter-industry variations in R&D incentives can be further explained by examining the underlying differences which exist in the technological opportunities and appropriability conditions within industries.

Mansfield (1986) conducts an empirical analysis based upon data from 100 United States (US) manufacturing firms – excluding very small firms – spanning twelve different industries. Appropriability is found to be more important for the introduction of new innovations in some industries: it is most important in the chemicals and pharmaceuticals industries, less so in the petroleum, machinery and fabricated metal products industries, and least of all in all other industries.

The industry appropriability regime (discussed in Section 2.2.3.1 above) is often thought to influence the amount of innovation expenditure undertaken by firms (Hall and Sena, 2017), a reasonable assumption given that firms invest more if they expect to appropriate the returns (Arrow, 1962). The particular appropriability regime a firm faces is determined by the nature of the technology within the industry and the knowledge-protection mechanisms that are available for the firms within the industry to use effectively. Parker (1972) and Rosenberg (1974) describe the nature of the firm's technology as an important determinant of its investment into innovative activities; firms are more likely, for example, to invest in innovative activities if natural protection against knowledge spillovers is offered to them in the form of tacit knowledge deep within their technological processes. As the technological element of an appropriability regime functions as a contingency factor significantly affecting innovation in the firm and within the industry (Cohen and Levin, 1989; Castellacci, 2007), firms facing similar technological regimes are likely to adopt similar innovation strategies (Revilla and Fernández, 2012).

The knowledge-protection mechanisms that are available for effective use by firms within a particular industry – also part of the industry appropriability regime – provide competitive firms with an incentive to innovate and invest in R&D. Arrow (1962) provides an analysis which counters the Schumpeterian (large firm/market power) theory discussed above. Knowledge protection (in the form of IP rights) allows the competitive firm to become a temporary monopolist. However, not all firms are able to take advantage of all knowledge-protection mechanisms, for example, small firms may be financially constrained and some IP rights may be ineffective in particular industries (Greenhalgh and Rogers, 2007).

Theoretically, there is no consensus within the literature over the welfare and efficiency effects of stronger knowledge-protection regimes (Park, 2005). Bessen and Maskin (2009) develop a sequential and complementary innovation in which patent protection reduces innovation and social welfare, and Takalo and Kanniainen (2000) suggest that strengthening patent rights may delay the introduction of a new technology into the market. In contrast, theoretical studies by Diwan and Rodrik (1991) and Taylor (1994) reveal that stronger IP protection may enhance global welfare and productivity.

Empirically, evidence shows that knowledge protection impacts upon R&D investment to a varying extent across different industries. Taking a sample of 27 firms from four British industries, Taylor and Silberston (1973) examine the use and effectiveness of patents. They find that 60 per cent of pharmaceutical R&D, 15 per cent of chemical R&D, 5 per cent of mechanical engineering R&D, and a negligible amount of electronics R&D is dependent upon patent protection.

Lerner (2009) examines the impact of changes in patent policy upon innovation. Significant shifts in patent policy over 150 years in 60 countries are analysed. Results show that strengthening patent protection does not have a positive impact upon innovation. This result fails to support economists’ view that incentives affect behaviour and is inconsistent with the literature which finds that stronger property rights encourage economic growth. Several reasons are suggested as to why this unexpected result is observed, including the use of an inappropriate measure of innovative output and the chosen time frame being too short.

Using data on 26 countries that established pharmaceutical patent laws during the 1978–2002 period, Qian (2007) investigates whether a country’s implementation of pharmaceutical patents stimulates domestic pharmaceutical R&D expenditure and innovation. Results show that the implementation of patent laws does not by itself stimulate innovation, but patent laws in countries with high levels of development, education, and economic freedom do stimulate innovation. This study also provides empirical support for the theory that the relationship between innovation and IP protection strength has an "inverted U" shape (Gallini, 1992; Horowitz and Lai, 1996) – there is an optimal level of IP protection, above which additional strengthening discourages innovation.

Sakakibara and Branstetter (1999) examine firm responses to the Japanese patent reforms of 1988. Results from interviews carried out suggest that the average response to the reforms, in terms of additional R&D expenditure and innovation, was small. Econometric analysis using Japanese and US patent data on 307 Japanese firms supports the interview findings that the magnitude of the response is minimal.

The most important dimensions of the industry appropriability regime – the nature of the industry technology and the means of intellectual property protection available to protect both the innovations themselves and any increased rents that flow from them (Teece, 1986, 1998, 2000a; Levin et al., 1987; Teece and Pisano, 1998) – have been found to have differing effects upon a firm's investment into R&D, and given this, it is proposed that:

Hypothesis 2a: A firm's investment into intangible assets increases when the industry appropriability regime strengthens

Hypothesis 2b: A firm's investment into intangible assets decreases when the industry appropriability regime strengthens

ii. Intangibles protection

The protection of knowledge assets and other intangibles limits imitation and helps firms to gain a competitive advantage (Teece et al., 1997). Across industries, variations exist in the manner in which firms protect their knowledge assets, mainly due to the different competitive dynamics which are present. As competition within an industry increases, one expects the use of both formal and informal knowledge-protection mechanisms to increase. By using knowledge-protection mechanisms, a firm is able to guard itself against imitation threats and appropriate the returns from its innovations – the firm becomes a temporary monopolist (Arrow, 1962). The degree of industry competitiveness may therefore impact upon firms' intangibles protection strategies. For example, if a monopolist were to control the market, it would be inefficient for other firms within the industry to use costly protection methods (Granstrand, 1999). The knowledge-protection mechanisms firms choose differ across competitive environments as the pool of available knowledge and innovation, as well as the networking opportunities which exist within an industry, also differ across competitive environments. Different industry environments also have different information and knowledge structures in terms of the degree of codification, complexity and observability of knowledge which exists. Given this, it is expected that:

Hypothesis 3: A firm's intangibles protection (use of knowledge-protection mechanisms) increases when industry competitiveness increases

The appropriability regime within an industry's environment and the IP laws which prevail within a country also impact upon a firm's intangibles protection strategy. For example, effective patent protection requires adequate patent laws and the enforcement of these laws by a governing body (Teece, 1986, 2006; Granstrand, 2006).

Across industrial sectors, the competitive strategies available to firms differ (Kaniovski and Peneder, 2002). The different technological characteristics which exist across industries help determine the knowledge-protection mechanisms that are applicable within each industry. For example, differences exist in the value of patents to firms in different industries (Levin et al., 1987; Harabi, 1995) and in how they are rated by firms (Granstrand, 1999) as a means of appropriating investments in innovation. Empirically, the effectiveness of patents in preventing imitation has been shown to vary across industrial sectors. In a study of Swiss firms for example, Harabi (1995) finds that patents are effective in the chemicals (including drugs) industry and occasionally in the machinery and electronics industries.

In sectors which produce complex products that are costly to copy, or where barriers to entry are created by high investment costs and expertise levels, for example in the aerospace industry, lead-time advantages and technical complexity are relatively more important than patents as methods of knowledge protection (Arundel and Kabla, 1998). However, firms in a complex product environment are more likely to patent; high-technology firms have a higher propensity to patent than low-technology firms (Brouwer and Kleinknecht, 1999). Firms using complex technologies may also require the use of more complex strategies as technological complexity affects the requirements in terms of intangible-asset management. For example, firms using complex technologies may require the use of various types of licensing strategies to enable the freedom to operate (Cohen et al., 2000; Hall and Ziedonis, 2001; Teece, 2009). In sectors where standards are important, for example, the telecommunications industry, the possibility of reaching a strong position in the standard by patenting essential inventions is an important motive to patent (Granstrand, 1999; Bekkers et al., 2002).

Coles et al. (2003) identify that the nature of the technology – one dimension of the industry appropriability regime – affects firms' protection strategies. Small and medium-sized enterprises (SMEs) in the textile-design sector of the UK, Italy and the US are examined. An increase in computer-aided design and communication technologies has increased the speed and quality of design copying, and this has impacted upon some sectors more than others. As enforcing protection may be problematic for some SMEs due to limited resources, the study concludes that SMEs need to be able to adapt their protection strategies in response to the problem; for example, they may need to frequently change designs, implement competitive pricing policies and increase technical complexity so that designs are difficult to copy. Leiponen and Byma (2009) conduct an empirical study of 504 small, Finnish manufacturing and service firms in order to identify firms' most-used mechanisms for protecting innovations. Findings suggest that R&D-intensive firms and science-based firms are more likely to use formal methods of innovation protection. Other firms are more likely to use speed-to-market or secrecy to protect their innovations.

Davis (2006) identifies considerable sectoral differences in the role and strategic value of patents. Some industries, for example telecommunications, are characterised by a "cumulative systems" technology where firms are mutually dependent upon access to each other's ideas or inventions. Firms apply for patents and then cross-license them to each other. In this case, the function of the patent is not to exclude others but to coordinate access to knowledge. In other sectors, for example the software industry, appropriating returns from R&D investments can be difficult. For instance, it is possible to perfectly reproduce digital information goods and distribute them easily via the internet (Shapiro and Varian, 1999). Instead, firms in such sectors can choose to appropriate returns by means such as secrecy or lead-time advantage (being first to take a new program to the market). In contrast, in the pharmaceutical-related biotechnology industry, patents are seen as the best means to appropriate returns from R&D investments (Davis, 2006). Products have a long development time and equipment and production facilities are costly. Patent protection is effectively used to ensure imitation is deterred; in such sectors, the cost of copying an innovation is considerably less than the initial cost of invention (Arundel and Kabla, 1998).

The distinction has also been made between the service and manufacturing sectors (Miles and Boden, 2000) in relation to the use of knowledge-protection mechanisms. Services are intangible in nature and innovation and appropriability conditions are different to those within the manufacturing sector. Thoma and Bizer (2013) examine small firms using German Community Innovation Survey (CIS) data, and they find that the specific firm context i.e. the type of innovator, the degree of innovativeness and the general industry conditions determine the importance of appropriation protection to the firm.

Firms' protection strategies differ across product and process innovations. Patents are typically more effective for product innovations than for process innovations (Levin et al., 1987; Granstrand, 1999) so that product innovations rather than process innovations tend to be protected by patents (Arundel and Kabla, 1998; Brouwer and Kleinknecht, 1999; Granstrand, 1999). Products released into the marketplace may be subject to reverse engineering and benefit from formal protection mechanisms, whereas processes can effectively be kept within the firm and protected with trade secrets, for example (Harabi, 1995). Levin et al. (1987) provide an early empirical study of different protection methods that supports this argument. In a survey of 650 individuals representing 130 business sub-sectors in the US, the effectiveness of alternative means of protecting new or improved products and processes is examined. Findings suggest that patents are more effective than secrecy for new products and secrecy is more effective for new processes. However, sales or service efforts, lead-time, and learning are found to be more effective than both patents and secrecy.

Grindley and Teece (1997) examine the use of licensing in the semiconductor and electronics industries. They find that the use of legal protection differs across industries due to regulatory and legal distortions. Firms in the semiconductor and electronics industries had previously been deterred from using legal protection by courts forcing them to license their technologies below market value. Once distortions in legal regimes are removed, firms realise the value of legal protection and its importance to success. Evolving legal protection regimes may therefore lead to differences in firms' intangibles protection strategies.

Hurmelinna-Laukkanen and Puumalainen (2007a) conduct a survey of 299 small Finnish companies, across nine different sectors. The role, availability, strength and efficiency of appropriability mechanisms are determined. The appropriability regime is found to be dynamic in nature with the availability and strength of protection mechanisms determining their usage. The study suggests that parallel strategies exist within firms, and that different appropriability mechanisms are used at different stages of the product or process life cycle. It is also suggested that some protection methods are difficult to implement in certain knowledge-intensive industries due to the legal restrictions which are in place. The availability, efficacy (i.e. the capacity to prevent imitation) and efficiency of different knowledge-protection mechanisms are analysed in order to examine the strength of the appropriability regime. The availability and efficacy are to a large extent 'given' within an industry, but there are some 'chosen' determinants of the regime, for example, firm goals and decisions (based upon the perceived efficiency of the mechanisms). The study suggests that the nature of the technology and the innovation itself largely define the ways in which the innovation can be protected.

Many of the factors in the literature discussed above are encompassed in the two dimensions of the industry appropriability regime. Evidence shows that the nature of the industry technology (for example, a technology characterised by tacit knowledge embedded deep within the production process) and the availability of effective knowledge-protection mechanisms together affect a firm's intangibles-protection strategy. Low usage of both formal and informal protection mechanisms across an industry contributes towards a weak appropriability regime, whereas high usage of protection mechanisms contributes towards a strong appropriability regime, and a technology characterised by tacit knowledge contributes towards a strong appropriability regime, whereas a technology characterised by codified knowledge contributes towards a weak appropriability regime.

The literature indicates that firms are more likely to use knowledge-protection mechanisms if they are faced with a strong appropriability regime in their industry as given by the knowledge-protection dimension of the appropriability regime, and more likely to use knowledge-protection mechanisms if they are faced with a weak appropriability regime in their industry as given by the nature of technology dimension of the appropriability regime (see for example Coles et al., 2003). In this way, the industry appropriability regime sets limits on a firm's intangibles knowledge-protection strategy and helps determine the knowledge-protection mechanisms that are used within an industry and whether they will be used at all. Given this, it is proposed that:

Hypothesis 4a: A firm's intangibles protection (use of knowledge-protection mechanisms) increases when the 'nature of technology' dimension of the industry appropriability regime weakens

Hypothesis 4b: A firm's intangibles protection (use of knowledge-protection mechanisms) increases when the knowledge-protection dimension of the industry appropriability regime strengthens

2.4 Data and methods

2.4.1 Data

The empirical analysis in the present study is based upon five waves of the UK Community Innovation Survey (CIS) covering the period 2002 to 2012 (CIS4 to CIS8) and data from the Business Structure Database (BSD) covering the period 1997 to 2012.

2.4.1.1 The UK Community Innovation Survey (CIS)

The first data source, the UK CIS, represents the main source of innovation data in the UK and Europe, providing detailed information on firms' innovation activity; it is a data source widely used by innovation researchers (see for example, Laursen and Salter, 2005; Love et al., 2010; Hall and Sena, 2017).

The UK CIS is based upon a core questionnaire developed by the European Commission (Eurostat) and Member States, and forms part of a wider CIS covering European countries – the European Union Community Innovation Survey. Background and motivation for the UK's innovation survey can be found in the Organisation for Economic Cooperation and Development's (OECD) Oslo manual (OECD, 2005), along with a description of the type of questions and definitions used. In the UK, the Office for National Statistics (ONS) – the UK official government statistical office – manages the administration of and data collection for the UK CIS.

The UK CIS is conducted every two years by means of a postal questionnaire and follow-up telephone interviews. The surveys are non-compulsory and, for the waves analysed here, achieved a response rate ranging between 51 per cent in 2012 (CIS 8) and 58 per cent in 2004 (CIS 4)[4]. The UK surveys provide detailed information on firms' innovation activity, an indication of the objectives of firms' innovation activity and their external innovation connections. Questions relating to firm size and structure, customer base, firm product and process innovation activity, the sources of innovation, perceived barriers to innovation, the levels of public support and basic economic information about the firm are included. The surveys contain up to approximately 16,000 firms with 10 or more employees. The data is designed to be statistically representative of the 12 regions of the UK, most industrial sectors and all sizes of firms. The sampling frame is taken from the Inter-departmental Business Register (IDBR), a UK-Government compiled register of all UK businesses based on tax and payroll records.

2.4.1.2 The Business Structure Database (BSD)

The second data source used in the empirical analysis is the BSD. The BSD is derived primarily from the IDBR, which is a live register of data collected by Her Majesty's Revenue and Customs via Value Added Tax (VAT) and Pay As You Earn (PAYE) records. In 2004 it was estimated that businesses listed on the IDBR

[4] See: https://www.gov.uk/government/collections/community-innovation-survey

accounted for almost 99 per cent of economic activity in the UK. Only very small businesses, such as the self-employed, are not listed. The BSD represents the IDBR at one particular moment in time and provides a version of the IDBR for research use. The reporting period is the financial year, and there are up to approximately 5.5 million firms included. The dataset contains a small number of variables for almost all UK firms, and these include employment, turnover, foreign ownership, Standard Industrial Classification (SIC) codes, start-up dates and termination dates.

2.4.1.3 Dependent variables

Using the CIS, two groups of dependent variables are defined which relate to a firm's intangibles strategy. The first group relates to a firm's *investment into intangible assets* and the second group relates to a firm's *protection of intangible assets*.

i. Investment into intangible assets

Corrado et al. (2006) divide intangible investment into three main types: computerised information, innovative property and economic competencies. Computerised information is investment that involves loading information into computers to make them more useful (Haskel and Westlake, 2018). Examples of computerised information include software and databases. Databases have become relatively more important in recent years following the growth of big data in the technology sector. Innovative property includes R&D (scientific-oriented spending) and other types of product and service development that do not rely upon science and technology. These include design and other forms of creation and discovery (for example, prospecting for oil) (Haskel and Westlake, 2018). Economic competencies are other investments which do not directly involve innovation or computers. This includes marketing and branding (investment in understanding customers' needs, for example), organisational capital (the creation of business models or corporate cultures, for example) and firm-specific training. Although thought of as intangible investment, economic competencies and design (part of innovative property) are not treated as investments in National Accounts (Corrado et al., 2013).

The first group of dependent variables – *firms' investment into intangible assets* – uses CIS data signalling firms' innovation activities. In the CIS surveys, the following question is asked, 'Did your enterprise engage in the following innovation-related activities / Did this business invest in any of the following, for the purposes of current or future innovation?' Four innovation activities listed in the surveys represent intangible investment as defined in Carrado (2006) – R&D, design, training, and computer software. Response data is binary indicating whether or not investment took place during the period. The intangibles investment dependent variables are constructed as follows:

a. *R&D* – The surveys examine both intramural and extramural investment into R&D, but for the purpose of this study, a firm is assumed to have made an R&D investment if either intramural or extramural investment has taken place during the period. R&D investment data from all five CIS waves is used in the analysis. The R&D dependent variable is set equal to one if investment took place and zero otherwise. The use of R&D data here is consistent with Webster and Jensen (2006) who also use R&D data to investigate intangible investments.

b. *Design* – The CIS question relating to design investment varies across the CIS waves. For the CIS 4 to CIS 6 surveys (2002 to 2008), the question relates to expenditure on design for the development or implementation of new or improved goods, services or processes. In CIS 7 and CIS 8 (2008 to 2012), design investment includes strategic design activities. For this reason, analysis of design investment is carried out in two parts, CIS 4 to CIS 6 and CIS 7 to CIS 8. The design dependent variables are set equal to one if investment took place and zero otherwise.

c. *Training* – Training investment in the CIS surveys relates to internal or external training which took place specifically for the development and/or introduction of innovations. Training investment data from all five CIS waves is used in the analysis. The training dependent variable is set equal to one if investment took place and zero otherwise.

d. *Computer software* – The acquisition of computer software is addressed in CIS 5 to CIS 8 (2004 to 2012), and this data is used in the analysis. In CIS 4, the question relating to the acquisition of computer software is combined with the acquisition of machinery and equipment, and therefore data from this CIS wave is not used. The computer-software dependent variable is set equal to one if investment took place and zero otherwise.

ii. Protection of intangible assets

The different forms of knowledge-protection mechanisms that can be used to protect innovation and the returns which flow from them are discussed in Section 2.2.3.1 above. Formal, legally enforceable, protection mechanisms typically include registered rights such as patents, design rights and trademarks and unregistered rights such as copyright whereas informal protection mechanisms such as secrecy, complexity of design and lead-time on competitors are not based directly on regulated structures and statutory enforcement possibilities (Hurmelinna-Laukkanen, 2014).

The second set of dependent variables in the analysis undertaken here relates to *firms' protection of intangible assets*. In CIS 4 and CIS 5 the firm is asked, 'Please indicate the *importance* to your enterprise of each of the following methods to protect innovations'. Responses to this question are subjective and reflect the manager's viewpoint as to how important he/she thinks each of the protection mechanisms were to innovation carried out during the previous three-year period. In addition, the response may reflect knowledge-protection mechanisms which were obtained by the firm more than three years ago and used to protect innovation carried out during the survey period as well as knowledge-protection mechanisms newly initiated during the survey period.

Firms are asked to indicate the importance of eight different protection mechanisms. Formal protection mechanisms as defined above include registration of design, trademarks, patents, confidentiality agreements and copyright, and informal protection mechanisms as defined above include secrecy, complexity of design and lead time. Respondents are able to choose their response from four possible answers – not used (0), low importance (1), medium importance (2), high importance (3). The number in parentheses represents the value assigned in the datasets. This data form thus gives rise to an ordered-categorical dependent variable.

In CIS 6 and CIS 7, the question relating to the protection of knowledge asks, ‘Did this business apply for a patent, register an industrial design, register a trademark…?’ etc. Formal protection mechanisms listed include patents, industrial design, trademarks and copyright; these are included in both CIS 6 and CIS 7. Informal protection mechanisms listed include secrecy, complexity of design and lead time; these are included in CIS 7 alone. This data provides a binary dependent variable, set equal to one if new protection took place during the survey period and zero otherwise.

2.4.1.4 Independent variables

i. The industry appropriability regime

The first group of independent variables in the analysis represent the industry appropriability regime. The nature of the industry technology (for example, whether firms undertake product or process innovations and/or whether knowledge is tacit or codified) and the means of knowledge protection used to protect both the innovations themselves and any increased rents which flow from them are two important dimensions of the industry appropriability regime (Teece, 1986, 1998, 2000a; Levin et al., 1987; Teece and Pisano, 1998). The appropriability regime is part of an industry’s environment, and its measure is created here using industry averages of the firm-level data. Averages of firm-level data are often used to represent industry variables. For example, in their study on informal and formal co-operations for innovation, Bonte and Keilbach (2005) compute an industry-level legal-appropriation variable using the mean score of firm-level data, Laursen and Salter (2014) create an industry variable using averages of their firm-level importance-of-appropriability measure in order to investigate the effects of inter-industry differences in appropriability regimes on the breadth of external search and formal collaboration for innovation, Hall and Sena (2017) create industry appropriability variables using binary firm-level data averaged over industries, and, although not subject related, Hansen and Wernerfelt (1989) in their study on the determinants of firm performance, define industry profitability as a sales weighted average of firm-level return.

In order to create the industry appropriability-regime measures, firms in the pooled CIS dataset are sorted into thirteen industry groups according to their five-digit UK

Standard Industrial Classification code in 2003 (SIC 2003). Six industry-level measures are formulated for each industry group using data from the pooled CIS dataset; the six measures represent the different dimensions of the industry appropriability regime.

Of these six measures, four reflect the *nature of technology* within each industry group:

a. The first variable indicating the nature of the technology within the industry is a firm's average propensity to be a product innovator (given its industry group), and this is calculated using the binary data indicating whether or not a firm is a product innovator. The average of the firm-level responses within each industry group is calculated. This calculated value represents the *average propensity for a firm to be a product innovator within its industry group*.

b. The second variable reflecting the nature of the technology within an industry is a firm's average propensity to be a process innovator (given its industry group). This is calculated in a similar way to the firm's average propensity to be a product innovator. Binary data indicating whether or not a firm is a process innovator is averaged across each industry group. This calculated average represents the *average propensity for a firm to be a process innovator within its industry group*.

In order to identify whether knowledge is tacit or codified within an industry group, firm-level data obtained from the question, 'How important to your firm's innovation activities were each of the following information sources?' is used. Two of the sources listed are, 'Scientific journals and trade/technical publications' and 'Technical, industry or service standards'. If firms identify these sources as being of medium or high importance to the firm's innovations, knowledge is assumed to be more codified, and if these sources are not used or of low importance, knowledge is assumed to be more tacit. Two further variables representing the nature of the technology within an industry group are created using this information.

c. A firm-level binary variable (for scientific journals and trade/technical publications) is created using all five CIS waves. The variable is set equal to one if the source is of medium or high importance to firm innovations and set equal to zero if it is not used or of low importance.

Using this data, a further variable indicating the nature of the technology in the industry is created by calculating the average of the firm-level binary data for each industry. These average values represent the *average propensity for firms to view scientific journals and trade/technical publications as being of medium or high importance to firm innovations within the industry group.*

d. A firm-level binary variable (for technical, industry or service standards) is created using all five CIS waves. The variable is set equal to one if the source is of medium or high importance to firm innovations and set equal to zero if it is not used or of low importance.

Using this data, a further variable indicating the nature of the technology in the industry is created by calculating the average of the firm-level binary data for each industry. These average values represent the *average propensity for firms to view technical, industry or service standards as being of medium or high importance to firm innovations within the industry group.*

The two variables created in *c* and *d* above are an indication of the average propensity for firm knowledge to be codified within the industry group.

The remaining two measures represent the knowledge-protection dimension of the industry appropriability regime i.e. the available, effective knowledge-protection mechanisms within the industry. CIS 4 to CIS 7 are used to create the industry-level protection measures despite the questions relating to knowledge protection being different across CIS waves. As mentioned above in Section 2.4.1.3, the question in CIS 4 and CIS 5 asks about the *importance* of the various protection mechanisms to the firm's innovations, whereas the question in CIS 6 and CIS 7 asks about *new protection* that has taken place during the survey period:

e. First, using CIS 4 and CIS 5 data, a formal-importance binary variable is created and set equal to one if any of the formal mechanisms of knowledge protection is of medium or high importance and zero otherwise. The average of this variable is calculated for each industry group, and an industry-level average formal-importance variable is created for the entire CIS 4 to CIS 8 period using this data. If no observations exist in CIS 4 and CIS 5 for a particular industry group, the overall sample average is used.

Second, using CIS 6 and CIS 7, a formal-new-protection binary variable is created and set equal to one if any new formal protection took place during the survey period and zero otherwise. The average of this variable is calculated for each industry group, and an industry-level formal-new-protection variable is created for the entire CIS 4 to CIS 8 dataset. Again, the whole-sample average is used if no observations exist for a particular industry group within the CIS 6 and CIS 7 data.

An industry-level formal-protection variable is created by averaging the industry-level formal-importance variable and the industry-level formal-new-protection variable. This variable represents the *average propensity for firms to use formal knowledge protection or to view formal knowledge protection as being important within an industry.* It is an indication of the available and effective formal knowledge-protection mechanisms within the industry group.

f. Third, using CIS 4 and CIS 5, an informal-importance binary variable is created and set equal to one if any of the informal mechanisms is of medium or high importance and zero otherwise. The average of this variable is calculated for each industry group and an industry-level informal-importance variable is created for the entire CIS 4 to CIS 8 period. If no observations exist for a particular industry group in CIS 4 or CIS 5, the overall sample average is used.

Fourth, using CIS 7, an informal-new-protection binary variable is created and set equal to one if any informal new protection took place during the survey period and zero otherwise (new informal protection data is only available in CIS 7). The average of this variable is calculated for each industry group and an industry-level informal-new-protection variable is created for the entire CIS 4 to CIS 8 period. Again, a whole-sample average is used if there are no observations for a particular industry group in the CIS 7 data.

An industry-level informal-protection variable is created by averaging the industry-level informal-importance variable and the industry-level informal-new-protection variable. This variable represents the *average propensity for firms to use informal knowledge protection or to view informal knowledge protection as being important within an industry.* It is an indication of the available and effective informal knowledge-protection mechanisms within the industry group.

ii. Industry structure

The second group of independent variables represent *industry structure* in the model. Drawing on the structure-conduct-performance paradigm and Porter's five-competitive forces framework (Porter, 1980) discussed in Section 2.2.2.1 above, the two industry-structure independent variables represent three of the underlying sources of competitive pressure which their strategies depend upon: the threat of new entrants, the threat of substitute products or services and the threat of established rivals i.e. the competitive forces which arise from horizontal competition. The model assumes that firms plan for and respond to these competitive forces so that their strategies take advantage of any opportunities which exist as well as addressing any threats which exist within the industry environment.

Typically, industry structure is summarised by the number of firms or some other measure of the distribution of firms, such as the relative market shares of the largest firms (Perloff et. al., 2007). In the present study, the concentration ratio – the first industry structure variable – is used to represent the competitive forces coming from established rivals as well as competitive forces coming from the threat of substitute products or services.

The most commonly used methods in determining industry structures are the Concentration Ratio and the Herfindahl-Hirschman Index (HHI).[5] The Concentration Ratio represents the sum of market shares of the *n* largest firms, where *n* is typically 3, 4 or 5 or 8. Its calculation is relatively easy, and some countries' statistics provide these statistics directly. However, this measure does not take into account the size distribution within the top *n* firms and the size distribution of the firms outside the *n* firms. Therefore, it may only provide a very rough idea of the competition level (Du and Chen, 2010). The HHI is equal to the sum of each firm's market share squared. It has a maximum value equal to 1 (or 10,000), and it declines as the number of firms increases. In a market where the number of firms is given, HHI is at its minimum when all firms are of equal size, and it increases with increasing variance of market shares. The HHI reflects number and size distribution of firms as well as concentration.

A large body of empirical literature uses the Concentration Ratio and the HHI as measures of market concentration: for example, both measures are used by Shukla and Thampy (2011) to investigate competition and market power in the wholesale electricity market in India; the concentration ratio is used by Roder et al. (2000) to represent market structure in their study investigating the determinants of product introductions in the US food industry, and by Ab-Rahim and Chiang (2016) to examine the relationship between the market structure and the financial performance of Malaysian commercial banks. Following these studies, the present analysis uses the five-firm concentration ratio to represent market structure and the competitive forces which exist within the industry.[6]

First, the *five-firm concentration ratio* is calculated for each industry group (the share of industry sales accounted for by the five largest firms). This measure provides information about the relative distribution of market shares between the top five and the remaining firms, but does not provide information about changes in distribution within these groups. The industry concentration ratio lies between zero and one hundred per cent. In an industry with a large number of firms operating

[5] Other measures of market concentration include the Hannah and Kay Index and the Gini Coefficient.
[6] A HHI was also constructed and used in the early stages of the analysis. The performance of the five-firm concentration ratio was superior to that of the HHI, and the decision was taken to remove the HHI from the analysis.

with small market shares, the concentration ratio will be low. Those firms producing homogeneous products have little market power and the industry operates close to a situation of perfect competition. As the degree of market power and concentration increases within an industry, the market tends towards one of oligopoly or monopoly. The level of competition within the industry is therefore given by the concentration ratio variable.

Using the pooled BSD dataset (1997 to 2012) and the five-digit SIC 2003 codes, total turnover for each of the thirteen industry groups is calculated by summing the individual-firm turnover values. This is repeated for all years which correspond with the CIS 4 to CIS 8 surveys. Each firm's market share is then calculated for each of the years. For each year, the five largest market shares within each industry group are summed. These summed values represent the concentration ratios for each industry group within each year. Using these values, a concentration-ratio variable is created for the CIS 4 to CIS 8 pooled dataset.

So as not to overemphasise the role of concentration, an additional dimension of market competition structure is included in the analysis. Other dimensions, such as entry barriers and product differentiation, are often overlooked in empirical work due to the difficulty in obtaining an appropriate empirical measure. In an attempt to overcome these shortcomings, a measure of market entry is included in the analysis. There are many studies detailing the effects of firm entry on competitiveness and market structure (see for example, Bresnahan and Reiss, 1990; Geroski, 1989). In the present study, the industry *birth rate* is used as an indication to the number of new entrants in a market. The industry birth rate represents competitive forces coming from the threat of new entrants and the threat of substitute products or services. A higher birth rate may also indicate lower barriers to entry to the industry. As the birth rate increases and the level of competition within the industry increases, economic rents and competitive advantages may be eroded away.

New entrants within an industry group are calculated using firm birth dates available in the pooled BSD dataset. The number of firms born in each of the thirteen industry groups in each year between 2002 and 2012 is calculated. Values are summed to calculate the total number of firms born within each industry group during each CIS wave (three-year period). Next, the total number of firms within each industry group during each CIS wave is calculated from the pooled BSD dataset. Using this information, a birth rate for each industry group and for each CIS wave is calculated.

2.4.1.5 Control variables

A series of firm-level independent variables are included as control variables. These are factors other than the industry appropriability regime and industry structure which may impact upon a firm's intangibles strategy.

i. Log of total employment

Following Schumpeterian practice, the log of total employment is included to reflect the scale of firms' resources. Empirically, studies testing the Schumpeterian hypothesis regarding the advantages of firm size for R&D and innovative activity have not reached a consensus, although a number of stylised facts have emerged (Cohen and Klepper, 1996). There are several reasons as to why a positive relationship may exist between firm size and R&D investment. Firstly, smaller firms face financial constraints that limit R&D expenditure, whereas larger firms have more internal funds available. Secondly, R&D is subject to a minimum project size and this prevents smaller firms from undertaking such investments (Galbraith, 1952). Thirdly, larger investments are more profitable for larger firms due to the existence of economies of scale. Fourthly, economies of scope, in terms of the availability of complementary assets, gives larger firms an advantage over smaller firms (Cohen and Levin, 1989), and finally, R&D investment involves risk taking. Larger firms are more able to mitigate these risks over different projects, whereas smaller firms typically focus on one or a few projects (Rammer et al., 2009). These arguments supporting the positive relationship between firm size and R&D investment are based upon assumptions relating to the nature and size of transaction costs; these assumptions are rarely tested Cohen et al. (1987). A series of arguments also exist in support of smaller firms investing relatively more in R&D than larger firms. These include smaller firms being more efficient in performing R&D activities due to the managerial control that exists within their organisations (Holmstrom, 1989) and individuals in smaller firms being incentivised more due to there being a higher number of possibilities to benefit from the results of their work (Cohen and Levin, 1989).

The protection of intangible assets also differs across large and small firms (Arundel and Kabla, 1998; Kitching and Blackburn, 1998; Brouwer and Kleinknecht, 1999; Davis, 2006). There is a relatively low usage of formal protection mechanisms in SMEs compared with larger firms. Larger firms invest in more of all forms of protection of innovation; 2.1 per cent of small firms protected an innovation with a patent during the 2008 to 2010 period, compared with 6.3 per cent of large firms (Hargreaves, 2011). SMEs view the use of formal mechanisms as a complex process. Owner-managers of small firms lack the knowledge and information required to pursue such protection. They are reluctant to adopt formal mechanisms because they perceive protection-related costs (both money and time) to be high (for example, dealing with patent offices and patent lawyers and gaining the knowledge/skills needed to enforce protection). Administering and enforcing protection is problematic for SMEs, especially when they are in dispute with larger firms. In practice, SMEs rely more on informal methods of protection (maintaining a lead-time advantage, trust and secrecy, for example).

ii. Graduate skills

The level of graduate skills within a firm is introduced as two control variables – the proportion of science and engineering graduates and the proportion of other graduates. These variables reflect the strength of human capital, and they are expected to be positively related to innovation activity (Freel, 2005; Leiponen, 2005).

iii. Exporter

A binary export variable, indicating whether or not a firm exports, is the fourth control variable capturing any benefit firms derive from selling in international markets. Previous studies have linked exporting and innovative activity through both competition and learning effects (Love and Roper, 2013).

iv. Co-operator

A binary innovation-co-operation variable, indicating whether or not a firm co-operates on any innovation activities, is the fifth control variable. Chesborough (2003) suggests that engaging in open innovation widens the innovation opportunities available to the firm. Firms can use internal and external ideas to advance their technology. Deliberately importing and exporting knowledge may promote innovative activity. Firms make use of innovative processes, products and IP from other companies and through partnerships and licensing etc., external parties can make use of firms' internal assets. The greater the number of external relationships and the more varied these relationships are, the greater the probability of gaining useful knowledge from outside the firm (Leiponen and Helfat, 2010). Empirical evidence also suggests that any knowledge gained is likely to be complementary with a firm's internal knowledge (Roper et al., 2008). Through co-operation, firms find new ways of sharing new and existing knowledge, and the extent to which a firm engages in open innovation impacts upon its intangibles strategy. Peeters and van Pottelsberghe (2006) identify that a firm's appropriation strategy depends upon the extent to which it enters into collaborative R&D, and Laursen and Salter (2014) look at how a firm's attitude towards appropriability is associated with the openness of the firm to external factors. They show that 'firm-level choices concerning the strength of appropriability strategy are connected to firms' relationships to external actors in the innovation system' (Laursen and Salter, 2014, p.876), although they do not make any claims about causality.

v. Public support

Finally, a binary public-support variable, indicating whether or not a firm has received any financial support for innovation activities from local or regional authorities, central government or the European Union, is included as a control. Unfortunately, this data is unavailable for CIS 5 and CIS 8. It is expected that public support has a positive effect on innovation activity (Hewitt-Dundas and Roper 2009). Other studies examining the effectiveness of various forms of public support for R&D and innovation have generally found positive effects in terms of the scale of private R&D investments and innovation outputs (Hsu et al., 2009; Luukkonen, 2000).

To control for any temporal effects on the dependent variable, wave dummies are included in each model. The industry-level independent variables within the models are assumed to summarise the effects of all industry-level variables, and for this reason, sectoral dummies are excluded. Inclusion would lead to misspecification of the models (Hansen and Wernerfelt, 1989).

2.4.2 Estimation method

The empirical approaches adopted here reflect the nature of the dependent variables being investigated. Two different types of model are estimated. The first – a probit model – is used to analyse firms' intangibles investment and protection. Firms choose to invest or not to invest and they choose to protect or not to protect. The data is coded as a zero or a one, and the probit estimation procedure models the probability that the dependent variable will be equal to one i.e. it models the probability that intangibles investment or protection will take place. The probit models are estimated using the maximum likelihood method, a method which is always consistent and efficient. In order to use this method, it is assumed that the errors are normally distributed: the probit model is the cumulative distribution function of the standard normal distribution.

The second model – an ordered-probit model – is used to analyse the *importance* firms attach to intangibles protection. The ordered-probit estimation method is a generalisation of the probit analysis to the case where more than two outcomes of an ordinal dependent variable exist. Firms indicate the importance to their business of various protection methods for innovation. Data is coded as a 0 (not important), 1 (low importance), 2 (medium importance) or a 3 (high importance) resulting in an ordered categorical dependent variable. As the categories are rankings and the difference between different outcomes may not be uniform, it is difficult to interpret the response data. Prediction with the ordered probit model is more complex than with the probit model as, in this case, there are four possible predicted probabilities (i.e. the number of possible values of the dependent variable). As with the probit model, the errors are assumed to be normally distributed.

The standard probit model assumes homoscedasticity (a constant error variance), a necessary characteristic to be able to give the estimation results a counterfactual interpretation. As industry differences are expected to be present in the estimation data, heteroscedasticity (a non-constant error variance) is likely to be present. In the presence of heteroscedasticity, the maximum likelihood estimation of the parameters of a standard probit model (homoscedastic model) lead to incorrect standard errors and biased and inconsistent parameters (Yatchew and Griliches, 1985). The solution is to estimate a heteroscedastic probit model that allows the error variance to depend upon some of the predictors in the regression model. First, the heteroscedastic probit model tests if there is heteroscedasticity, and second, it makes an adjustment by relaxing the assumption that the error distribution of the latent model has a unit variance. For each probit model, both the homoscedastic and heteroscedastic estimation results are obtained with the error variance in the heteroscedastic models being allowed to depend upon the industry-level variables (i.e. the appropriability regime, the five-firm concentration ratio and the birth rate).

Unfortunately, many of the variables representing the industry appropriability regime are highly correlated with one another leading to multicollinearity problems. Therefore it is not possible to examine their impact upon intangibles strategy in the same estimated equation. As a solution, each element of the industry appropriability regime is analysed separately. This method has been used by other researchers when faced with a similar issue (see for example Hall and Sena (2017) who estimated separate productivity equations when faced with process and product innovation probabilities that were highly correlated with one another).

2.5 Results

2.5.1 Descriptive statistics

Descriptive statistics and correlation coefficients are given in Tables 2.1 to 2.6. Section 2.2.4.1 above discusses firms' choices of formal and informal protection mechanisms and details how they differ across sectors and industries (due to the presence of tacit or codified knowledge, product and process technologies and the industry appropriability regime, for example) (Levin et al., 1987; Cohen et al., 2000), across firms (due to resources and capabilities, for example) (Lopez, 2009; Hall et al., 2014), and across innovations according to the degree of novelty of the innovation (Hanel, 2005). CIS 2008 to 2010 provides data on firms' actual knowledge protection choices during the three-year survey period. Table 2.1 shows the use of formal knowledge-protection mechanisms (patents, registered industrial designs, registered trademarks and copyright) and informal knowledge-protection mechanisms (secrecy – including non-disclosure agreements, complexity of design and lead-time advantage) within different groups of innovating firms. Levin et al.

(1987) and Cohen et al. (2000) identify secrecy as being an important knowledge-protection mechanism across all innovators, and the data here supports this finding as secrecy (including non-disclosure agreements) is the most used knowledge-protection mechanism within each innovator group. The highest values are experienced in the new-to-the-market, high-technology/knowledge-intensive and manufacturing groups with 36.3 per cent, 35.4 per cent and 34.0 per cent of firms respectively using secrecy (including non-disclosure agreements) to protect innovations during the 2008 to 2010 period. The lowest values are in the low-technology/less knowledge-intensive and the new-to-the-firm group: 20.2 per cent and 22.0 per cent of firms respectively use secrecy to protect innovations during the three-year period.

Registered trademarks are the second most popular knowledge-protection mechanism used by all innovators in the UK CIS 2008 to 2010 (14.7 per cent of firms). Trademarks are also the second most popular knowledge-protection mechanism for five of the individual innovator groups (new-to-the-firm, medium-sized, large-sized, low-technology/less knowledge-intensive and service-sector innovators). For three of the remaining four innovator groups (new-to-the-market, high-technology/knowledge-intensive and manufacturing-sector innovators), patents are the second most popular knowledge-protection mechanism: 22.8 per cent, 15.8 per cent and 20.2 percent of firms respectively use patents to protect innovations. Previous studies (for example, Levin et al., 1987; Harabi, 1995; Cohen et al., 2000) find patents to be an important protection mechanism for firms in the pharmaceutical and chemical industries. The data here is consistent with these studies as patents are more widely used by R&D-intensive innovators. In the final innovator group – small-sized firms – copyright and lead-advantage time are the second most popular knowledge-protection mechanisms. Around 12 per cent of firms in this small-sized-firm group use these knowledge-protection mechanisms. This is supported by Leiponen and Byma (2009) who find that small firms use secrecy and speed-to-market to protect their knowledge. Informal mechanisms such as secrecy, copyright and lead-advantage time are accessed more easily by small firms than the other knowledge-protection mechanisms as their use requires fewer firm resources and capabilities. Given that small firms often lack resources and capabilities, the popularity of secrecy, copyright and lead-advantage time amongst small firms is unsurprising.

There is a relatively high use of all seven knowledge-protection mechanisms in the new-to-the-market and manufacturing sector innovator groups. In each of these groups, the proportion of firms using each protection mechanism is similar.

The least popular protection mechanism within all innovator groups is the registration of industrial designs. The proportion of firms using the mechanism is highest in the manufacturing sector innovator group (7.9 per cent) and lowest in the new-to-the-firm innovator group (2.2 per cent). The new-to-the-market and large-sized innovator groups have values towards the top of this range; 6.5 per cent and 7.1 per cent of firms respectively use the registration of design as a knowledge-protection mechanism.

The use of complexity of design as a protection mechanism is the sixth most popular knowledge-protection mechanism in all innovator groups. The largest proportion of firms using this mechanism is found in both the new-to-the-market and manufacturing-sector innovator groups (13.6 per cent and 13.2 percent respectively), although 10.1 per cent of firms in the large-sized innovator group and 11.9 per cent of firms in the high-technology/knowledge-intensive innovator group use this protection mechanism.

The proportion of firms using patents, registered industrial designs and registered trademarks – all formal knowledge-protection mechanisms – increases with firm size as does the proportion of firms using complexity of design – an informal protection method.

The mean and standard deviation for each of the model variables included in the econometric analysis are also given in Table 2.1. Minimum and maximum values are not given in compliance with the ONS's rule on disclosure. The mean of each binary (0/1) variable indicates the proportion of firms that gave a positive 'yes' response to the particular question being asked. Of the four intangible investments that a firm is able to make, investment into Computer Software has the highest participation rate with, on average, 35 per cent of firms engaging in this investment.

Firm investment into R&D and Training is similar with, on average, 27 per cent and 28 per cent of firms investing in these intangibles, respectively. Investment into Design is the least popular intangible investment made by firms with, on average, 20 per cent of CIS 4 to CIS 6 firms and 12 per cent of CIS 7 to CIS 8 firms investing into design activities.

Turning to intangibles protection, binary (0/1) responses are obtained from firms in CIS 6 and CIS 7 when asked about the knowledge-protection mechanisms that they use. Secrecy is the most used protection mechanism with, on average, 9 per cent of firms indicating that they used this knowledge-protection mechanism during the previous three-year period. On average, 6 per cent and 5 per cent of firms indicate that they used Trademarks and Copyright, respectively. Lead-time advantage and Patents were used by, on average, 4 per cent of firms, and Complexity of Design and Registered Designs were the least used knowledge-protection mechanisms with, on average, 3 per cent and 2 per cent of firms engaging in these types of protection, respectively.

With regards to the industry appropriability regime, on average, 25 per cent of firms are product innovators within each industry group, whereas on average, 15 per cent of firms are process innovators within each industry group. On average, 9 per cent of firms within each industry group view technical, industry or service standards as being of medium or high importance to firm innovations and 4 per cent of firms within each industry group view scientific journals and trade/technical publications as being of medium or high importance to firm innovations. Examining the knowledge-protection dimension of the industry appropriability regime i.e. the effective protection mechanisms that are available for use, shows that on average, 22 per cent of firms within an industry group use formal knowledge protection or view formal knowledge protection as being important to their innovations, and 23 per cent of firms within an industry group use informal knowledge protection or view informal knowledge protection as being important to their innovations.

The industry structure variables – the industry five-firm concentration ratio and the industry birth rate – indicate that, on average, 12 per cent of the industry group's sales are accounted for by the five largest firms, and on average, the industry birth rate is 0.19 per cent.

Tables 2.2 to 2.6 show the correlation coefficients for all variables included in the empirical analysis. The variables which represent the industry appropriability regime are highly correlated with one another (discussed in Section 2.4.2 above), although no other collinearity problems are indicated by the remaining correlations in the tables.

2.5.2 Econometric results

The econometric analysis in the present study is undertaken across all firms included in the CIS datasets so that results depict *average effects* across all firms in the sample. Sub-sample groups of firms (the manufacturing sector, for example) are not analysed separately at this stage.

The estimation results are given in Tables 2.7 to 2.38. The parameters in the tables represent marginal effects which allow for some degree of interpretation. A marginal effect is a rate of change: it is the probability per unit of the independent variable, not a probability itself and can therefore be greater than 1. It is the derivative – i.e. the slope – of the prediction function, and the slope of a function can be greater than one, even if the values of the function are all between 0 and 1.[7]

2.5.2.1 Intangibles investment

Tables 2.7 to 2.16 show the probit regression results for the intangibles investment analysis. The probit model estimates the probability that a firm will invest in an intangible asset based upon the industry appropriability regime and particular aspects of the industry's structure. Both the heteroscedastic probit-model results and the homoscedastic probit-model results are presented, although the discussion of results relates to the heteroscedastic models.

The dependent variables – R&D, Design, Training and Computer Software – represent firms' investment into intangible assets, one element of a firm's intangibles strategy. The results indicate the direction, strength and statistical significance of the

[7] https://www.stata.com/support/faqs/statistics/marginal-effect-greater-than-1/

independent-variable effects on each intangible investment. They show the extent to which firms' intangibles investments are contingent upon the industry appropriability regime and particular elements of industry structure.

i. Industry structure variables

Tables 2.7 to 2.11 report the probit-model results for the heteroscedastic models. The industry birth rate and the five-firm concentration ratio represent industry structure within the model and more specifically, the level of competition which exists. A unit increase in the industry birth rate (ceteris paribus) has a significant, negative effect (at the 1 per cent level) on the probability that a firm will invest in R&D and Design (all CIS waves), and a significant, positive effect (at varying significance levels) on the probability that a firm will invest in Computer Software. The effects on the probability that a firm will invest in Training are generally positive and insignificant, although a negative, significant effect (at the 5 per cent level) is found in the Training regression which includes the 'average propensity for firms to view scientific journals and trade/technical publications as being of medium or high importance to innovations within the industry' variable.

A unit increase in the industry five-firm concentration ratio (ceteris paribus) has a significant, positive effect (at the 1 per cent and 5 per cent levels) on the probability of investing in R&D, Training and Computer Software investment; a significant, negative effect (to varying significance levels) on the probability of investing in Design (CIS 4, 5 and 6); and a significant, negative effect (at the 1 per cent level) on the probability of investing in Design (CIS 7 and 8). The positive effects on the probability of intangibles investment are similar in magnitude for Training, R&D and Computer Software, although slightly stronger for Computer Software investment.

When the industry birth rate increases, competition within the industry also increases, whereas when the industry five-firm concentration ratio increases, competition within the industry falls. One would therefore expect the direction of the effect on the intangible investments to differ when these industry structure variables change by one unit (ceteris paribus). Indeed, this is the case as an increase in the industry birth rate is associated with a fall in the probability that a firm will invest in R&D, Design and Training (for one regression). In contrast, an increase in the industry five-firm concentration ratio is associated with an increase in the probability that a firm will invest in R&D, Training and Computer Software. The results for R&D and Training are consistent with one another, whereas those for Design and Computer Software are not.

> *In general, the results support the Schumpetarian viewpoint that an increase in competition leads to less market power for some firms. It becomes more difficult for these firms to appropriate returns from their investments, firm profits fall and future investment is further reduced (Schumpeter, 1942). These results support earlier findings by Kraft (1989) and Artés (2009) and lead to the rejection of Hypothesis 1a in favour of Hypothesis 1b.*

ii. Industry appropriability regime variables

The remaining explanatory variables together represent the industry appropriability regime. A unit increase in the average propensity for a firm to be an innovator – either product or process – (ceteris paribus) has a significant, positive effect on the probability that a firm will invest in R&D and Training at the 1 per cent level and on Computer Software at the 5 per cent level. The effect is also positive and significant, at the 1 per cent level, on the probability that a firm will invest in Design for CIS 4, 5 and 6 data, but the effect is insignificant for CIS 7 and 8 data, although the sign is positive. The effects are strongest for R&D investment, followed by Design investment (CIS 4, 5 and 6), Training investment and Computer Software investment. The marginal effects are larger for the ‘average propensity for a firm to be a process innovator’ variable compared with those for the ‘average propensity for a firm to be a product innovator’ variable across all forms of intangible investment. These results indicate that firms’ intangibles investment is more responsive to firms’ process innovation activity within an industry than to firms’ product innovation activity within the same industry. These variables are included in the model to indicate how the nature of the technology within an industry (one element of the industry appropriability regime) can influence a firm’s intangibles investment. The results indicate that industries that are highly innovative are more likely to undertake intangible investment, and that the nature of the technology i.e. whether it is a product technology or a process technology, has implications for the extent to which investment in intangibles takes place – a unit change in the average propensity for firms within an industry to be a process innovator leads to stronger positive effects upon the probability that a firm will invest in intangibles than a one unit change in the propensity for firms within an industry to be a product innovator. Process technologies are more tacit in nature than product technologies, and this added natural protection may explain the stronger positive effects on the probability that a firm will invest in intangibles.

The ‘average propensity for firms to view scientific journals and trade/technical publications as being of medium or high importance to innovations within the industry’ and the ‘average propensity for firms to view technical, industry or service standards as being of medium or high importance to innovations within the industry’ are included in the model to indicate the codified/tacit nature of knowledge embedded within the industry’s technology – another element of the nature of technology within the industry appropriability regime. A unit increase in both of these variables (ceteris paribus) has a significant, positive effect (at the 1 per cent level) on the probability that a firm will invest in R&D, Design (CIS 4, 5 and 6) and Training. There are also positive effects on the probability that a firm will invest in Design (CIS 7 and 8) and Computer Software, although the effects are insignificant. In Section 2.3.2 above, it is proposed that firms are more likely to invest in innovative activities if natural protection against knowledge spillovers – in the form of tacit knowledge, for example – exists (Parker, 1972; Rosenberg, 1974). Hurmelinna et al., (1997) suggest that as a firm becomes more engaged in standardisation, knowledge becomes less tacit (or more codified). When knowledge becomes less tacit, the industry appropriability regime weakens, and firms’ expected returns to investment into innovation fall. When expected returns to innovation are lower, actual investment into innovation is likely to fall. In contrast, the opposite occurs in the estimation results here; the probability that a firm will invest in intangibles increases when standards and publications become more important to innovation activities i.e. when knowledge becomes less tacit. The results here indicate that as knowledge becomes more codified (less tacit) and the ‘nature of technology’ dimension of the industry appropriability regime weakens, the probability of firms investing into intangible assets increases.

In summary, the estimation results indicate that the probability of a firm investing in intangible assets increases when the average propensity to be a product or a process innovator within the industry increases. The probability of a firm investing in intangible assets increases by more for process technologies than for product technologies.

The probability of a firm investing in intangibles increases if knowledge is made more codified by increasing the 'average propensity for firms to view scientific journals and trade/technical publications as being of medium or high importance to innovations within the industry' and the 'average propensity for firms to view technical, industry or service standards as being of medium or high importance to innovations within the industry.' This result leads to the rejection of Hypothesis 2a in favour of Hypothesis 2b.

The knowledge-protection regime within an industry, discussed in Section 2.2.3.1 above, is the second dimension of the industry appropriability regime – the first being the nature of the industry technology. In the model, two variables represent the industry knowledge-protection regime or the effective, available knowledge-protection mechanisms within the industry: 'the average propensity for firms to use formal knowledge protection or to view formal knowledge protection as being important within an industry' and 'the average propensity for firms to use informal knowledge protection or to view informal knowledge protection as being important within an industry.' A unit increase in these variables (ceteris paribus) has a significant, positive effect (at the 1 per cent level) on the probability that a firm will invest in R&D, Design (CIS 4, 5 and 6) and Training, and a significant, positive effect (at the 10 per cent level) on the probability that a firm will invest in Computer Software. The effects are positive for the probability that a firm will invest in Design (CIS 7 and 8), although they are statistically insignificant. The effects on the probability of a firm investing in intangible assets are generally stronger following a unit increase in the formal knowledge-protection variable (ceteris paribus) than those following a unit increase (ceteris paribus) in the informal knowledge-protection variable. Overall, the positive effects imply that as the knowledge-protection dimension of the industry appropriability regime strengthens i.e. the effective, available knowledge-protection mechanisms within an industry increases, firms' investment into intangibles increases. The stronger knowledge-protection element of the industry appropriability regime provides firms with knowledge-protection mechanisms that can be used to help in the appropriation of returns from their investments. Using knowledge-protection mechanisms allows a firm to become a temporary monopolist (Arrow, 1962), and the higher expect returns to innovation investment leads to higher actual intangibles investment.

> *Strengthening the industry appropriability regime through the knowledge-protection dimension involves increasing the effectiveness and availability of knowledge-protection mechanisms within the industry. The estimation results show that the probability of a firm investing in intangible assets increases if 'the average propensity for firms to use formal knowledge protection or to view formal knowledge protection as being important within an industry' and 'the average propensity for firms to use informal knowledge protection or to view informal knowledge protection as being important within an industry' increase. This result provides evidence that firm investment into intangible assets increases when the industry appropriability regime strengthens, and therefore Hypothesis 2b can be rejected in favour of Hypothesis 2a.*

2.5.2.2 Intangibles protection: Importance to the firm

Tables 2.17 to 2.24 show the knowledge-protection regression results for the ordered-probit models. The parameters are marginal effects and indicate how much less likely (negative sign) or more likely (positive sign) a firm is to belong to the response group, given a one unit change in the independent variable (ceteris paribus) – where 0 indicates that the knowledge-protection mechanism is not important, 1 indicates that it is of low importance, 2 indicates that it is of medium importance and 3 indicates that it is of high importance. Across the four different response groups, the parameters sum to one as a marginal effect indicating that a firm is less likely to belong to one response group, for example, is matched by another marginal effect or effects indicating that the firm is more likely to belong to another group or groups. The regression results for informal and formal knowledge-protection importance are considered separately.

i. Industry structure variables: Informal knowledge-protection mechanisms

The effects of a unit increase in the industry birth rate (ceteris paribus) on the importance firms attach to Secrecy for their innovations within the industry are mixed. Across the six different regressions, results are significant in only two cases – the regressions including the 'average propensity for firms to view technical, industry or service standards as being of medium or high importance to innovations within the industry' and the 'average propensity for firms to view scientific journals and trade/technical publications as being of medium or high importance to innovations within the industry'. Here, a unit increase in the industry birth rate (ceteris paribus) leads to a firm within the industry being more likely to belong to the 'not important' response group and less likely to belong to each of the other three groups (at the 1 per cent level). The parameters indicate that firms are much less likely to belong to the 'medium importance' response group followed by the 'high importance' response group and then the 'low importance' response group.

The effects of a unit increase in the industry birth rate (ceteris paribus) on the importance firms attach to Lead-time Advantage for their innovations within the industry are significant (at the 1 per cent level) across the six different regressions. As with those results that are significant for Secrecy, a unit increase in the industry birth rate (ceteris paribus) leads to a firm within the industry being more likely to belong to the 'not important' response group and less likely to belong to each of the other three groups, and the parameters indicate that firms are much less likely to belong to the 'medium importance' response group followed by the 'high importance' response group and then the 'low importance' response group.

The effects of a unit increase in the industry birth rate (ceteris paribus) on the importance firms attach to Complexity of Design for their innovations within the industry are significant (at the 1 per cent level) across five of the regressions. The results are significant at the 5 per cent level for the regression including the 'average propensity for a firm to be a product innovator within an industry' variable. As with Lead-time advantage, and the significant results for Secrecy, a unit increase in the industry birth rate (ceteris paribus) leads to a firm within the industry being more likely to belong to the 'not important' response group and less likely to belong to each of the other three groups. The parameters indicate that firms are much less likely to belong to the ‘medium importance’ response group followed by the ‘low importance’ response group and then the ‘high importance’ response group.

The effects of a unit increase in the industry birth rate (ceteris paribus) on the importance firms attach to Confidentiality Agreements for their innovations within the industry are significant (at the 1 per cent level) in five of the six regressions. The effects are insignificant in the regression containing the ‘average propensity for firms to view technical, industry or service standards as being of medium or high importance to innovations within the industry’ variable. In contrast to the results for the other informal knowledge-protection mechanisms, four of the regressions show that a unit increase in the industry birth rate (ceteris paribus) leads to a firm within the industry being less likely to belong to the ‘not important’ response group and more likely to belong to each of the other three groups. Firms are much more likely to belong to the high importance response group followed by the medium importance response group and then the low importance response group. In the regression including the ‘average propensity for firms to view scientific journals and trade/technical publications as being of medium or high importance to innovations within the industry’ variable, a unit increase in the industry birth rate (ceteris paribus) leads to a firm within the industry being more likely to belong to the ‘not important’ response group and less likely to belong to each of the other three groups – consistent with many of the results for the other informal knowledge-protection mechanisms. A firm is much less likely to belong to the ‘high importance’ response group followed by the ‘medium importance’ response group and then the ‘low importance’ response group.

> *In summary, in the ordered-probit models for Secrecy, Lead-time Advantage and Complexity of Design there is a general tendency for an increase in the industry birth rate to lead to an increase in the probability that a firm will belong to the ‘not important group’ and a decrease in the probability that a firm will belong to each of the other three groups. The opposite is true for Confidentiality Agreements; as the industry birth rate increases, there is a reduction in the probability that a firm will belong to the ‘not important group’ and an increase in the probability that a firm will belong to each of the other three groups.*

The effects of a unit increase in the industry five-firm concentration ratio (ceteris paribus) on the importance firms attach to Secrecy for their innovations within the industry are significant (at the 1 per cent level) in four of the six regressions. The effects are insignificant in the regressions containing 'the average propensity for a firm to be a product innovator' and 'the average propensity for a firm to be a process innovator' variables, although the parameters do have the same sign as those in the other regressions. In the regressions where the parameters are statistically significant, a unit increase in the five-firm concentration ratio (ceteris paribus) leads to a firm within the industry being less likely to belong to the 'not important' response group and more likely to belong to each of the other groups. Firms are much more likely to belong to the 'medium importance' response group followed by the 'high importance' response group and then the 'low importance' response group.

As with Secrecy, the effects of a unit increase in the industry five-firm concentration ratio (ceteris paribus) on the importance firms attach to Lead-time Advantage for their innovations within the industry are significant (at either the 1 per cent or 5 per cent levels) in four of the six regressions. The effects are insignificant in the regressions containing 'the average propensity for a firm to be a product innovator' and 'the average propensity for a firm to be a process innovator' variables, although, as with Secrecy, the parameters do have the same sign as those in the other regressions. In the regressions where the parameters are statistically significant, a unit increase in the five-firm concentration ratio (ceteris paribus) leads to a firm within the industry being less likely to belong to the 'not important' response group and more likely to belong to each of the other groups. Firms are much more likely to belong to the 'medium importance' response group followed by the 'high importance' response group and then the 'low importance' response group.

The effects of a unit increase in the industry five-firm concentration ratio (ceteris paribus) on the importance firms attach to the Complexity of Design for their innovations within the industry are statistically significant in three of the six regressions. The effects are insignificant in the regressions containing 'the average propensity for a firm to be a product innovator', 'the average propensity for a firm to be a process innovator' and 'the average propensity for firms to use informal knowledge protection or to view informal knowledge protection as being important within an industry' variables. In the regressions where the parameters are statistically significant, a unit increase in the five-firm concentration ratio (ceteris paribus) leads to a firm within the industry being less likely to belong to the 'not important' response group and more likely to belong to each of the other groups, although the degrees of statistical significance vary. Firms are much more likely to belong to the 'medium importance' response group followed by the 'low importance' response group and then the 'high importance' response group.

The effects of a unit increase in the industry five-firm concentration ratio (ceteris paribus) on the importance firms attach to Confidentiality Agreements for their innovations within the industry are statistically significant in all six regressions (at the 1 per cent level in four of the regressions and at the 5 per cent and 10 per cent levels in the other two). In all six regressions, a unit increase in the five-firm concentration ratio (ceteris paribus) leads to a firm within the industry being less likely to belong to the 'not important' response group and more likely to belong to each of the other groups. Firms are much more likely to belong to the 'high importance' response group followed by the 'medium importance' response group and then the 'low importance' response group.

> *In summary, in the ordered-probit models for all informal knowledge-protection mechanisms, there is a general tendency for an increase in the five-firm concentration ratio to lead to a fall in the probability that a firm will belong to the 'not important group' and an increase in the probability that a firm will belong to each of the other three groups.*
>
> *Overall, the majority of the industry structure results suggest that as the level of competition within an industry increases, the probability of firms viewing informal knowledge-protection mechanisms as being important falls so that they are less likely to use informal protection methods. This result leads to the rejection of Hypothesis 3 which proposes that the use of knowledge-protection mechanisms increases when industry competitiveness increases.*

ii. Industry appropriability regime variables: Informal knowledge-protection mechanisms

A unit increase in the average propensity for a firm to be an innovator – either product or process – (ceteris paribus) within an industry leads a firm within the industry to be less likely to belong to the group where informal knowledge-protection mechanisms are ‘not important’ and more likely to belong to the other three groups (significant at the 1 per cent level for all four informal knowledge-protection mechanisms). The magnitude of this effect is greatest for process innovators across all four informal knowledge-protection mechanisms. Consequently, as firms within an industry become more likely to engage in innovation, they are more likely to view informal knowledge-protection mechanisms as being of low, medium or high importance if the innovation is a process rather than a product.

As the average propensity for a firm to be an innovator within the industry increases (ceteris paribus), firms are more likely to view Secrecy, Complexity of Design and Lead-time Advantage as being of low, medium or high importance, although firms are much more likely to give a medium-importance response, followed by a high-importance and then a low-importance response. As for Confidentiality Agreements, firms are much more likely to give a ‘high-importance’ response followed by a ‘medium-importance’ response and then a ‘low-importance’ response.

A unit increase in the ‘average propensity for firms to view technical, industry or service standards as being of medium or high importance to innovations within the industry’ and the ‘average propensity for firms to view scientific journals and trade/technical publications as being of medium or high importance to innovations within the industry’ (ceteris paribus) leads to a firm within the industry being less likely to belong to the group where informal knowledge-protection mechanisms are ‘not important’ and more likely to belong to the other three groups (significant at the 1 per cent level for all four informal knowledge-protection mechanisms). The magnitude of this effect is greatest for firms viewing scientific journals and trade/technical publications as being of medium or high importance to innovations within their industry, and consequently, as firms within an industry become more likely to view scientific journals and trade/technical publications as being of medium or high importance to innovations, they are much more likely to view informal knowledge-protection mechanisms as being of low, medium or high importance than firms that are more likely to view technical, industry or service standards as being of medium or high importance to innovations within the industry.

As the ‘average propensity for firms to view technical, industry or service standards as being of medium or high importance to innovations within the industry’ and the ‘average propensity for firms to view scientific journals and trade/technical publications as being of medium or high importance to innovations within the industry’ increases (ceteris paribus), firms are more likely to view Secrecy, Complexity of Design and Lead-time Advantage as being of low, medium or high importance, although firms are much more likely to give a medium-importance response, followed by a high-importance and then a low-importance response for Secrecy and Lead-time Advantage, and a low-importance and then a high-importance response for Complexity of Design. Firms are much more likely to give a ‘high-importance’ response followed by a ‘medium-importance’ response and then a low-importance response when asked about Confidentiality Agreements.

> *In summary, as the average propensity to become an innovator (product or process) increases within an industry, the probability of a firm belonging to the ‘not important’ group – for all four informal knowledge-protection mechanisms – falls, and the probability of a firm belonging to any of the other three groups increases. As the ‘average propensity for firms to view technical, industry or service standards as being of medium or high importance to innovations within the industry’ and the ‘average propensity for firms to view scientific journals and trade/technical publications as being of medium or high importance to innovations within the industry’ variables increase, knowledge becomes more codified, and the probability of a firm belonging to the ‘not important’ group regarding all four forms of informal knowledge protection falls, and the probability of a firm belonging to any of the other three groups increases. In general, these results support Hypothesis 4a which proposes that a firm’s intangibles protection increases when the ‘nature of technology’ dimension of the industry appropriability regime weakens.*

A unit increase in the available, effective knowledge-protection mechanisms within an industry i.e. ‘the average propensity for firms to use formal knowledge protection or to view formal knowledge protection as being important within an industry’ and ‘the average propensity for firms to use informal knowledge protection or to view informal knowledge protection as being important within an industry’ variables (ceteris paribus) leads to a firm within the industry being less likely to belong to the group where informal knowledge-protection mechanisms are ‘not important’ and more likely to belong to the other three groups (significant at the 1 per cent level for all four informal knowledge-protection mechanisms). The magnitude of this effect is greatest for ‘the average propensity for firms to use formal knowledge protection or to view formal knowledge protection as being important within an industry’ variable, indicating that as firms within an industry become more likely to use formal knowledge-protection mechanisms or view formal knowledge-protection mechanisms as being important, they are much more likely to view informal knowledge-protection mechanisms as being of low, medium or high importance than when the ‘the average propensity for firms to use informal knowledge protection or to view informal knowledge protection as being important within an industry’ increases.

As ‘the average propensity for firms to use formal knowledge protection or to view formal knowledge protection as being important within an industry’ and ‘the average propensity for firms to use informal knowledge protection or to view informal knowledge protection as being important within an industry’ increases (ceteris paribus), firms are more likely to view Secrecy, Complexity of Design and Lead-time Advantage as being of low, medium or high importance, although firms are much more likely to give a medium-importance response, followed by a high-importance and then a low-importance response for Secrecy and Lead-time Advantage, and a low-importance and then a high-importance response for Complexity of Design. Firms are much more likely to give a high-importance response followed by a medium-importance response and then a low-importance response when asked about Confidentiality Agreements.

> *In summary, when the available, effective informal and formal knowledge-protection mechanisms within an industry increase, the probability of a firm*

belonging to the 'not important' group – regarding informal knowledge-protection mechanisms – falls and the probability of a firm belonging to the other three groups increases. This provides evidence in support of Hypothesis 4b which states that a firm's intangibles protection increases when the knowledge-protection dimension of the industry appropriability regime strengthens.

iii. Industry structure variables: Formal knowledge-protection mechanisms

The effects of a unit increase in the industry birth rate (ceteris paribus) on the importance firms attach to Copyright for their innovations within the industry are statistically significant in two out of the six regressions (at the 1 per cent level). The effects are statistically significant when the 'average propensity for firms to view technical, industry or service standards as being of medium or high importance to innovations within the industry' and the 'average propensity for firms to view scientific journals and trade/technical publications as being of medium or high importance to innovations within the industry' are included in the regressions. Here, a unit increase in the industry birth rate (ceteris paribus) leads a firm within the industry to be more likely to belong to the 'not important' response group and less likely to belong to each of the other three response groups. Again, the magnitude of the effects is similar, although the likelihood of a firm giving a 'low importance' response is reduced by slightly more than the likelihood of a firm giving a 'medium importance' or a 'high importance' response.

The effects of a unit increase in the industry birth rate (ceteris paribus) on the importance firms attach to Patents for their innovations within the industry are statistically significant in all six regressions (at the 1 per cent level). In all six cases, the sign of the effects indicates that a firm is more likely to belong to the 'not important' response group and less likely to belong to the other three response groups. The negative effects are slightly larger for the high and low importance responses indicating that the likelihood of a firm giving either of these responses is reduced by slightly more than the likelihood of a firm giving a medium importance response.

The effects of a unit increase in the industry birth rate (ceteris paribus) on the importance firms attach to Trademarks for their innovations within the industry are statistically significant in all six regressions (at the 1 per cent level). A firm is more likely to belong to the 'not important' response group and less likely to belong to the other three response groups in all six cases. The strongest effects are found when the 'average propensity for firms to view technical, industry or service standards as being of medium or high importance to innovations within the industry' and the 'average propensity for firms to view scientific journals and trade/technical publications as being of medium or high importance to innovations within the industry' variables are included in the regressions. The likelihood of giving a 'high importance' response is reduced by more than the likelihood of giving a 'medium importance' response which is itself reduced by more than the likelihood of giving a low importance response.

Similarly, the effects of a unit increase in the industry birth rate (ceteris paribus) on the importance firms attach to the Registration of Designs for their innovations within the industry are statistically significant in all six regressions (at the 1 per cent level). Again, a firm is more likely to belong to the 'not important' response group and less likely to belong to the other three response groups in all six cases. The magnitude of the parameters indicate that the likelihood of giving a 'low' or 'medium importance' response is reduced by more than the likelihood of giving a 'medium importance' response in all six regressions.

> *In summary, the ordered-probit models show that an increase in the industry birth rate increases the probability that a firm will belong to the 'not important' group for all four formal knowledge-protection mechanisms and lowers the probability that the firm will belong to the other three groups where formal knowledge-protection mechanisms are of low, medium or high importance. The strongest results occur with Patents, Trademarks and Registered Designs.*

The effects of a unit increase in the industry five-firm concentration ratio (ceteris paribus) on the importance firms attach to Copyright for innovations within their industry are statistically significant at the 1 per cent level in two of the six regressions (i.e. those including the ‘average propensity for a firm to be a product innovator’ and the ‘average propensity for a firm to be a process innovator’ variables), and statistically significant at the 10 per cent level in one (i.e. the regression including the ‘average propensity for firms to use informal knowledge protection or to view informal knowledge protection as being important’ variable). Effects in the other three regressions are insignificant. In the regressions where the parameters are statistically significant, a unit increase in the five-firm concentration ratio (ceteris paribus) leads a firm within the industry to be more likely to belong to the ‘not important’ response group and less likely to belong to each of the other groups. The negative effects are similar across the responses – ‘low’, ‘medium’ and ‘high importance’ – in each of the regressions where the coefficients are significant.

The effects of a unit increase in the industry five-firm concentration ratio (ceteris paribus) on the importance firms attach to Patents for innovations within their industry are statistically significant at the 1 per cent level in five of the six regressions. The effects are insignificant in the regression containing the ‘average propensity for firms to view scientific journals and trade/technical publications as being of medium or high importance to innovations within the industry’ variable. In the five regressions where the parameters are statistically significant, a unit increase in the five-firm concentration ratio (ceteris paribus) leads a firm within the industry to be more likely to belong to the ‘not important’ response group and less likely to belong to each of the other groups with the negative effects in these three response groups are similar in magnitude.

The effects of a unit increase in the industry five-firm concentration ratio (ceteris paribus) on the importance firms attach to Trademarks for innovations in their industry are statistically significant in only one of the six regressions (at the 10 per cent level). The significant effects occur when the ‘average propensity for firms to view technical, industry or service standards as being of medium or high importance to innovations within the industry’ variable is included in the regression, and the sign of the effects indicate that a unit increase in the five-firm concentration ratio (ceteris paribus) leads firms to be more likely to belong to the ‘not important’ response group and less likely to belong to each of the other three response groups. The negative effect is similar in magnitude across the three response groups.

The effects of a unit increase in the industry five-firm concentration ratio (ceteris paribus) on the importance firms attach to the Registration of Design for innovations in their industry are statistically significant in five of the six regressions. The regression including the 'average propensity for firms to view scientific journals and trade/technical publications as being of medium or high importance to innovations within the industry' variable gives statistically insignificant effects. The statistically significant effects show that a unit increase in the five-firm concentration ratio (ceteris paribus) leads a firm within the industry to be more likely to belong to the 'not important' response group and less likely to belong to each of the other groups. Although similar in magnitude, the negative effects on the 'low importance' and the 'medium importance' parameters are slightly larger than that on the 'high importance' parameter.

> *In summary, the ordered-probit models show that an increase in the industry five-firm concentration ratio (a fall in industry competition) leads to an increase in the probability that a firm will belong to the 'not important' group and a reduction in the probability that a firm will belong to the other three groups for all formal knowledge-protection mechanisms, although the effects are strongest for Patents and Registered Designs.*
>
> *Overall, the industry structure results provide contrasting results. As new entrant competition within an industry increases, the probability that a firm will view formal knowledge-protection mechanisms as being important falls, and as the level of incumbent competition within an industry increases, the probability that a firm will view formal knowledge-protection mechanisms as being important rises. These results indicate that the type of competition is important. An increase in incumbent competition within the industry leads to results which support Hypothesis 3, whereas an increase in new entrant competition leads to results which reject Hypothesis 3.*

iv. Industry appropriability regime variables: Formal protection mechanisms

As with the informal knowledge-protection mechanisms discussed above, a unit increase in the average propensity for a firm to be an innovator – either product or process – (ceteris paribus) within an industry leads to a firm within the industry being less likely to belong to the group where formal knowledge-protection mechanisms are ‘not important’ and more likely to belong to the other three groups (significant at the 1 per cent level for all four formal knowledge-protection mechanisms). The magnitude of the effects is greatest for process innovators across all four formal knowledge-protection mechanisms. Consequently, as a firm within an industry becomes more likely to engage in innovation, the likelihood that they will view formal knowledge-protection mechanisms as being of low, medium or high importance is increased by more if the innovation is a process rather than a product.

The magnitude of the parameters for the Patents and Trademarks regressions indicate that the increase in the likelihood that a firm will give a ‘high importance’ response is greater than the increase in the likelihood that a firm will give a ‘low’ or ‘medium importance’ response. As for Copyright, the increase in the likelihood that a firm will give a ‘low importance’ response is greater than the increase in the likelihood that a firm will give a ‘medium’ or ‘high importance’ response, and the parameters for the Registration of Design regressions indicate that the increase in the likelihood that a firm will give a ‘low importance’ response is the same as the increase in the likelihood that a firm will give a ‘medium importance’ response, both of which are greater than the increase in the likelihood that a firm will give a ‘high importance’ response.

A unit increase in the ‘average propensity for firms to view technical, industry or service standards as being of medium or high importance to innovations within the industry’ and the ‘average propensity for firms to view scientific journals and trade/technical publications as being of medium or high importance to innovations within the industry’ (ceteris paribus) leads a firm within the industry to be less likely to belong to the group where formal knowledge-protection mechanisms are ‘not important’ and more likely to belong to the other three groups. The parameters for both variables are significant (at the 1 per cent level) for three formal knowledge-protection mechanisms – Copyright, Patents and Registered Designs. The parameters in the Trademark regressions are significant (at the 1 per cent level) when the ‘average propensity for firms to view technical, industry or service standards as being of medium or high importance to innovations within the industry’ is included in the regression, but they are insignificant when the 'average propensity for firms to view scientific journals and trade/technical publications as being of medium or high importance to innovations within the industry' variable is included in the regression.

As with the results for informal knowledge-protection mechanisms, the magnitude of the effects is greatest for firms viewing scientific journals and trade/technical publications as being of medium or high importance to innovations within their industry, and consequently, as firms within an industry become more likely to view scientific journals and trade/technical publications as being of medium or high importance to innovations, the increase in the likelihood that they will view formal knowledge-protection mechanisms as being of low, medium or high importance is greater than the increase in the likelihood that firms within the industry experience when they become more likely to view technical, industry or service standards as being of medium or high importance to innovations within the industry.

As the 'average propensity for firms to view technical, industry or service standards as being of medium or high importance to innovations within the industry' and the 'average propensity for firms to view scientific journals and trade/technical publications as being of medium or high importance to innovations within the industry' increases (ceteris paribus), the likelihood of a firm viewing Copyright, Patents and Registered Designs as being of low, medium or high importance also increases. The likelihood of a firm viewing Trademarks as being of low, medium or high importance also increases when the 'average propensity for firms to view scientific journals and trade/technical publications as being of medium or high importance to innovations within the industry' increases. The parameters indicate that the increase in the likelihood that a firm will give a 'low importance' response when asked about Copyright is greater than the increase in the likelihood that a firm will give a 'medium' or 'high importance' response. The increase in the likelihood that a firm will give a 'high importance' response is greater than the increase in the likelihood that a firm will give a 'medium' or 'low importance' response for Patents and Trademarks. As for Registered Designs, the increase in the likelihood that a firm will give a 'low importance' response is equal to the increase in likelihood that a firm will give a 'medium importance' response, greater than the increase in likelihood that a firm will give a 'high importance' response.

In summary, as the average propensity to become an innovator (product or process) increases within an industry, the probability of a firm belonging to the 'not important' group – for all four formal knowledge-protection mechanisms – falls, and the probability of a firm belonging to any of the other three groups increases. As the 'average propensity for firms to view technical, industry or service standards as being of medium or high importance to innovations within the industry' and the 'average propensity for firms to view scientific journals and trade/technical publications as being of medium or high importance to innovations within the industry' variables increase, knowledge becomes more codified, and the probability of a firm belonging to the 'not important' group regarding all four forms of formal knowledge protection falls, and the probability of a firm belonging to any of the other three groups increases. In general, these results support Hypothesis 4a which proposes that a firm's intangibles protection increases when the 'nature of technology' dimension of the industry appropriability regime weakens.

A unit increase in the available, effective knowledge-protection mechanisms within an industry i.e. 'the average propensity for firms to use formal knowledge protection or to view formal knowledge protection as being important within an industry' and 'the average propensity for firms to use informal knowledge protection or to view informal knowledge protection as being important within an industry' variables (ceteris paribus) leads a firm within the industry to be less likely to belong to the group where formal knowledge-protection mechanisms are 'not important' and more likely to belong to the other three groups (significant at the 1 per cent level for all four formal knowledge-protection mechanisms). The magnitude of these effects is larger when the available, effective formal knowledge-protection mechanisms within the industry increases than when the available, effective informal knowledge-protection mechanisms within the industry increases.

As 'the average propensity for firms to use formal knowledge protection or to view formal knowledge protection as being important within an industry' and 'the average propensity for firms to use informal knowledge protection or to view informal knowledge protection as being important within an industry' increases (ceteris paribus), the likelihood of a firm viewing Copyright, Patents, Trademarks and Registered Designs as being of low, medium or high importance also increases. The parameters indicate that the increase in the likelihood that a firm will view Copyright as being of 'low importance' is greater than the increase in the likelihood that a firm will view it with 'medium' or 'high importance'. As for Patents and Trademarks, the increase in the likelihood that a firm will give a 'high importance' response is greater than the increase in the likelihood that a firm will give a 'medium' or 'low importance' response. With Registered Designs, the increase in the likelihood that a firm will give a 'low importance' response is equal to the increase in likelihood that a firm will give a 'medium importance' response, greater than the increase in likelihood that a firm will give a 'high importance' response.

> *In summary, when the available, effective informal and formal knowledge-protection mechanisms within an industry increase, the probability of a firm belonging to the 'not important' group – for all four formal knowledge-protection mechanisms – falls and the probability of a firm belonging to the other three groups increases. This provides evidence in support of Hypothesis 4b which states that a firm's intangibles protection increases when the knowledge-protection dimension of the industry appropriability regime strengthens.*

2.5.2.3 Intangibles protection: Actual protection decisions

Tables 2.25 to 2.38 show the probit regression results for the new intangibles protection analysis. The probit model estimates the probability that a firm will protect an intangible asset (using a particular knowledge-protection method) based upon the industry appropriability regime and particular aspects of the industry's structure. As with the intangibles investment estimations discussed above, both the heteroscedastic probit-model results and the homoscedastic probit-model results are presented, although the discussion here relates to the heteroscedastic models alone.

The dependent variables – Secrecy, Complexity of Design, Lead-time Advantage, Patents, Registered Designs, Trademarks and Copyright – represent firms' new protection of intangible assets, another element of a firm's intangibles strategy. The results indicate the direction, strength and statistical significance of the independent-variable effects on each intangible knowledge-protection method. They show the extent to which firms' intangibles knowledge protection are contingent upon particular elements of industry structure and the industry appropriability regime.

i. Industry structure variables

Tables 2.25 to 2.31 report the probit-model results for the heteroscedastic models. The industry birth rate and the industry five-firm concentration ratio represent industry structure within the model and more specifically are an indication of the competition which exists within the industry.

A unit increase in the industry birth rate (ceteris paribus) has a significant, negative effect (at the 1 per cent level) on the probability that a firm will use Patents, Registered Designs and Trademarks. The parameters indicate that the reduction in the probability of use is greatest for Trademarks followed by Patents and then Registered Designs. There is a significant, negative effect on the probability that a firm will use Lead-time Advantage – at the 10 per cent level when the 'average propensity for a firm to be a product innovator' is include in the regression equation and at the 1 per cent level when each of the other variables representing elements of the industry appropriability regime are included in the regression equations. The effects on the probability that a firm will use Copyright are negative, although only significant for the 'average propensity for firms to view technical, industry or service standards as being of medium or high importance to innovations within the industry' and the 'average propensity for firms to view scientific journals and trade/technical publications as being of medium or high importance to innovations within the industry' variables (at the 5 per cent and 1 per cent level respectively). The effects on the probability that a firm will use Complexity of Design are negative but insignificant. As for the probability that a firm will use Secrecy, effects are mixed. When three of the industry appropriability regime variables (the 'average propensity for a firm to be a product/process innovator' and the 'average propensity for firms to view technical, industry or service standards as being of medium or high importance to innovations within the industry') are included in the regressions, there is a significant, positive effect on the probability that a firm will use Secrecy.

The effects of a unit increase in the industry five-firm concentration ratio on the probability that a firm will use knowledge protection are mixed. There are insignificant effects on the probability of a firm using Secrecy, Lead-time Advantage, Patents, Registered Designs and Copyright. Effects are significant for the probability of using Complexity of Design and Trademarks, although the direction of the effects differ. The effects on the probability of using Complexity of Design are negative and significant at the 5 and 10 per cent level, whereas the effects on the probability of using Trademarks are positive and significant at the 5 and 10 per cent level (apart from the effect being insignificant when the 'average propensity for firms to view technical, industry or service standards as being of medium or high importance to innovations within the industry' variable is included in the regression).

> *In summary, the regressions suggest that as the level of competition within an industry increases (the industry birth rate increases or the industry five-firm concentration ratio falls), there is likely to be a negative effect (birth rate) or no significant effect (five-firm concentration ratio) on the probability that a firm will use knowledge-protection mechanisms. In only two cases – Secrecy (birth rate) and Complexity of Design (five-firm concentration ratio) – does the probability of a firm's use increase when there is an increase in competition within the industry. These results lead to the rejection of Hypothesis 3 which proposes that the use of knowledge-protection mechanisms increases when industry competitiveness increases.*

ii. Industry appropriability regime variables

The industry appropriability regime is represented by six industry variables. The first two signal the nature of the industry technology. A unit increase in the average propensity for a firm to be an innovator – either product or process – (ceteris paribus) has a significant, positive effect on the probability of a firm using Secrecy and Lead-time advantage (at the 1 per cent level) and Copyright (at the 5 per cent level) as knowledge-protection mechanisms. The effects are strongest for Secrecy followed by Lead-time advantage and then Copyright. There are statistically insignificant effects on the probability of a firm using Complexity of Design, Patents and Registered Designs following a unit increase in both variables. There is a significant, negative effect (at the 5 per cent level) on the probability of a firm using

Trademarks when both variables increase by one unit. As with the ordered-probit regression results, the results here indicate that firms' new intangibles protection is more responsive to firms' process innovation activity within an industry than to firms' product innovation in the same industry.

The 'average propensity for firms to view scientific journals and trade/technical publications as being of medium or high importance to innovations within the industry' and the 'average propensity for firms to view technical, industry or service standards as being of medium or high importance to innovations within the industry' are included in the model to indicate the codified/tacit nature of knowledge embedded within the industry's technology. A unit increase in both of these variables (ceteris paribus) has a significant, positive effect (at the 1 per cent level) on the probability that a firm will protect their knowledge using Secrecy, Lead-time Advantage and Copyright. As knowledge becomes less tacit and the industry appropriability regime weakens, firms are more likely to undertake new use of these knowledge-protection mechanisms. A unit increase in the 'average propensity for firms to view scientific journals and trade/technical publications as being of medium or high importance to innovations within the industry' variable leads to a greater increase in the probability that a firm will protect knowledge using these three mechanisms than a unit increase in the 'average propensity for firms to view technical, industry or service standards as being of medium or high importance to innovations within the industry' variable. The increase in the probability of protection is greatest for Secrecy followed by Lead-time Advantage and then Copyright. The effects on the probability of protecting knowledge using Patents, Complexity of Design and Registered Designs are insignificant. As for the probability of protecting knowledge using Trademarks, the effects are negative and significant at the 10 per cent and 1 per cent levels for the 'average propensity for firms to view scientific journals and trade/technical publications as being of medium or high importance to innovations within the industry' and the 'average propensity for firms to view technical, industry or service standards as being of medium or high importance to innovations within the industry' variables respectively.

> *In summary, as the average propensity to become an innovator (product or process) increases within an industry, the probability that a firm will use*

Secrecy, Lead-time Advantage and Copyright increases as does the probability that a firm will use these three knowledge-protection mechanisms when the 'average propensity for firms to view technical, industry or service standards as being of medium or high importance to innovations within the industry' and the 'average propensity for firms to view scientific journals and trade/technical publications as being of medium or high importance to innovations within the industry' variables increase. The effects on a firm's probability of using Patents, Registered Designs and Complexity of Design are insignificant. When knowledge becomes more codified, the probability of a firm using easily-accessible informal and formal knowledge-protection mechanisms increases. These results support Hypothesis 4a which proposes that a firm's intangibles protection increases when the 'nature of technology' dimension of the industry appropriability regime weakens.

The effective and available knowledge-protection mechanisms within an industry – given by the knowledge-protection regime – is the second element of the industry appropriability regime. A unit increase in the variables representing the industry knowledge-protection regime (the 'average propensity for firms to use formal knowledge protection or to view formal knowledge protection as being important within an industry' and the 'average propensity for firms to use informal knowledge protection or to view informal knowledge protection as being important within an industry') – ceteris paribus – has a significant, positive effect (at the one per cent level) on the probability that a firm will protect knowledge using Secrecy, Lead-time Advantage and Copyright. The effects are largest for Secrecy followed by Lead-time Advantage and then Copyright. In addition, the one unit increase in the 'average propensity for firms to use formal knowledge protection or to view formal knowledge protection as being important within an industry' leads to larger, positive effects than a one unit increase in the 'average propensity for firms to use informal knowledge protection or to view informal knowledge protection as being important within an industry' for all three knowledge-protection mechanisms. The effects on the probability that a firm will protect knowledge using Complexity of Design, Patents and Registered Designs are insignificant, but the effect on the probability that a firm will protect knowledge using Trademarks is negative and significant at the 5 per cent level when there is a unit increase in the 'average propensity for firms to use informal knowledge protection or to view informal knowledge protection as being important within an industry', although insignificant following a unit increase in the 'average propensity for firms to use formal knowledge protection or to view formal knowledge protection as being important within an industry'.

> *In summary, when the available, effective informal and formal knowledge-protection mechanisms within an industry increase, the probability of a firm using the more easily accessible informal and formal knowledge-protection mechanisms increases, whereas there is no significant effect on the probability of a firm using the less accessible knowledge-protection mechanisms – Patents, Registered Designs and Complexity of Design. This provides some evidence in support of Hypothesis 4b which states that a firm's intangibles protection increases when the knowledge-protection dimension of the industry appropriability regime strengthens.*

2.6 Discussion and conclusions

During recent years, new technologies have emerged which have led firms to increase their investment into intangible assets. Indeed, intangible investment has risen above that of tangibles (Haskel et al., 2011). A firm's intangible assets reflect value in the firm, and therefore firm strategy relating to them requires careful thought and attention. A firm's intangibles strategy – its investment into and its protection of intangible assets – is the focus of this study.

The IO viewpoint lies at the heart of this study. Firms' decisions relating to intangibles – their intangibles strategies – are assumed to depend upon the market environment in which the firm operates (Scott, 1982). Using UK CIS data covering the 2002 to 2012 period and BSD data covering the 1997 to 2012 period, a series of probit and ordered-probit models are estimated to examine a firm's investment into and protection of intangible assets and to explore whether a firm's investment and protection strategy is contingent upon the appropriability regime of the industry within which the firm operates or some other element of industry structure.

This study adds to existing literature by examining factors which influence both firm investment into intangibles and firm-protection strategies. Previous studies examine the link which exists between intangibles investment and performance (for example, Nesta, 2008), and how the protection of intangible assets influences performance (for example, Hu, 2013). The present study examines the determinants of intangibles strategy itself and asks whether the industry appropriability regime, or some other element of industry structure, drives a firm's intangibles investment and protection decisions.

The present analysis adds to the existing body of knowledge by examining how the strength of the industry appropriability regime and the level of industry competitiveness impacts upon a firm's intangible investment, the importance firm managers attach to informal and formal knowledge-protection mechanisms and a firm's informal and formal knowledge-protection choices. The study contributes to knowledge by asking if any one element of the industry environment being examined matters more than another in determining a firm's intangible investment and protection strategies, or whether each element is equally important in determining a firm's intangibles strategy. In addition, the study adds to knowledge by examining if the relative importance of the different elements of the industry environment is consistent across the investment and protection components of firm strategy.

This study deepens our understanding of how firms make intangible investment and protection decisions. The empirical analysis leads to a number of key findings.

i. First, the results suggest that new industry competition impacts negatively on a firm's intangibles investment into R&D and Training. New industry competition originates from two sources – new entrants and existing incumbents. In addition to the negative effects on firm investment into R&D and Training, new competition from new entrants has a negative effect on investment into Design, whereas new competition from incumbents has a negative effect on Computer Software investment.

The reduction in a firm's intangibles investment following an increase in the birth rate (an increase in new-entrant competition) provides evidence of creative destruction – the increase in competition within the industry lowers a firm’s expected returns to the intangibles investment.

ii. Second, as the ‘nature of technology’ dimension of the industry appropriability regime weakens, there is a consistent, positive effect on the investment component of a firm’s intangibles strategy.

It was proposed that as knowledge becomes more codified and the natural protection against knowledge spillovers is reduced, a firm’s investment into innovative activities falls. In contrast, the results here indicate that the importance of standards and publications to innovation activities proves to be a source of benefit for a firm. With standards come related network externalities (Farrell and Saloner, 1985), for example, producers are able to obtain inputs more cheaply through the exploitation of economies of scale (Bekkers et al., 2002). Standards can also facilitate pro-competitive effects, for example, competitive markets for replacement parts (Lemley, 2002). Standards also protect the market share and bargaining power of the firm or firms controlling them, and ‘‘under some conditions, firms that share technological knowledge may achieve higher innovative performance than firms that do not share knowledge. Knowledge-sharing strategies can help a firm shape the institutional environment in favour of its own technological design.’’ (Spencer, 2003 p.218).

iii. Third, as the ‘knowledge-protection dimension’ of the industry appropriability regime strengthens, there is a clear, consistent, positive effect on the investment component of a firm’s intangibles strategy.

As the available, effective knowledge-protection mechanisms within an industry increase, there are more effective tools for competitive firms to use to enable them to appropriate the returns from their investment – knowledge-protection mechanisms enable a firm to become a temporary monopolist (Arrow, 1962). Stronger appropriability conditions increase a firm's incentives to commit to internally developing resources due to the greater certainty of the returns from such investments (Levin et al., 1987).

iv. Fourth, as new industry competition increases, firms are less likely to view informal and formal knowledge-protection mechanisms as being important if the increased competition is due to new entrants. When new industry competition is due to incumbents, firms are more likely to view formal knowledge-protection mechanisms as being important.

As the level of competition in the industry increases, economic rents and competitive advantages may be eroded away. The industry birth rate is an indication to the number of new entrants in a market and reflects the proportion of young firms present. When the industry birth rate increases, the new, young firms may not have the necessary resources and capabilities to compete and be successful. Older firms (incumbents), on the other hand, may have accumulated resources and capabilities over time and represent a credible threat. Given this, firms may be more likely to view formal knowledge-protection mechanisms as being important when industry competition is increased due to incumbents. In contrast, firm managers are not so concerned with knowledge protection when the increased competition is from new firms entering the industry.

v. Fifth, as the 'nature of technology' dimension of the industry appropriability regime weakens, firms are more likely to view informal and formal knowledge-protection mechanisms as being important.

When knowledge within an industry becomes more codified, the use of knowledge-protection mechanisms allows a firm to guard against imitation and appropriate returns from investment. It is therefore expected that firms will view informal and formal knowledge-protection mechanisms as being more important when the degree of knowledge codification increases.

vi. Sixth, as the 'knowledge-protection dimension' of the industry appropriability regime strengthens, firms are more likely to view both informal and formal knowledge-protection mechanisms as being important – there is a clear, consistent, positive effect on the importance to the firm of all knowledge-protection mechanisms in order to protect innovations.

The available, effective knowledge-protection mechanisms within an industry increases so that there are more effective tools for firms to use to enable them to appropriate the returns from their investment. Firms are therefore more likely to view knowledge-protection mechanisms as being important.

vii. Seventh, new industry competition from new entrants into the industry leads to an increase in the probability that a firm will use Secrecy and Complexity of Design. There is a reduction in the probability that a firm will use the other knowledge-protection mechanisms.

viii. Eighth, as the 'nature of technology' dimension of the industry appropriability regime weakens, the probability that a firm will use informal knowledge-protection mechanisms – Secrecy, Lead-time Advantage and Copyright – increases.

ix. Ninth, as the 'knowledge-protection dimension' of the industry appropriability regime strengthens, the probability that a firm will use informal knowledge-protection mechanisms – Secrecy, Lead-time Advantage and Copyright – increases.

The results of this study show that in reality, a firm's actual knowledge-protection decisions differ from what managers say is important. As competition levels within an industry change and the industry appropriability regime changes in strength, there is a positive effect on intangibles protection where protection is easy to implement or has a low cost of implementation, for example Secrecy, Lead-time Advantage and Copyright. Where protection is more difficult to implement, for example, the Complexity of Designs and Registered Designs, a change in appropriability-regime strength has no significant effect. It is clear from the results that a firm's view of the *importance* of knowledge-protection mechanisms to innovation does not translate into practice.

Many previous studies (for example, Laursen and Salter, 2005; Hall and Sena, 2017) use the data reflecting importance of knowledge-protection mechanisms to reflect actual protection decisions made by firms. These results show that this data may be prone to subjectivity bias (Veugelers and Schneider, 2018), and therefore may not reflect the actual protection decisions that firms make. It may therefore be the case that managers' subjective viewpoints enter into the survey responses. The survey responses depend upon a manager's understanding of knowledge-protection mechanisms as well as their attitudes towards knowledge-protection mechanisms i.e. whether they think that they are important or not. A deeper understanding of what this data is saying is needed, but it is clear from the results that the responses are not a reflection of the actual knowledge-protection decisions which take place during the previous three-year period.

2.6.1 The drivers of a firm's intangibles strategy

The analysis undertaken in this study shows that both industry structure and the industry appropriability regime play a part in driving a firm's intangibles investment strategy. An increase in industry competition – from new entrants or from incumbents – has a consistent, negative effect on R&D investment. For other intangible investments, it seems that the source of the increase in competition matters for the direction of the effect. The probability of a firm investing in Computer Software is reduced following an increase in competition from incumbents, whereas the probability of a firm investing in Computer Software increases if the additional competition is from new entrants, for example.

In addition, the study also finds that the industry appropriability regime affects a firm's intangibles-investment strategy. In contrast to the results following a change in industry competition, a change in the industry appropriability regime has a similar impact – in terms of the direction of the effect – on the different intangible investments being examined.

With regards to knowledge protection, the analysis shows that both industry structure and the industry appropriability regime influence the importance firms attach to different informal and formal knowledge-protection mechanisms, although following a change in industry structure, it is only formal protection mechanisms that are viewed by firms as being more important (i.e. when competition from incumbents increases). Firms view both informal and formal knowledge-protection mechanisms as being more important following an increase in the industry appropriability-regime strength.

Whereas both industry structure and the industry appropriability regime influence intangibles investment and the importance firms attach to different knowledge-protection mechanisms, industry structure is less important for firms' actual protection decisions. Competition from incumbents has an insignificant effect on the probability of a firm using most knowledge-protection mechanisms. In contrast, as the industry appropriability regime strengthens, there is a significant, positive effect on a firm's use of the easier-to-implement protection mechanisms.

It is clear from the results that both industry structure and the industry appropriability regime drive firms' intangibles strategies. It is not possible to single out one component of the industry environment as having the greatest impact upon a firm's intangibles strategy – different parts of the industry environment impact on the different elements of a firm's intangibles strategy to varying extents.

2.6.2 Policy implications

The analysis here provides policymakers with an understanding of how different elements of the industry environment – industry structure and the industry appropriability regime – impact upon firms' innovation strategies. By ensuring that the correct policy levers are in place, the government can help firms foster the accumulation of intangibles and, in turn, unleash potential growth.

Policy designed to increase the available, effective protection mechanisms that firms have access to within an industry or policy designed to help firms strengthen natural protection – by promoting the use of tacit knowledge, for example (i.e. policy designed to strengthen industry appropriability regimes) will encourage firms to invest in innovative activities. Some industries, for example the pharmaceutical industry, have strong appropriability regimes. Some firms in these industries may face barriers to formal protection (for example, smaller firms), and government policy should target these firms; innovation vouchers should be issued to help those firms facing financial constraints, firms should be helped to identify the IP that they own, firms should be guided through the formal-IP application process, and firms should be able to seek advice if an IP-infringement occurs. Other industries, for example the soft-drinks industry, have weak appropriability regimes. Typically, formal protection such as patents is ineffective, and firms rely on trademarks, copyright and easier-to-implement protection such as secrecy. In the case of the soft-drinks industry, secret recipes help deter imitation, for example. Government policy should help firms in these industries develop a protection strategy using formal protection mechanisms such as trademarks and copyright and informal protection mechanisms such as secrecy. Examples of ways in which government policy initiatives can support firms to increase their informal protection include: designating an individual within the firm to identify intellectual property and implement and enforce secrecy compliance; making IP protection part of the employees' orientation and training program, and informing those employees who have access to firm-specific knowledge and confidential information of their continuing duty to prevent disclosure; prohibiting individuals from making copies of confidential information unless it is necessary for them to perform their duties; and prohibiting employees from downloading proprietary software onto portable computers without prior authorisation and maintain detailed records of employees permitted to download proprietary software. The Intellectual Property Office (IPO) (the official UK government body responsible for intellectual property rights) should, in the same way as they do for formal protection, provide events, tool-kits, case studies and guidance to help firms use these and other informal strategies as a way of protecting their knowledge in an informal way. In summary, government policy aimed at increasing appropriability strength across all industries – by promoting both informal and formal knowledge protection – will encourage innovative investment in all firms.

An increase in industry competition sees firms increase their use of informal protection mechanisms and identify formal mechanisms as having an increased level of importance in the innovation process. Firms should be encouraged to know their market – they should actively monitor the market in which they are engaged as firms can only react to changes in their competitive environment if they know that they have happened. Monitoring competitors' behaviour can be costly - both financially and in terms of time. Large firms may employ market analysts to keep abreast of the industry climate, whereas small firms may be resource constrained. Policy initiatives should be put in place to help firms monitor their market and set up appropriate strategies in order to protect themselves.

2.6.3 Limitations and future work

There are several limitations to this study. First, the high degree of correlation between the variables designed to represent the industry appropriability regime means that each element of the regime is analysed in a separate regression model – it is not possible to examine the impact of the industry appropriability regime on a firm's intangibles strategy in a single estimated equation. Future work will aim to address this issue and seek ways to create a single measure representing the industry appropriability regime. Second, the analysis here considers the UK only. Some countries are more intangible-intensive than others. For example, Spain and Italy have relatively lower shares of intangibles as a proportion of GDP and tend to be more tangible-intensive. Germany, France and the Netherlands have a low-to-moderate intensity whereas Finland, the UK, the US and Sweden have the highest intangible intensities. IP systems vary from country to country, and the availability and effectiveness of knowledge-protection mechanisms may differ in different countries. Consequently, the findings in this study may not be observed in other countries. Future work aims to carry out a similar analysis in other countries, providing that the data is available. Third, the UK CIS data on knowledge protection is binary data indicating whether protection took place or not. There is no indication as to how much knowledge protection firms use. Future research will attempt to link firms' IP application and acquisition data – more specifically, data for patents, trademarks and registered designs – with a pooled UK CIS panel dataset in order to address this limitation and enable a more in-depth analysis to be carried out. Fourth, the analysis here is carried out across all industries and all sizes of firm. Using a pooled UK CIS panel dataset and matched IP data, future research will conduct a more detailed exploration of a firm's intangibles strategy. Results for different sizes of firm and different sectoral contexts will be explored – for example individual-industry comparisons will be made as well as comparisons between high-technology/knowledge-intensive industries and low-technology/less knowledge-intensive industries. Fifth, the analysis assumes that the industry appropriability regime is exogenous, and firms are required to consider the protection mechanisms that are available. The assumption that firms only adjust their knowledge-protection strategies in this way may be too narrow. Sixth, the theoretical framework here reflects the knowledge-protection mechanisms which are currently available to firms in the UK. It is becoming increasingly acknowledged that these knowledge-protection mechanisms may not be suitable in economies with a growing role for intangible capital. The fundamental shift in technology and in the economic landscape which has taken place in recent years has made the current system of intellectual property rights unworkable and ineffective (Thurow, 1997). The present IP system, designed more than one hundred years ago, may have worked when patents were granted for mechanical devices, for example, but the so-called 'brain-power' economy of today, poses additional challenges. It is clear, for example, that "the invention of a new gene cannot be handled in the same way as the invention of a new gearbox," (Thurow, 1997 p.98). The software industry is an example where firms have suffered due to patenting and copyright laws not keeping up with technology. Courts ruled that the look and feel of software programs could not be patented, opening the door to imitators. Programmers with the knowledge to write their own code have been able to imitate successfully because they know what the program is supposed to do and how the final program is supposed to look and feel. It is desirable that a new, optimal IP system be different across industries, types of knowledge and types of inventors. For example, the electronics industry wants speed and short-term protection, whereas the pharmaceuticals industry wants long-term protection because most of its money is earned after a long period of testing to prove a drug's effectiveness and the absence of adverse side effects. Advances in knowledge need to be distinguished from one another and patents awarded on that basis. In addition, a differentiated patent system may offer innovators the opportunity to choose from a selection of protection mechanisms. An overhaul of the current one-size-fits-all, one-dimensional IP system is required to accommodate fast-developing knowledge-based economies. Finally, this study is limited because the estimations adopt a reductionist perspective (Venkatraman and Prescott, 1990) – this has the advantage of being able to separate out specified theoretical links but the disadvantage of specification errors due to ceteris paribus conditions.

Table 2.1: Descriptive statistics

Variable	No. of observations	Mean	Standard deviation
R&D investment (0/1)	74,427	0.27	0.44
Design investment (0/1) (CIS 4, 5, 6)	43,423	0.20	0.40
Design investment (0/1) (CIS 7, 8)	28,829	0.12	0.32
Training (0/1)	72,275	0.28	0.45
Computer software (0/1)	56,439	0.35	0.48
Importance of secrecy (0/1/2/3)	28,594	0.79	1.09
Importance of complexity of design (0/1/2/3)	28,589	0.60	0.94
Importance of lead time (0/1/2/3)	28,604	0.84	1.12
Importance of confidentiality agreements (0/1/2/3)	28,638	0.89	1.17
Importance of copyright (0/1/2/3)	28,579	0.51	0.96
Importance of patents (0/1/2/3)	28,591	0.46	0.94
Importance of trademarks (0/1/2/3)	28,610	0.60	1.03
Importance of registration of designs (0/1/2/3)	28,595	0.47	0.92
Use of secrecy (0/1)	14,342	0.09	0.28
Use of complexity of design (0/1)	14,342	0.03	0.16
Use of lead time (0/1)	14,342	0.04	0.18
Use of patents (0/1)	28,623	0.04	0.20
Use of registration of designs (0/1)	28,623	0.02	0.12
Use of trademarks (0/1)	28,623	0.06	0.24
Use of copyright (0/1)	28,623	0.05	0.22
Employment (log)	63,149	3.87	1.76
Exporter (0/1)	74,427	0.29	0.45
Engaged in co-operation - any innovation activity (0/1)	74,427	0.20	0.40
Science graduates (% workforce)	58,438	6.35	15.96
Other graduates (% workforce)	59,918	9.35	19.31
Received public financial support for innovation (0/1)	45,068	0.08	0.27
Average propensity for a firm to be a product innovator within the industry	13	0.25	0.08
Average propensity for a firm to be a process innovator within the industry	13	0.15	0.06
Average propensity within the industry to view industry standards as being important to innovation activities	13	0.09	0.02
Average propensity within the industry for a firm to view industry publications as being important to innovation activities	13	0.04	0.01
Average propensity within the industry for a firm to use new informal methods of protection or to view them as being important	13	0.23	0.09
Average propensity within the industry for a firm to use new formal methods of protection or to view them as being important	13	0.22	0.07
Industry birth rate (%) *	65	0.19	0.07
Industry concentration ratio (five-firm) **	65	0.12	0.10

Notes: * The proportion of new firms entering the industry group during the three-year CIS period
** The share of industry-group turnover accounted for by the five largest firms within the industry group – in terms of turnover (individual year values are averaged across each CIS wave)
Source: UK CIS 2002 to 2012 and BSD 1997 to 2012

Table 2.1 (continued): Descriptive statistics

	Proportion of firms using each knowledge-protection mechanism (%)									
Knowledge-protection mechanism	**All innovators** **N=3,520**	**New-to-the-market innovators** **N=557**	**New-to-the-firm innovators** **N=1,344**	**Small-sized innovators** **N=1,491**	**Medium-sized innovators** **N=1,143**	**Large-sized innovators** **N=789**	**High-technology, knowledge-intensive innovators** **N=1,758**	**Low-technology, less knowledge-intensive innovators** **N=1,762**	**Service sector innovators** **N=2,310**	**Manufacturing sector innovators** **N=1,210**
Patent	12.8	22.8	7.2	9.6	14.7	17.0	15.8	9.8	8.9	20.2
Registered industrial design	4.5	6.5	2.2	3.0	5.0	7.1	4.5	4.5	2.7	7.9
Registered trademark	14.7	18.9	10.8	10.9	15.3	21.5	15.0	14.4	13.0	17.9
Copyright	12.6	16.7	8.6	12.2	11.2	15.7	15.4	9.7	11.5	14.6
Secrecy (including non-disclosure agreements)	27.8	36.3	22.0	26.9	29.0	28.8	35.4	20.2	24.5	34.0
Complexity of design	9.0	13.6	6.7	8.3	9.5	10.1	11.9	6.0	6.8	13.2
Lead-advantage time	11.8	16.5	8.3	12.3	11.1	12.0	13.1	10.5	9.1	16.9

Source: UK CIS, 2008 to 2010

Table 2.2: Correlation matrix: R&D, training and computer software investment (N=22,653)

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
(1) R&D investment (0/1)	1.00																
(2) Training investment (0/1)	0.49	1.00															
(3) Computer software investment (0/1)	0.42	0.46	1.00														
(4) Employment (log)	0.08	0.07	0.02	1.00													
(5) Exporter (0/1)	0.32	0.17	0.16	0.10	1.00												
(6) Engaged in co-operation - any innovation activity (0/1)	0.48	0.38	0.35	0.09	0.26	1.00											
(7) Science graduates (% workforce)	0.25	0.18	0.15	-0.01	0.26	0.21	1.00										
(8) Other graduates (% workforce)	0.14	0.11	0.11	0.01	0.15	0.12	0.14	1.00									
(9) Received public financial support for innovation (0/1)	0.28	0.22	0.18	0.01	0.19	0.27	0.24	0.03	1.00								
(10) Average propensity for a firm to be a product innovator within the industry	0.22	0.09	0.07	0.02	0.30	0.14	0.05	-0.01	0.14	1.00							
(11) Average propensity for a firm to be a process innovator within the industry	0.23	0.09	0.08	0.02	0.29	0.14	0.07	0.02	0.13	0.98	1.00						
(12) Average propensity within the industry to view industry standards as being important to innovation activities	0.19	0.09	0.07	0.00	0.19	0.12	0.15	0.10	0.12	0.73	0.81	1.00					
(13) Average propensity within the industry for a firm to view industry publications as being important to innovation activities	0.17	0.08	0.07	0.01	0.19	0.11	0.20	0.13	0.12	0.68	0.72	0.85	1.00				
(14) Average propensity within the industry for a firm to use new informal methods of protection or to view them as being important	0.22	0.09	0.08	0.02	0.29	0.15	0.08	0.02	0.14	0.98	0.99	0.83	0.79	1.00			
(15) Average propensity within the industry for a firm to use new formal methods of protection or to view them as being important	0.22	0.09	0.08	0.02	0.28	0.14	0.11	0.06	0.13	0.95	0.95	0.82	0.85	0.97	1.00		
(16) Industry birth rate (%) *	-0.06	0.01	0.02	0.03	-0.20	-0.07	0.14	0.13	-0.05	-0.39	-0.31	0.07	0.16	-0.30	-0.23	1.00	
(17) Industry concentration ratio (five-firm) **	-0.07	-0.03	-0.01	-0.02	-0.05	-0.03	-0.05	-0.01	-0.06	-0.30	-0.22	-0.31	-0.39	-0.30	-0.36	0.01	1.00

Notes: * The proportion of new firms entering the industry group during the three-year CIS period
** The share of industry-group turnover accounted for by the five largest firms within the industry group – in terms of turnover (individual year values are averaged across each CIS wave)
Source: UK CIS 2002 to 2012 and BSD 1997 to 2012

Table 2.3: Correlation matrix: Design investment (CIS 4, CIS 5 and CIS 6, N=30,020)

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
(1) design investment (0/1)	1.00														
(2) Employment (log)	0.12	1.00													
(3) Exporter (0/1)	0.25	0.16	1.00												
(4) Engaged in co-operation - any innovation activity (0/1)	0.32	0.13	0.22	1.00											
(5) Science graduates (% workforce)	0.17	0.02	0.23	0.19	1.00										
(6) Other graduates (% workforce)	0.09	0.05	0.12	0.10	0.16	1.00									
(7) Received public financial support for innovation (0/1)	0.21	0.03	0.19	0.24	0.23	0.05	1.00								
(8) Average propensity for a firm to be a product innovator within the industry	0.21	0.05	0.32	0.11	0.04	-0.01	0.15	1.00							
(9) Average propensity for a firm to be a process innovator within the industry	0.20	0.05	0.31	0.11	0.06	0.02	0.15	0.98	1.00						
(10) Average propensity within the industry to view industry standards as being important to innovation activities	0.16	0.03	0.22	0.11	0.15	0.08	0.13	0.74	0.81	1.00					
(11) Average propensity within the industry for a firm to view industry publications as being important to innovation activities	0.14	0.05	0.22	0.10	0.19	0.10	0.14	0.70	0.72	0.83	1.00				
(12) Average propensity within the industry for a firm to use new informal methods of protection or to view them as being important	0.21	0.05	0.31	0.11	0.07	0.01	0.15	0.98	0.99	0.84	0.79	1.00			
(13) Average propensity within the industry for a firm to use new formal methods of protection or to view them as being important	0.20	0.06	0.30	0.11	0.10	0.05	0.15	0.95	0.96	0.82	0.85	0.98	1.00		
(14) Industry birth rate (%) *	-0.12	-0.10	-0.17	-0.08	0.15	0.13	-0.02	-0.46	-0.38	-0.08	0.06	-0.38	-0.32	1.00	
(15) Industry concentration ratio (five-firm) **	-0.06	-0.02	-0.04	-0.02	-0.05	-0.01	-0.06	-0.21	-0.13	-0.27	-0.38	-0.23	-0.30	0.11	1.00

Notes: * The proportion of new firms entering the industry group during the three-year CIS period
** The share of industry-group turnover accounted for by the five largest firms within the industry group – in terms of turnover (individual year values are averaged across each CIS wave)
Source: UK CIS 2002 to 2012 and BSD 1997 to 2012

Table 2.4: Correlation matrix: Design investment (CIS 7 and CIS 8, N=8,384)

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
(1) Design investment	1.00														
(2) Employment (log)	0.09	1.00													
(3) Exporter (0/1)	0.26	0.15	1.00												
(4) Engaged in co-operation - any innovation activity (0/1)	0.41	0.15	0.24	1.00											
(5) Science graduates (% workforce)	0.19	0.03	0.26	0.21	1.00										
(6) Other graduates (% workforce)	0.06	0.03	0.12	0.08	0.11	1.00									
(7) Received public financial support for innovation (0/1)	0.22	0.05	0.17	0.29	0.24	0.01	1.00								
(8) Average propensity for a firm to be a product innovator within the industry	0.21	0.08	0.36	0.17	0.06	0.00	0.13	1.00							
(9) Average propensity for a firm to be a process innovator within the industry	0.20	0.08	0.35	0.17	0.08	0.03	0.13	0.98	1.00						
(10) Average propensity within the industry to view industry standards as being important to innovation activities	0.15	0.05	0.21	0.14	0.17	0.12	0.13	0.72	0.80	1.00					
(11) Average propensity within the industry for a firm to view industry publications as being important to innovation activities	0.13	0.03	0.23	0.13	0.21	0.16	0.12	0.70	0.74	0.85	1.00				
(12) Average propensity within the industry for a firm to use new informal methods of protection or to view them as being important	0.20	0.08	0.35	0.17	0.09	0.03	0.14	0.98	0.99	0.83	0.80	1.00			
(13) Average propensity within the industry for a firm to use new formal methods of protection or to view them as being important	0.19	0.07	0.34	0.17	0.12	0.08	0.13	0.95	0.96	0.80	0.86	0.97	1.00		
(14) Industry birth rate (%) *	-0.11	-0.06	-0.22	-0.07	0.17	0.20	-0.03	-0.43	-0.30	0.16	0.16	-0.30	-0.26	1.00	
**(15) Industry concentration ratio (five-firm) ** **	-0.09	0.04	-0.05	-0.03	-0.05	-0.02	-0.05	-0.30	-0.25	-0.32	-0.33	-0.29	-0.33	0.11	1.00

Notes: * The proportion of new firms entering the industry group during the three-year CIS period
** The share of industry-group turnover accounted for by the five largest firms within the industry group – in terms of turnover (individual year values are averaged across each CIS wave)
Source: UK CIS 2002 to 2012 and BSD 1997 to 2012

Table 2.5: Correlation matrix: Importance of knowledge-protection mechanisms (CIS 4 and CIS 5, N=15,648)

Variable	1	2	3	4	5	6	7	8	9	10	11
(1) Importance of secrecy (0/1/2/3)	1.00										
(2) Importance of complexity of design (0/1/2/3)	0.72	1.00									
(3) Importance of lead time (0/1/2/3)	0.71	0.74	1.00								
(4) Importance of confidentiality agreements (0/1/2/3)	0.76	0.64	0.64	1.00							
(5) Importance of copyright (0/1/2/3)	0.60	0.59	0.53	0.63	1.00						
(6) Importance of patents (0/1/2/3)	0.56	0.59	0.52	0.59	0.65	1.00					
(7) Importance of trademarks (0/1/2/3)	0.56	0.54	0.52	0.58	0.67	0.72	1.00				
(8) Importance of registration of designs (0/1/2/3)	0.54	0.59	0.52	0.56	0.67	0.76	0.74	1.00			
(9) Employment (log)	0.25	0.23	0.23	0.25	0.19	0.21	0.23	0.20	1.00		
(10) Exporter (0/1)	0.33	0.35	0.33	0.33	0.27	0.33	0.29	0.27	0.23	1.00	
(11) Engaged in co-operation - any innovation activity (0/1)	0.27	0.25	0.26	0.30	0.19	0.20	0.17	0.15	0.14	0.18	1.00
(12) Science graduates (% workforce)	0.24	0.25	0.20	0.28	0.22	0.22	0.14	0.14	0.06	0.21	0.17
(13) Other graduates (% workforce)	0.14	0.12	0.11	0.17	0.17	0.08	0.10	0.09	0.09	0.09	0.06
(14) Received public financial support for innovation (0/1)	0.24	0.25	0.24	0.25	0.17	0.24	0.16	0.16	0.07	0.19	0.25
(15) Average propensity for a firm to be a product innovator within the industry	0.23	0.27	0.27	0.22	0.18	0.24	0.18	0.21	0.10	0.36	0.09
(16) Average propensity for a firm to be a process innovator within the industry	0.23	0.27	0.27	0.23	0.17	0.23	0.17	0.20	0.10	0.35	0.09
(17) Average propensity within the industry to view industry standards as being important to innovation activities	0.20	0.23	0.22	0.22	0.15	0.18	0.12	0.15	0.08	0.26	0.09
(18) Average propensity within the industry for a firm to view industry publications as being important to innovation activities	0.20	0.22	0.21	0.21	0.17	0.19	0.13	0.16	0.08	0.27	0.08
(19) Average propensity within the industry for a firm to use new informal methods of protection or to view them as being important	0.23	0.27	0.27	0.23	0.18	0.24	0.18	0.21	0.11	0.36	0.09
(20) Average propensity within the industry for a firm to use new formal methods of protection or to view them as being important	0.23	0.27	0.26	0.23	0.19	0.23	0.18	0.20	0.11	0.34	0.10
(21) Industry birth rate (%) *	-0.08	-0.13	-0.13	-0.05	-0.06	-0.13	-0.12	-0.13	-0.07	-0.19	-0.03
(22) Industry concentration ratio (five-firm) **	-0.04	-0.06	-0.04	-0.04	-0.07	-0.07	-0.05	-0.06	-0.02	-0.02	-0.02

Table 2.5 (continued): Correlation matrix: Importance of knowledge-protection mechanisms (CIS4 and CIS5, N=15,648)

Variable	12	13	14	15	16	17	18	19	20	21	22
(12) Science graduates (% workforce)	1.00										
(13) Other graduates (% workforce)	0.16	1.00									
(14) Received public financial support for innovation (0/1)	0.22	0.05	1.00								
(15) Average propensity for a firm to be a product innovator within the industry	0.04	-0.01	0.16	1.00							
(16) Average propensity for a firm to be a process innovator within the industry	0.06	0.02	0.16	0.98	1.00						
(17) Average propensity within the industry to view industry standards as being important to innovation activities	0.14	0.07	0.14	0.74	0.81	1.00					
(18) Average propensity within the industry for a firm to view industry publications as being important to innovation activities	0.19	0.08	0.15	0.72	0.74	0.83	1.00				
(19) Average propensity within the industry for a firm to use new informal methods of protection or to view them as being important	0.07	0.01	0.16	0.98	0.99	0.83	0.81	1.00			
(20) Average propensity within the industry for a firm to use new formal methods of protection or to view them as being important	0.09	0.04	0.16	0.96	0.96	0.81	0.85	0.98	1.00		
(21) Industry birth rate (%) *	0.14	0.12	-0.04	-0.51	-0.43	-0.18	0.00	-0.44	-0.39	1.00	
(22) Industry concentration ratio (five-firm) **	-0.04	0.00	-0.05	-0.16	-0.07	-0.25	-0.35	-0.18	-0.24	0.22	1.00

Notes: * The proportion of new firms entering the industry group during the three-year CIS period
** The share of industry-group turnover accounted for by the five largest firms within the industry group – in terms of turnover (individual year values are averaged across each CIS wave)
Source: UK CIS 2002 to 2012 and BSD 1997 to 2012

Table 2.6: Correlation matrix: Use of knowledge-protection mechanisms (CIS6 and CIS7, N=8,384)

Variable	1	2	3	4	5	6	7	8	9	10	11
(1) Use of secrecy (0/1)	1.00										
(2) Use of complexity of design (0/1)	0.37	1.00									
(3) Use of lead time (0/1)	0.32	0.34	1.00								
(4) Use of patents (0/1)	0.36	0.29	0.18	1.00							
(5) Use of registration of designs (0/1)	0.22	0.23	0.21	0.44	1.00						
(6) Use of trademarks (0/1)	0.29	0.17	0.15	0.35	0.33	1.00					
(7) Use of copyright (0/1)	0.39	0.31	0.24	0.33	0.32	0.35	1.00				
(8) Employment (log)	0.08	0.04	0.03	0.11	0.07	0.11	0.05	1.00			
(9) Exporter (0/1)	0.32	0.18	0.15	0.25	0.14	0.18	0.19	0.15	1.00		
(10) Engaged in co-operation - any innovation activity (0/1)	0.36	0.22	0.24	0.24	0.15	0.21	0.23	0.15	0.24	1.00	
(11) Science graduates (% workforce)	0.31	0.19	0.12	0.25	0.06	0.09	0.19	0.03	0.26	0.21	1.00
(12) Other graduates (% workforce)	0.09	0.04	0.02	0.02	0.02	0.08	0.14	0.03	0.12	0.08	0.11
(13) Received public financial support for innovation (0/1)	0.29	0.21	0.17	0.27	0.10	0.13	0.17	0.05	0.17	0.29	0.24
(14) Average propensity for a firm to be a product innovator within the industry	0.19	0.12	0.14	0.17	0.11	0.09	0.11	0.08	0.36	0.17	0.06
(15) Average propensity for a firm to be a process innovator within the industry	0.20	0.12	0.14	0.16	0.10	0.08	0.11	0.08	0.35	0.17	0.08
(16) Average propensity within the industry to view industry standards as being important to innovation activities	0.17	0.10	0.10	0.13	0.06	0.03	0.10	0.05	0.21	0.14	0.17
(17) Average propensity within the industry for a firm to view industry publications as being important to innovation activities	0.18	0.09	0.09	0.13	0.05	0.04	0.11	0.03	0.23	0.13	0.21
(18) Average propensity within the industry for a firm to use new informal methods of protection or to view them as being important	0.20	0.12	0.14	0.17	0.10	0.08	0.11	0.08	0.35	0.17	0.09
(19) Average propensity within the industry for a firm to use new formal methods of protection or to view them as being important	0.20	0.11	0.13	0.16	0.10	0.09	0.12	0.07	0.34	0.17	0.12
(20) Industry birth rate (%) *	-0.04	-0.04	-0.08	-0.08	-0.09	-0.09	-0.02	-0.06	-0.22	-0.07	0.17
(21) Industry concentration ratio (five-firm) **	-0.06	-0.04	-0.04	-0.07	-0.04	-0.02	-0.04	0.04	-0.05	-0.03	-0.05

Table 2.6 (continued): Correlation matrix: Use of knowledge-protection mechanisms (CIS6 and CIS7, N=8,384)

Variable	12	13	14	15	16	17	18	19	20	21
(12) Other graduates (% workforce)	1.00									
(13) Received public financial support for innovation (0/1)	0.01	1.00								
(14) Average propensity for a firm to be a product innovator within the industry	0.00	0.13	1.00							
(15) Average propensity for a firm to be a process innovator within the industry	0.03	0.13	0.98	1.00						
(16) Average propensity within the industry to view industry standards as being important to innovation activities	0.12	0.13	0.72	0.80	1.00					
(17) Average propensity within the industry for a firm to view industry publications as being important to innovation activities	0.16	0.12	0.70	0.74	0.85	1.00				
(18) Average propensity within the industry for a firm to use new informal methods of protection or to view them as being important	0.03	0.14	0.98	0.99	0.83	0.80	1.00			
(19) Average propensity within the industry for a firm to use new formal methods of protection or to view them as being important	0.08	0.13	0.95	0.96	0.80	0.86	0.97	1.00		
(20) Industry birth rate (%) *	0.20	-0.03	-0.43	-0.30	0.16	0.16	-0.30	-0.26	1.00	
(21) Industry concentration ratio (five-firm) **	-0.02	-0.05	-0.30	-0.25	-0.32	-0.33	-0.29	-0.33	0.11	1.00

Notes: * The proportion of new firms entering the industry group during the three-year CIS period
** The share of industry-group turnover accounted for by the five largest firms within the industry group – in terms of turnover (individual year values are averaged across each CIS wave)
Source: UK CIS 2002 to 2012 and BSD 1997 to 2012

Table 2.7: R&D investment – Heteroscedastic probit model (marginal effects)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Employment (log)	0.025***	0.025***	0.024***	0.024***	0.025***	0.024***
	0.001	0.001	0.001	0.001	0.001	0.001
Exporter (0/1)	0.147***	0.148***	0.154***	0.154***	0.147***	0.147***
	0.006	0.006	0.006	0.006	0.006	0.006
Engaged in co-operation - any innovation activity (0/1)	0.379***	0.378***	0.370***	0.374***	0.377***	0.375***
	0.007	0.007	0.007	0.007	0.007	0.007
Science graduates (% workforce)	0.004***	0.004***	0.003***	0.003***	0.004***	0.004***
	0.000	0.000	0.000	0.000	0.000	0.000
Other graduates (% workforce)	0.002***	0.002***	0.002***	0.002***	0.002***	0.002***
	0.000	0.000	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	0.242***	0.243***	0.236***	0.241***	0.240***	0.241***
	0.011	0.011	0.010	0.010	0.011	0.011
Industry birth rate (%)	-0.096*	-0.179***	-0.607***	-0.805***	-0.197***	-0.282***
	0.057	0.054	0.049	0.048	0.054	0.052
Industry concentration ratio (five-firm)	0.136***	0.105**	0.211**	0.199***	0.204***	0.238***
	0.049	0.046	0.084	0.066	0.051	0.054
Av. propensity to be a product innovator within the industry	0.861***					
	0.041					
Av. propensity to be a process innovator within the industry		1.128***				
		0.052				
Av. propensity within the industry to view industry standards as being important to innovation			2.517***			
			0.145			
Av. propensity within the industry to view industry publications as being important to innovation				4.112***		
				0.268		
Av. propensity within the industry to use informal knowledge protection/view informal methods as being important					0.760***	
					0.037	
Av. propensity within the industry to use formal knowledge protection/view formal methods as being important						0.925***
						0.045
N	39046.000	39046.000	39046.000	39046.000	39046.000	39046.000
Chi-squared	308.382	413.988	297.969	326.615	377.156	328.392
p	0.000	0.000	0.000	0.000	0.000	0.000
bic	37588.753	37571.987	37683.436	37791.550	37609.235	37613.409

Notes: See Table 2.6
Coefficients are reported with standard errors below. Models contain wave dummies, * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2002 to 2012 and BSD 1997 to 2012.

Table 2.8: Design investment (CIS 4, CIS 5 and CIS 6) – Heteroscedastic probit model (marginal effects)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Employment (log)	0.015***	0.015***	0.015***	0.015***	0.015***	0.015***
	0.001	0.001	0.001	0.001	0.001	0.001
Exporter (0/1)	0.079***	0.081***	0.082***	0.081***	0.080***	0.080***
	0.005	0.005	0.005	0.005	0.005	0.005
Engaged in co-operation - any innovation activity (0/1)	0.216***	0.215***	0.209***	0.210***	0.215***	0.212***
	0.007	0.007	0.007	0.007	0.007	0.007
Science graduates (% workforce)	0.002***	0.002***	0.002***	0.002***	0.002***	0.002***
	0.000	0.000	0.000	0.000	0.000	0.000
Other graduates (% workforce)	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	0.107***	0.107***	0.104***	0.103***	0.106***	0.105***
	0.009	0.009	0.009	0.009	0.009	0.009
Industry birth rate (%)	-0.279***	-0.330***	-0.518***	-0.582***	-0.327***	-0.385***
	0.050	0.047	0.042	0.041	0.048	0.047
Industry concentration ratio (five-firm)	-0.101**	-0.129***	-0.082**	-0.051	-0.071*	-0.076*
	0.039	0.038	0.041	0.046	0.040	0.041
Av. propensity to be a product innovator within the industry	0.419***					
	0.035					
Av. propensity to be a process innovator within the industry		0.537***				
		0.045				
Av. propensity within the industry to view industry standards as being important to innovation			1.138***			
			0.108			
Av. propensity within the industry to view industry publications as being important to innovation				1.794***		
				0.225		
Av. propensity within the industry to use informal knowledge protection/view informal methods as being important					0.364***	
					0.032	
Av. propensity within the industry to use formal knowledge protection/view formal methods as being important						0.382***
						0.038
N	30020.000	30020.000	30020.000	30020.000	30020.000	30020.000
Chi-squared	282.964	355.035	296.151	349.623	338.929	310.840
p	0.000	0.000	0.000	0.000	0.000	0.000
bic	24824.256	24825.149	24859.198	24906.366	24835.583	24864.479

Notes: See Table 2.6
Coefficients are reported with standard errors below. Models contain wave dummies, * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2002 to 2012 and BSD 1997 to 2012.

Table 2.9: Design investment (CIS 7 and CIS 8) – Heteroscedastic probit model (marginal effects)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Employment (log)	0.002	0.002	0.002	0.002	0.002	0.002
	0.002	0.002	0.002	0.002	0.002	0.002
Exporter (0/1)	0.081***	0.081***	0.080***	0.081***	0.081***	0.082***
	0.010	0.010	0.010	0.010	0.010	0.010
Engaged in co-operation - any innovation activity (0/1)	0.257***	0.257***	0.257***	0.256***	0.257***	0.257***
	0.011	0.011	0.011	0.011	0.011	0.011
Science graduates (% workforce)	0.002***	0.002***	0.002***	0.002***	0.002***	0.002***
	0.000	0.000	0.000	0.000	0.000	0.000
Other graduates (% workforce)	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	0.076***	0.076***	0.075***	0.076***	0.075***	0.077***
	0.015	0.015	0.015	0.015	0.015	0.015
Industry birth rate (%)	-0.704***	-0.716***	-0.785***	-0.767***	-0.718***	-0.745***
	0.147	0.138	0.135	0.132	0.138	0.137
Industry concentration ratio (five-firm)	-0.714***	-0.712***	-0.715***	-0.745***	-0.719***	-0.731***
	0.144	0.139	0.135	0.133	0.136	0.133
Av. propensity to be a product innovator within the industry	0.065					
	0.072					
Av. propensity to be a process innovator within the industry		0.102				
		0.089				
Av. propensity within the industry to view industry standards as being important to innovation			0.251			
			0.203			
Av. propensity within the industry to view industry publications as being important to innovation				0.141		
				0.373		
Av. propensity within the industry to use informal knowledge protection/view informal methods as being important					0.064	
					0.060	
Av. propensity within the industry to use formal knowledge protection/view formal methods as being important						0.071
						0.069
N	8384.000	8384.000	8384.000	8384.000	8384.000	8384.000
Chi-squared	46.830	66.620	79.436	89.513	68.876	67.295
p	0.000	0.000	0.000	0.000	0.000	0.000
bic	6567.730	6567.169	6567.479	6568.421	6567.582	6565.936

Notes: See Table 2.6
Coefficients are reported with standard errors below. Models contain wave dummies, * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2002 to 2012 and BSD 1997 to 2012.

Table 2.10: Training investment – Heteroscedastic probit model (marginal effects)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Employment (log)	0.023***	0.023***	0.023***	0.023***	0.023***	0.023***
	0.001	0.001	0.001	0.001	0.001	0.001
Exporter (0/1)	0.026***	0.026***	0.029***	0.031***	0.027***	0.029***
	0.006	0.006	0.006	0.006	0.006	0.006
Engaged in co-operation - any innovation activity (0/1)	0.311***	0.311***	0.310***	0.311***	0.311***	0.311***
	0.006	0.006	0.006	0.006	0.006	0.006
Science graduates (% workforce)	0.002***	0.002***	0.002***	0.002***	0.002***	0.002***
	0.000	0.000	0.000	0.000	0.000	0.000
Other graduates (% workforce)	0.002***	0.002***	0.002***	0.002***	0.002***	0.002***
	0.000	0.000	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	0.171***	0.171***	0.170***	0.173***	0.171***	0.172***
	0.010	0.010	0.010	0.010	0.010	0.010
Industry birth rate (%)	0.087	0.067	-0.053	-0.104**	0.049	0.006
	0.054	0.053	0.047	0.046	0.052	0.050
Industry concentration ratio (five-firm)	0.158***	0.154***	0.218***	0.168***	0.175***	0.165***
	0.041	0.042	0.044	0.044	0.043	0.042
Av. propensity to be a product innovator within the industry	0.269***					
	0.038					
Av. propensity to be a process innovator within the industry		0.372***				
		0.050				
Av. propensity within the industry to view industry standards as being important to innovation			1.041***			
			0.123			
Av. propensity within the industry to view industry publications as being important to innovation				0.952***		
				0.242		
Av. propensity within the industry to use informal knowledge protection/view informal methods as being important					0.231***	
					0.035	
Av. propensity within the industry to use formal knowledge protection/view formal methods as being important						0.222***
						0.041
N	38404.000	38404.000	38404.000	38404.000	38404.000	38404.000
Chi-squared	243.632	318.368	281.225	309.270	303.988	269.146
p	0.000	0.000	0.000	0.000	0.000	0.000
bic	41481.630	41474.279	41458.317	41516.461	41486.390	41502.705

Notes: See Table 2.6
Coefficients are reported with standard errors below. Models contain wave dummies, * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2002 to 2012 and BSD 1997 to 2012.

Table 2.11: Computer software investment – Heteroscedastic probit model (marginal effects)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Employment (log)	-0.006***	-0.006***	-0.006***	-0.006***	-0.006***	-0.006***
	0.002	0.002	0.002	0.002	0.002	0.002
Exporter (0/1)	0.059***	0.060***	0.062***	0.062***	0.060***	0.061***
	0.008	0.008	0.008	0.008	0.008	0.008
Engaged in co-operation - any innovation activity (0/1)	0.332***	0.332***	0.332***	0.332***	0.332***	0.332***
	0.007	0.007	0.007	0.007	0.007	0.007
Science graduates (% workforce)	0.001***	0.001***	0.002***	0.002***	0.001***	0.002***
	0.000	0.000	0.000	0.000	0.000	0.000
Other graduates (% workforce)	0.002***	0.002***	0.002***	0.002***	0.002***	0.002***
	0.000	0.000	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	0.154***	0.154***	0.157***	0.158***	0.155***	0.155***
	0.014	0.014	0.014	0.014	0.014	0.014
Industry birth rate (%)	0.206***	0.187***	0.120*	0.119*	0.178**	0.168**
	0.074	0.071	0.067	0.068	0.071	0.069
Industry concentration ratio (five-firm)	0.386***	0.385***	0.340***	0.337***	0.379***	0.376***
	0.089	0.089	0.087	0.089	0.090	0.089
Av. propensity to be a product innovator within the industry	0.125**					
	0.055					
Av. propensity to be a process innovator within the industry		0.159**				
		0.070				
Av. propensity within the industry to view industry standards as being important to innovation			0.172			
			0.163			
Av. propensity within the industry to view industry publications as being important to innovation				0.268		
				0.316		
Av. propensity within the industry to use informal knowledge protection/view informal methods as being important					0.095*	
					0.049	
Av. propensity within the industry to use formal knowledge protection/view formal methods as being important						0.109*
						0.057
N	22653.000	22653.000	22653.000	22653.000	22653.000	22653.000
Chi-squared	89.800	117.690	121.783	138.808	118.610	110.035
p	0.000	0.000	0.000	0.000	0.000	0.000
bic	26551.681	26551.252	26553.419	26552.324	26551.579	26551.521

Notes: See Table 2.6
Coefficients are reported with standard errors below. Models contain wave dummies, * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2002 to 2012 and BSD 1997 to 2012.

Table 2.12: R&D investment – Homoscedastic probit model (marginal effects)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Employment (log)	0.025***	0.025***	0.025***	0.025***	0.025***	0.025***
	0.001	0.001	0.001	0.001	0.001	0.001
Exporter (0/1)	0.152***	0.154***	0.168***	0.164***	0.154***	0.156***
	0.006	0.006	0.006	0.006	0.006	0.006
Engaged in co-operation - any innovation activity (0/1)	0.385***	0.385***	0.384***	0.386***	0.385***	0.385***
	0.006	0.006	0.006	0.006	0.006	0.006
Science graduates (% workforce)	0.004***	0.004***	0.004***	0.004***	0.004***	0.004***
	0.000	0.000	0.000	0.000	0.000	0.000
Other graduates (% workforce)	0.002***	0.002***	0.002***	0.002***	0.002***	0.002***
	0.000	0.000	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	0.253***	0.254***	0.258***	0.259***	0.254***	0.257***
	0.011	0.011	0.011	0.011	0.011	0.011
Industry birth rate (%)	-0.130**	-0.233***	-0.641***	-0.784***	-0.259***	-0.339***
	0.052	0.050	0.046	0.046	0.050	0.049
Industry concentration ratio (five-firm)	0.128***	0.086**	0.164***	0.240***	0.175***	0.213***
	0.041	0.040	0.043	0.046	0.042	0.043
Av. propensity to be a product innovator within the industry	0.891***					
	0.039					
Av. propensity to be a process innovator within the industry		1.157***				
		0.050				
Av. propensity within the industry to view industry standards as being important to innovation			2.277***			
			0.125			
Av. propensity within the industry to view industry publications as being important to innovation				3.966***		
				0.251		
Av. propensity within the industry to use informal knowledge protection/view informal methods as being important					0.769***	
					0.035	
Av. propensity within the industry to use formal knowledge protection/view formal methods as being important						0.906***
						0.042
N	39046.000	39046.000	39046.000	39046.000	39046.000	39046.000
Chi-squared	11660.676	11675.167	11471.786	11391.346	11622.963	11600.827
p	0.000	0.000	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.237	0.238	0.234	0.232	0.237	0.236
bic	37590.633	37576.142	37779.523	37859.963	37628.346	37650.481

Notes: See Table 2.6
Coefficients are reported with standard errors below. Models contain wave dummies, * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2002 to 2012 and BSD 1997 to 2012.

Table 2.13: Design investment (CIS 4, CIS 5 and CIS 6) – Homoscedastic probit model (marginal effects)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Employment (log)	0.016***	0.015***	0.015***	0.015***	0.016***	0.015***
	0.001	0.001	0.001	0.001	0.001	0.001
Exporter (0/1)	0.083***	0.085***	0.092***	0.090***	0.084***	0.087***
	0.006	0.006	0.005	0.006	0.006	0.006
Engaged in co-operation - any innovation activity (0/1)	0.228***	0.227***	0.227***	0.229***	0.227***	0.228***
	0.007	0.007	0.007	0.007	0.007	0.007
Science graduates (% workforce)	0.002***	0.001***	0.001***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000	0.000	0.000
Other graduates (% workforce)	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	0.111***	0.112***	0.116***	0.117***	0.112***	0.115***
	0.009	0.009	0.009	0.009	0.009	0.009
Industry birth rate (%)	-0.273***	-0.332***	-0.563***	-0.657***	-0.337***	-0.415***
	0.045	0.043	0.039	0.038	0.043	0.042
Industry concentration ratio (five-firm)	-0.055	-0.085**	-0.034	0.015	-0.019	-0.017
	0.036	0.036	0.038	0.042	0.038	0.038
Av. propensity to be a product innovator within the industry	0.516***					
	0.035					
Av. propensity to be a process innovator within the industry		0.660***				
		0.045				
Av. propensity within the industry to view industry standards as being important to innovation			1.351***			
			0.114			
Av. propensity within the industry to view industry publications as being important to innovation				2.246***		
				0.230		
Av. propensity within the industry to use informal knowledge protection/view informal methods as being important					0.455***	
					0.031	
Av. propensity within the industry to use formal knowledge protection/view formal methods as being important						0.483***
						0.038
N	30020.000	30020.000	30020.000	30020.000	30020.000	30020.000
Chi-squared	4951.204	4945.996	4870.704	4823.315	4939.064	4890.689
p	0.000	0.000	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.167	0.167	0.164	0.162	0.166	0.165
bic	24875.303	24880.510	24955.803	25003.191	24887.442	24935.818

Notes: See Table 2.6
Coefficients are reported with standard errors below. Models contain wave dummies, * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2002 to 2012 and BSD 1997 to 2012.

Table 2.14: Design investment (CIS 7 and CIS 8) – Homoscedastic probit model (marginal effects)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Employment (log)	0.002	0.002	0.002	0.002	0.002	0.002
	0.002	0.002	0.002	0.002	0.002	0.002
Exporter (0/1)	0.083***	0.083***	0.083***	0.085***	0.082***	0.083***
	0.010	0.010	0.010	0.010	0.010	0.010
Engaged in co-operation - any innovation activity (0/1)	0.269***	0.268***	0.268***	0.269***	0.268***	0.269***
	0.010	0.010	0.010	0.010	0.010	0.010
Science graduates (% workforce)	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000	0.000	0.000
Other graduates (% workforce)	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	0.076***	0.076***	0.075***	0.076***	0.076***	0.076***
	0.015	0.015	0.015	0.015	0.015	0.015
Industry birth rate (%)	-0.719***	- 0.746***	-0.883***	-0.876***	-0.752***	-0.779***
	0.137	0.127	0.118	0.119	0.126	0.123
Industry concentration ratio (five-firm)	-0.810***	- 0.807***	-0.826***	-0.901***	-0.816***	-0.852***
	0.142	0.137	0.131	0.125	0.135	0.129
Av. propensity to be a product innovator within the industry	0.131*					
	0.071					
Av. propensity to be a process innovator within the industry		0.186**				
		0.087				
Av. propensity within the industry to view industry standards as being important to innovation			0.462**			
			0.198			
Av. propensity within the industry to view industry publications as being important to innovation				0.469		
				0.365		
Av. propensity within the industry to use informal knowledge protection/view informal methods as being important					0.126**	
					0.058	
Av. propensity within the industry to use formal knowledge protection/view formal methods as being important						0.134**
						0.068
N	8384.000	8384.000	8384.000	8384.000	8384.000	8384.000
Chi-squared	1793.352	1794.570	1795.407	1791.580	1794.682	1793.844
p	0.000	0.000	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.218	0.218	0.218	0.217	0.218	0.218
bic	6545.430	6544.212	6543.375	6547.202	6544.101	6544.938

Notes: See Table 2.6
Coefficients are reported with standard errors below. Models contain wave dummies, * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2002 to 2012 and BSD 1997 to 2012.

Table 2.15: Training investment – Homoscedastic probit model (marginal effects)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Employment (log)	0.024***	0.024***	0.024***	0.023***	0.024***	0.023***
	0.001	0.001	0.001	0.001	0.001	0.001
Exporter (0/1)	0.026***	0.026***	0.029***	0.032***	0.027***	0.029***
	0.006	0.006	0.006	0.006	0.006	0.006
Engaged in co-operation - any innovation activity (0/1)	0.312***	0.312***	0.312***	0.313***	0.312***	0.312***
	0.006	0.006	0.006	0.006	0.006	0.006
Science graduates (% workforce)	0.002***	0.002***	0.002***	0.002***	0.002***	0.002***
	0.000	0.000	0.000	0.000	0.000	0.000
Other graduates (% workforce)	0.002***	0.002***	0.002***	0.002***	0.002***	0.002***
	0.000	0.000	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	0.169***	0.169***	0.169***	0.172***	0.170***	0.171***
	0.010	0.010	0.010	0.010	0.010	0.010
Industry birth rate (%)	0.067	0.044	-0.074*	-0.121***	0.028	-0.015
	0.050	0.048	0.045	0.045	0.048	0.047
Industry concentration ratio (five-firm)	0.163***	0.156***	0.232***	0.178***	0.178***	0.171***
	0.039	0.039	0.041	0.044	0.040	0.041
Av. propensity to be a product innovator within the industry	0.269***					
	0.038					
Av. propensity to be a process innovator within the industry		0.372***				
		0.048				
Av. propensity within the industry to view industry standards as being important to innovation			1.067***			
			0.121			
Av. propensity within the industry to view industry publications as being important to innovation				0.951***		
				0.239		
Av. propensity within the industry to use informal knowledge protection/view informal methods as being important					0.231***	
					0.034	
Av. propensity within the industry to use formal knowledge protection/view formal methods as being important						0.220***
						0.040
N	38404.000	38404.000	38404.000	38404.000	38404.000	38404.000
Chi-squared	6710.081	6717.920	6736.332	6674.502	6705.349	6688.553
p	0.000	0.000	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.140	0.140	0.140	0.139	0.140	0.139
bic	41450.883	41443.045	41424.632	41486.462	41455.616	41472.411

Notes: See Table 2.6
Coefficients are reported with standard errors below. Models contain wave dummies, * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2002 to 2012 and BSD 1997 to 2012.

Table 2.16: Computer software investment – Homoscedastic probit model (marginal effects)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Employment (log)	-0.006***	-0.006***	-0.006***	-0.006***	-0.006***	-0.006***
	0.002	0.002	0.002	0.002	0.002	0.002
Exporter (0/1)	0.058***	0.058***	0.060***	0.060***	0.059***	0.059***
	0.008	0.008	0.008	0.008	0.008	0.008
Engaged in co-operation - any innovation activity (0/1)	0.331***	0.331***	0.331***	0.332***	0.331***	0.331***
	0.007	0.007	0.007	0.007	0.007	0.007
Science graduates (% workforce)	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000	0.000	0.000
Other graduates (% workforce)	0.002***	0.002***	0.002***	0.002***	0.002***	0.002***
	0.000	0.000	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	0.151***	0.151***	0.151***	0.152***	0.151***	0.151***
	0.013	0.013	0.013	0.013	0.013	0.013
Industry birth rate (%)	0.220***	0.201***	0.133**	0.125*	0.194***	0.182***
	0.073	0.070	0.065	0.066	0.070	0.068
Industry concentration ratio (five-firm)	0.413***	0.413***	0.374***	0.376***	0.414***	0.410***
	0.091	0.091	0.091	0.094	0.093	0.092
Av. propensity to be a product innovator within the industry	0.132**					
	0.054					
Av. propensity to be a process innovator within the industry		0.169**				
		0.070				
Av. propensity within the industry to view industry standards as being important to innovation			0.225			
			0.165			
Av. propensity within the industry to view industry publications as being important to innovation				0.379		
				0.322		
Av. propensity within the industry to use informal knowledge protection/view informal methods as being important					0.107**	
					0.048	
Av. propensity within the industry to use formal knowledge protection/view formal methods as being important						0.126**
						0.057
N	22653.000	22653.000	22653.000	22653.000	22653.000	22653.000
Chi-squared	3421.963	3422.008	3417.988	3417.511	3421.026	3420.990
p	0.000	0.000	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.115	0.115	0.115	0.115	0.115	0.115
bic	26515.953	26515.908	26519.927	26520.405	26516.889	26516.926

Notes: See Table 2.6
Coefficients are reported with standard errors below. Models contain wave dummies, * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2002 to 2012 and BSD 1997 to 2012.

Table 2.17: Importance of Secrecy – Homoscedastic ordered-probit model (marginal effects)

a. Average propensity to be a product innovator within the industry				
	Not important	**Low importance**	**Medium importance**	**High importance**
Employment (log)	-0.047***	0.011***	0.019***	0.017***
	0.002	0.001	0.001	0.001
Exporter (0/1)	-0.164***	0.033***	0.064***	0.067***
	0.009	0.002	0.004	0.004
Engaged in co-operation - any innovation activity (0/1)	-0.197***	0.031***	0.075***	0.091***
	0.010	0.001	0.004	0.006
Science graduates (% workforce)	-0.004***	0.001***	0.002***	0.001***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.002***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.155***	0.026***	0.059***	0.070***
	0.012	0.002	0.005	0.007
Av. propensity to be a product innovator within the industry	-0.812***	0.184***	0.325***	0.304***
	0.057	0.014	0.024	0.022
Industry birth rate (%)	-0.106	0.024	0.042	0.040
	0.073	0.017	0.029	0.027
Industry concentration ratio (five-firm)	-0.084	0.019	0.033	0.031
	0.056	0.013	0.022	0.021
N	15658.000	15658.000	15658.000	15658.000
Chi-squared	3870.073	3870.073	3870.073	3870.073
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.114	0.114	0.114	0.114
bic	30220.353	30220.353	30220.353	30220.353

b. Average propensity to be a process innovator within the industry				
	Not important	**Low importance**	**Medium importance**	**High importance**
Employment (log)	-0.047***	0.011***	0.019***	0.017***
	0.002	0.001	0.001	0.001
Exporter (0/1)	-0.166***	0.033***	0.065***	0.068***
	0.009	0.002	0.004	0.004
Engaged in co-operation - any innovation activity (0/1)	-0.196***	0.031***	0.074***	0.090***
	0.010	0.001	0.004	0.006
Science graduates (% workforce)	-0.004***	0.001***	0.002***	0.001***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.002***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.156***	0.026***	0.060***	0.070***
	0.012	0.002	0.005	0.007
Av. propensity to be a process innovator within the industry	-1.081***	0.245***	0.432***	0.404***
	0.074	0.018	0.031	0.028
Industry birth rate (%)	-0.032	0.007	0.013	0.012
	0.070	0.016	0.028	0.026
Industry concentration ratio (five-firm)	-0.053	0.012	0.021	0.020
	0.055	0.013	0.022	0.021
N	15658.000	15658.000	15658.000	15658.000
Chi-squared	3879.041	3879.041	3879.041	3879.041
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.114	0.114	0.114	0.114
bic	30211.385	30211.385	30211.385	30211.385

Table 2.17 (continued): Importance of Secrecy – Homoscedastic ordered-probit model (marginal effects)

c. Average propensity within the industry to view industry standards as being important to innovation

	Not important	Low importance	Medium importance	High importance
Employment (log)	-0.047***	0.010***	0.019***	0.018***
	0.002	0.001	0.001	0.001
Exporter (0/1)	-0.179***	0.035***	0.070***	0.075***
	0.008	0.002	0.003	0.004
Engaged in co-operation - any innovation activity (0/1)	-0.194***	0.031***	0.073***	0.089***
	0.010	0.001	0.004	0.006
Science graduates (% workforce)	-0.004***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.002***	0.000***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.162***	0.027***	0.062***	0.074***
	0.012	0.002	0.005	0.007
Av. propensity within the industry to view industry standards as being important to innovation	-2.423***	0.545***	0.967***	0.910***
	0.197	0.047	0.081	0.075
Industry birth rate (%)	0.262***	-0.059***	-0.105***	-0.098***
	0.065	0.015	0.026	0.024
Industry concentration ratio (five-firm)	-0.268***	0.060***	0.107***	0.101***
	0.061	0.014	0.024	0.023
N	15658.000	15658.000	15658.000	15658.000
Chi-squared	3817.355	3817.355	3817.355	3817.355
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.112	0.112	0.112	0.112
bic	30273.071	30273.071	30273.071	30273.071

d. Average propensity within the industry to view industry publications as being important to innovation

	Not important	Low importance	Medium importance	High importance
Employment (log)	-0.047***	0.011***	0.019***	0.017***
	0.002	0.001	0.001	0.001
Exporter (0/1)	-0.167***	0.033***	0.065***	0.069***
	0.009	0.002	0.004	0.004
Engaged in co-operation - any innovation activity (0/1)	-0.196***	0.031***	0.074***	0.090***
	0.010	0.001	0.004	0.006
Science graduates (% workforce)	-0.004***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.002***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.159***	0.026***	0.061***	0.072***
	0.012	0.002	0.005	0.007
Av. Propensity within the industry to view industry publications as being important to innovation	-5.408***	1.221***	2.161***	2.026***
	0.405	0.098	0.167	0.154
Industry birth rate (%)	0.467***	-0.105***	-0.187***	-0.175***
	0.063	0.015	0.025	0.024
Industry concentration ratio (five-firm)	-0.500***	0.113***	0.200***	0.187***
	0.069	0.016	0.028	0.026
N	15658.000	15658.000	15658.000	15658.000
Chi-squared	3845.571	3845.571	3845.571	3845.571
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.113	0.113	0.113	0.113
bic	30244.855	30244.855	30244.855	30244.855

Table 2.17 (continued): Importance of Secrecy – Homoscedastic ordered-probit model (marginal effects)

e. Average propensity within the industry to use informal knowledge protection/view informal methods as being important

	Not important	Low importance	Medium importance	High importance
Employment (log)	-0.047***	0.011***	0.019***	0.017***
	0.002	0.001	0.001	0.001
Exporter (0/1)	-0.165***	0.033***	0.065***	0.068***
	0.009	0.002	0.004	0.004
Engaged in co-operation - any innovation activity (0/1)	-0.196***	0.031***	0.075***	0.091***
	0.010	0.001	0.004	0.006
Science graduates (% workforce)	-0.004***	0.001***	0.002***	0.001***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.002***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.156***	0.026***	0.060***	0.070***
	0.012	0.002	0.005	0.007
Av. propensity within the industry to use informal knowledge protection/view informal methods as being important	-0.737***	0.167***	0.295***	0.276***
	0.052	0.013	0.021	0.020
Industry birth rate (%)	-0.024	0.005	0.010	0.009
	0.070	0.016	0.028	0.026
Industry concentration ratio (five-firm)	-0.170***	0.038***	0.068***	0.064***
	0.057	0.013	0.023	0.021
N	15658.000	15658.000	15658.000	15658.000
Chi-squared	3867.663	3867.663	3867.663	3867.663
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.114	0.114	0.114	0.114
bic	30222.763	30222.763	30222.763	30222.763

f. Average propensity within the industry to use formal knowledge protection/view formal methods as being important

	Not important	Low importance	Medium importance	High importance
Employment (log)	-0.046***	0.011***	0.019***	0.017***
	0.002	0.001	0.001	0.001
Exporter (0/1)	-0.166***	0.033***	0.065***	0.068***
	0.009	0.002	0.004	0.004
Engaged in co-operation - any innovation activity (0/1)	-0.196***	0.031***	0.074***	0.090***
	0.010	0.001	0.004	0.006
Science graduates (% workforce)	-0.004***	0.001***	0.002***	0.001***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.002***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.158***	0.026***	0.061***	0.071***
	0.012	0.002	0.005	0.007
Av. propensity within the industry to use formal knowledge protection/view formal methods as being important	-0.901***	0.204***	0.360***	0.337***
	0.063	0.015	0.026	0.024
Industry birth rate (%)	0.028	-0.006	-0.011	-0.011
	0.069	0.016	0.027	0.026
Industry concentration ratio (five-firm)	-0.239***	0.054***	0.096***	0.089***
	0.059	0.013	0.024	0.022
N	15658.000	15658.000	15658.000	15658.000
Chi-squared	3873.746	3873.746	3873.746	3873.746
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.114	0.114	0.114	0.114
bic	30216.680	30216.680	30216.680	30216.680

Notes: See Table 2.6
Coefficients are reported with standard errors below. Models contain wave dummies, * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2002 to 2012 and BSD 1997 to 2012.

Table 2.18: Importance of Lead-time Advantage – Homoscedastic ordered-probit model (marginal effects)

a. Average propensity to be a product innovator within the industry				
	Not important	**Low importance**	**Medium importance**	**High importance**
Employment (log)	-0.040***	0.008***	0.016***	0.016***
	0.002	0.000	0.001	0.001
Exporter (0/1)	-0.164***	0.028***	0.065***	0.071***
	0.009	0.002	0.004	0.004
Engaged in co-operation - any innovation activity (0/1)	-0.194***	0.026***	0.074***	0.093***
	0.010	0.001	0.004	0.006
Science graduates (% workforce)	-0.003***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.002***	0.000***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.155***	0.022***	0.060***	0.073***
	0.012	0.001	0.005	0.007
Average propensity to be a product innovator within the industry	-0.921***	0.182***	0.376***	0.362***
	0.057	0.012	0.024	0.023
Industry birth rate (%)	0.209***	-0.041***	-0.086***	-0.082***
	0.074	0.015	0.030	0.029
Industry concentration ratio (five-firm)	-0.040	0.008	0.016	0.016
	0.056	0.011	0.023	0.022
N	15656.000	15656.000	15656.000	15656.000
Chi-squared	3673.773	3673.773	3673.773	3673.773
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.107	0.107	0.107	0.107
bic	30717.405	30717.405	30717.405	30717.405

b. Average propensity to be a process innovator within the industry				
	Not important	**Low importance**	**Medium importance**	**High importance**
Employment (log)	-0.040***	0.008***	0.016***	0.016***
	0.002	0.000	0.001	0.001
Exporter (0/1)	-0.166***	0.028***	0.066***	0.072***
	0.009	0.002	0.004	0.004
Engaged in co-operation - any innovation activity (0/1)	-0.193***	0.026***	0.074***	0.093***
	0.010	0.001	0.004	0.006
Science graduates (% workforce)	-0.003***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.002***	0.000***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.157***	0.022***	0.061***	0.074***
	0.012	0.001	0.005	0.007
Average propensity to be a process innovator within the industry	-1.210***	0.240***	0.495***	0.476***
	0.074	0.016	0.032	0.030
Industry birth rate (%)	0.300***	-0.059***	-0.123***	-0.118***
	0.071	0.014	0.029	0.028
Industry concentration ratio (five-firm)	-0.004	0.001	0.001	0.001
	0.056	0.011	0.023	0.022
N	15656.000	15656.000	15656.000	15656.000
Chi-squared	3677.154	3677.154	3677.154	3677.154
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.107	0.107	0.107	0.107
bic	30714.025	30714.025	30714.025	30714.025

Table 2.18 (continued): Importance of Lead-time Advantage – Homoscedastic ordered-probit model (marginal effects)

c. Average propensity within the industry to view industry standards as being important to innovation				
	Not important	**Low importance**	**Medium importance**	**High importance**
Employment (log)	-0.040***	0.008***	0.016***	0.016***
	0.002	0.000	0.001	0.001
Exporter (0/1)	-0.181***	0.030***	0.072***	0.079***
	0.008	0.001	0.004	0.004
Engaged in co-operation - any innovation activity (0/1)	-0.190***	0.026***	0.073***	0.092***
	0.010	0.001	0.004	0.006
Science graduates (% workforce)	-0.003***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.002***	0.000***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.163***	0.023***	0.063***	0.078***
	0.012	0.001	0.005	0.007
Av. propensity within the industry to view industry standards as being important to innovation	-2.718***	0.535***	1.107***	1.076***
	0.198	0.042	0.084	0.080
Industry birth rate (%)	0.637***	-0.125***	-0.259***	-0.252***
	0.066	0.013	0.027	0.026
Industry concentration ratio (five-firm)	-0.245***	0.048***	0.100***	0.097***
	0.062	0.012	0.025	0.024
N	15656.000	15656.000	15656.000	15656.000
Chi-squared	3598.711	3598.711	3598.711	3598.711
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.105	0.105	0.105	0.105
bic	30792.467	30792.467	30792.467	30792.467

d. Average propensity within the industry to view industry publications as being important to innovation				
	Not important	**Low importance**	**Medium importance**	**High importance**
Employment (log)	-0.040***	0.008***	0.016***	0.016***
	0.002	0.000	0.001	0.001
Exporter (0/1)	-0.168***	0.029***	0.067***	0.073***
	0.009	0.002	0.004	0.004
Engaged in co-operation - any innovation activity (0/1)	-0.193***	0.026***	0.074***	0.093***
	0.010	0.001	0.004	0.006
Science graduates (% workforce)	-0.003***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.002***	0.000***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.160***	0.022***	0.062***	0.076***
	0.012	0.001	0.005	0.007
Av. propensity within the industry to view industry publications as being important to innovation	-6.124***	1.210***	2.500***	2.414***
	0.408	0.089	0.173	0.164
Industry birth rate (%)	0.861***	-0.170***	-0.352***	-0.340***
	0.064	0.014	0.027	0.026
Industry concentration ratio (five-firm)	-0.511***	0.101***	0.208***	0.201***
	0.070	0.014	0.029	0.028
N	15656.000	15656.000	15656.000	15656.000
Chi-squared	3637.888	3637.888	3637.888	3637.888
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.106	0.106	0.106	0.106
bic	30753.290	30753.290	30753.290	30753.290

Table 2.18 (continued): Importance of Lead-time Advantage – Homoscedastic ordered-probit model (marginal effects)

e. Average propensity within the industry to use informal knowledge protection/view informal methods as being important				
	Not important	**Low importance**	**Medium importance**	**High importance**
Employment (log)	-0.040***	0.008***	0.016***	0.016***
	0.002	0.000	0.001	0.001
Exporter (0/1)	-0.165***	0.028***	0.066***	0.071***
	0.009	0.002	0.004	0.004
Engaged in co-operation - any innovation activity (0/1)	-0.194***	0.026***	0.074***	0.093***
	0.010	0.001	0.004	0.006
Science graduates (% workforce)	-0.003***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.002***	0.000***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.156***	0.022***	0.060***	0.074***
	0.012	0.001	0.005	0.007
Av. propensity within the industry to use informal knowledge protection/view informal methods as being important	-0.849***	0.168***	0.347***	0.334***
	0.052	0.011	0.022	0.021
Industry birth rate (%)	0.293***	-0.058***	-0.120***	-0.115***
	0.071	0.014	0.029	0.028
Industry concentration ratio (five-firm)	-0.143**	0.028**	0.058**	0.056**
	0.058	0.011	0.024	0.023
N	15656.000	15656.000	15656.000	15656.000
Chi-squared	3676.884	3676.884	3676.884	3676.884
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.107	0.107	0.107	0.107
bic	30714.294	30714.294	30714.294	30714.294

f. Average propensity within the industry to use formal knowledge protection/view formal methods as being important				
	Not important	**Low importance**	**Medium importance**	**High importance**
Employment (log)	-0.039***	0.008***	0.016***	0.016***
	0.002	0.000	0.001	0.001
Exporter (0/1)	-0.168***	0.029***	0.067***	0.072***
	0.009	0.002	0.004	0.004
Engaged in co-operation - any innovation activity (0/1)	-0.193***	0.026***	0.074***	0.093***
	0.010	0.001	0.004	0.006
Science graduates (% workforce)	-0.003***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.002***	0.000***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.159***	0.022***	0.062***	0.076***
	0.012	0.001	0.005	0.007
Av. propensity within the industry to use formal knowledge protection/view formal methods as being important	-0.971***	0.192***	0.397***	0.383***
	0.063	0.014	0.027	0.025
Industry birth rate (%)	0.384***	-0.076***	-0.157***	-0.151***
	0.070	0.014	0.029	0.028
Industry concentration ratio (five-firm)	-0.199***	0.039***	0.081***	0.079***
	0.059	0.012	0.024	0.023
N	15656.000	15656.000	15656.000	15656.000
Chi-squared	3650.729	3650.729	3650.729	3650.729
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.107	0.107	0.107	0.107
bic	30740.449	30740.449	30740.449	30740.449

Notes: See Table 2.6
Coefficients are reported with standard errors below. Models contain wave dummies, * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2002 to 2012 and BSD 1997 to 2012.

Table 2.19: Importance of Complexity of Design – Homoscedastic ordered-probit model (marginal effects)

a. Average propensity to be a product innovator within the industry	Not important	Low importance	Medium importance	High importance
Employment (log)	-0.038***	0.014***	0.017***	0.008***
	0.002	0.001	0.001	0.000
Exporter (0/1)	-0.173***	0.056***	0.078***	0.039***
	0.009	0.003	0.004	0.002
Engaged in co-operation - any innovation activity (0/1)	-0.159***	0.048***	0.072***	0.039***
	0.010	0.003	0.005	0.003
Science graduates (% workforce)	-0.004***	0.001***	0.002***	0.001***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.002***	0.001***	0.001***	0.000***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.158***	0.046***	0.072***	0.040***
	0.012	0.003	0.006	0.004
Average propensity to be a product innovator within the industry	-0.901***	0.324***	0.400***	0.177***
	0.055	0.021	0.025	0.012
Industry birth rate (%)	0.180**	-0.065**	-0.080**	-0.035**
	0.073	0.026	0.032	0.014
Industry concentration ratio (five-firm)	0.035	-0.013	-0.015	-0.007
	0.055	0.020	0.025	0.011
N	15657.000	15657.000	15657.000	15657.000
Chi-squared	4030.728	4030.728	4030.728	4030.728
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.132	0.132	0.132	0.132
bic	26658.115	26658.115	26658.115	26658.115

b. Average propensity to be a process innovator within the industry	Not important	Low importance	Medium importance	High importance
Employment (log)	-0.038***	0.014***	0.017***	0.007***
	0.002	0.001	0.001	0.000
Exporter (0/1)	-0.175***	0.057***	0.079***	0.039***
	0.008	0.003	0.004	0.002
Engaged in co-operation - any innovation activity (0/1)	-0.158***	0.048***	0.072***	0.039***
	0.010	0.003	0.005	0.003
Science graduates (% workforce)	-0.004***	0.001***	0.002***	0.001***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.002***	0.001***	0.001***	0.000***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.159***	0.047***	0.072***	0.040***
	0.012	0.003	0.006	0.004
Average propensity to be a process innovator within the industry	-1.177***	0.423***	0.522***	0.231***
	0.072	0.028	0.033	0.016
Industry birth rate (%)	0.272***	-0.098***	-0.121***	-0.053***
	0.070	0.025	0.031	0.014
Industry concentration ratio (five-firm)	0.074	-0.027	-0.033	-0.014
	0.055	0.020	0.024	0.011
N	15657.000	15657.000	15657.000	15657.000
Chi-squared	4030.646	4030.646	4030.646	4030.646
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.132	0.132	0.132	0.132
bic	26658.198	26658.198	26658.198	26658.198

Table 2.19 (continued): Importance of Complexity of Design – Homoscedastic ordered-probit model (marginal effects)

c. Average propensity within the industry to view industry standards as being important to innovation				
	Not important	**Low importance**	**Medium importance**	**High importance**
Employment (log)	-0.038***	0.014***	0.017***	0.008***
	0.002	0.001	0.001	0.000
Exporter (0/1)	-0.190***	0.061***	0.085***	0.044***
	0.008	0.003	0.004	0.003
Engaged in co-operation - any innovation activity (0/1)	-0.156***	0.047***	0.071***	0.038***
	0.010	0.003	0.005	0.003
Science graduates (% workforce)	-0.004***	0.001***	0.002***	0.001***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.002***	0.001***	0.001***	0.000***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.166***	0.048***	0.076***	0.043***
	0.012	0.003	0.006	0.004
Av. propensity within the industry to view industry standards as being important to innovation	-2.623***	0.938***	1.165***	0.520***
	0.194	0.073	0.088	0.041
Industry birth rate (%)	0.613***	-0.219***	-0.272***	-0.122***
	0.064	0.023	0.029	0.013
Industry concentration ratio (five-firm)	-0.150**	0.054**	0.067**	0.030**
	0.060	0.022	0.027	0.012
N	15657.000	15657.000	15657.000	15657.000
Chi-squared	3948.693	3948.693	3948.693	3948.693
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.129	0.129	0.129	0.129
bic	26740.151	26740.151	26740.151	26740.151

d. Average propensity within the industry to view industry publications as being important to innovation				
	Not important	**Low importance**	**Medium importance**	**High importance**
Employment (log)	-0.038***	0.014***	0.017***	0.008***
	0.002	0.001	0.001	0.000
Exporter (0/1)	-0.179***	0.058***	0.080***	0.041***
	0.008	0.003	0.004	0.002
Engaged in co-operation - any innovation activity (0/1)	-0.158***	0.047***	0.072***	0.039***
	0.010	0.003	0.005	0.003
Science graduates (% workforce)	-0.004***	0.001***	0.002***	0.001***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.002***	0.001***	0.001***	0.000***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.163***	0.047***	0.074***	0.042***
	0.012	0.003	0.006	0.004
Av. propensity within the industry to view industry publications as being important to innovation	-5.559***	1.990***	2.468***	1.100***
	0.398	0.151	0.182	0.085
Industry birth rate (%)	0.828***	-0.296***	-0.368***	-0.164***
	0.061	0.023	0.028	0.013
Industry concentration ratio (five-firm)	-0.377***	0.135***	0.167***	0.075***
	0.069	0.025	0.031	0.014
N	15657.000	15657.000	15657.000	15657.000
Chi-squared	3960.747	3960.747	3960.747	3960.747
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.130	0.130	0.130	0.130
bic	26728.097	26728.097	26728.097	26728.097

Table 2.19 (continued): Importance of Complexity of Design – Homoscedastic ordered-probit model (marginal effects)

e. Average propensity within the industry to use informal knowledge protection/view informal methods as being important				
	Not important	**Low importance**	**Medium importance**	**High importance**
Employment (log)	-0.038***	0.014***	0.017***	0.008***
	0.002	0.001	0.001	0.000
Exporter (0/1)	-0.174***	0.056***	0.078***	0.039***
	0.008	0.003	0.004	0.002
Engaged in co-operation - any innovation activity (0/1)	-0.158***	0.048***	0.072***	0.039***
	0.010	0.003	0.005	0.003
Science graduates (% workforce)	-0.004***	0.001***	0.002***	0.001***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.002***	0.001***	0.001***	0.000***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.159***	0.047***	0.072***	0.040***
	0.012	0.003	0.006	0.004
Av. propensity within the industry to use informal knowledge protection/view informal methods as being important	-0.825***	0.297***	0.366***	0.162***
	0.050	0.020	0.023	0.011
Industry birth rate (%)	0.266***	-0.096***	-0.118***	-0.052***
	0.070	0.025	0.031	0.014
Industry concentration ratio (five-firm)	-0.063	0.023	0.028	0.012
	0.057	0.020	0.025	0.011
N	15657.000	15657.000	15657.000	15657.000
Chi-squared	4030.326	4030.326	4030.326	4030.326
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.132	0.132	0.132	0.132
bic	26658.518	26658.518	26658.518	26658.518

f. Average propensity within the industry to use formal knowledge protection/view formal methods as being important				
	Not important	**Low importance**	**Medium importance**	**High importance**
Employment (log)	-0.038***	0.014***	0.017***	0.007***
	0.002	0.001	0.001	0.000
Exporter (0/1)	-0.177***	0.057***	0.080***	0.040***
	0.008	0.003	0.004	0.002
Engaged in co-operation - any innovation activity (0/1)	-0.158***	0.047***	0.072***	0.039***
	0.010	0.003	0.005	0.003
Science graduates (% workforce)	-0.004***	0.001***	0.002***	0.001***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.002***	0.001***	0.001***	0.000***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.162***	0.047***	0.074***	0.041***
	0.012	0.003	0.006	0.004
Av. propensity within the industry to use formal knowledge protection/view formal methods as being important	-0.917***	0.329***	0.407***	0.181***
	0.061	0.023	0.028	0.013
Industry birth rate (%)	0.374***	-0.134***	-0.166***	-0.074***
	0.068	0.025	0.030	0.014
Industry concentration ratio (five-firm)	-0.105*	0.038*	0.047*	0.021*
	0.058	0.021	0.026	0.012
N	15657.000	15657.000	15657.000	15657.000
Chi-squared	3989.185	3989.185	3989.185	3989.185
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.131	0.131	0.131	0.131
bic	26699.659	26699.659	26699.659	26699.659

Notes: See Table 2.6
Coefficients are reported with standard errors below. Models contain wave dummies, * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2002 to 2012 and BSD 1997 to 2012.

Table 2.20: Importance of Confidentiality Agreements – Homoscedastic ordered-probit model (marginal effects)

a. Average propensity to be a product innovator within the industry

	Not important	Low importance	Medium importance	High importance
Employment (log)	-0.045***	0.008***	0.017***	0.020***
	0.002	0.000	0.001	0.001
Exporter (0/1)	-0.159***	0.025***	0.057***	0.076***
	0.009	0.001	0.003	0.005
Engaged in co-operation - any innovation activity (0/1)	-0.236***	0.027***	0.078***	0.132***
	0.010	0.001	0.003	0.007
Science graduates (% workforce)	-0.005***	0.001***	0.002***	0.002***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.003***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.162***	0.021***	0.055***	0.086***
	0.013	0.001	0.004	0.008
Average propensity to be a product innovator within the industry	-0.886***	0.163***	0.327***	0.395***
	0.057	0.012	0.022	0.026
Industry birth rate (%)	-0.383***	0.071***	0.141***	0.171***
	0.073	0.014	0.027	0.033
Industry concentration ratio (five-firm)	-0.126**	0.023**	0.046**	0.056**
	0.056	0.010	0.021	0.025
N	15657.000	15657.000	15657.000	15657.000
Chi-squared	4267.254	4267.254	4267.254	4267.254
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.126	0.126	0.126	0.126
bic	29733.655	29733.655	29733.655	29733.655

b. Average propensity to be a process innovator within the industry

	Not important	Low importance	Medium importance	High importance
Employment (log)	-0.045***	0.008***	0.017***	0.020***
	0.002	0.000	0.001	0.001
Exporter (0/1)	-0.159***	0.026***	0.057***	0.077***
	0.009	0.001	0.003	0.005
Engaged in co-operation - any innovation activity (0/1)	-0.235***	0.027***	0.078***	0.131***
	0.010	0.001	0.003	0.007
Science graduates (% workforce)	-0.005***	0.001***	0.002***	0.002***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.003***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.163***	0.021***	0.056***	0.086***
	0.013	0.001	0.004	0.008
Average propensity to be a process innovator within the industry	-1.220***	0.225***	0.451***	0.543***
	0.075	0.016	0.029	0.034
Industry birth rate (%)	-0.318***	0.059***	0.118***	0.142***
	0.070	0.013	0.026	0.031
Industry concentration ratio (five-firm)	-0.096*	0.018*	0.036*	0.043*
	0.055	0.010	0.020	0.025
N	15657.000	15657.000	15657.000	15657.000
Chi-squared	4295.218	4295.218	4295.218	4295.218
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.127	0.127	0.127	0.127
bic	29705.691	29705.691	29705.691	29705.691

Table 2.20 (continued): Importance of Confidentiality Agreements – Homoscedastic ordered-probit model (marginal effects)

c. Average propensity within the industry to view industry standards as being important to innovation	Not important	Low importance	Medium importance	High importance
Employment (log)	-0.045***	0.008***	0.017***	0.020***
	0.002	0.000	0.001	0.001
Exporter (0/1)	-0.172***	0.027***	0.061***	0.083***
	0.009	0.001	0.003	0.005
Engaged in co-operation - any innovation activity (0/1)	-0.233***	0.027***	0.077***	0.129***
	0.010	0.001	0.003	0.007
Science graduates (% workforce)	-0.005***	0.001***	0.002***	0.002***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.003***	0.000***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.168***	0.022***	0.057***	0.089***
	0.013	0.001	0.004	0.008
Av. propensity within the industry to view industry standards as being important to innovation	-3.114***	0.574***	1.151***	1.388***
	0.200	0.041	0.078	0.091
Industry birth rate (%)	-0.016	0.003	0.006	0.007
	0.065	0.012	0.024	0.029
Industry concentration ratio (five-firm)	-0.392***	0.072***	0.145***	0.175***
	0.061	0.011	0.023	0.027
N	15657.000	15657.000	15657.000	15657.000
Chi-squared	4273.224	4273.224	4273.224	4273.224
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.126	0.126	0.126	0.126
bic	29727.686	29727.686	29727.686	29727.686

d. Average propensity within the industry to view industry publications as being important to innovation	Not important	Low importance	Medium importance	High importance
Employment (log)	-0.045***	0.008***	0.017***	0.020***
	0.002	0.000	0.001	0.001
Exporter (0/1)	-0.160***	0.026***	0.057***	0.077***
	0.009	0.001	0.003	0.005
Engaged in co-operation - any innovation activity (0/1)	-0.236***	0.027***	0.078***	0.131***
	0.010	0.001	0.003	0.007
Science graduates (% workforce)	-0.005***	0.001***	0.002***	0.002***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.003***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.166***	0.021***	0.057***	0.088***
	0.013	0.001	0.004	0.008
Av. propensity within the industry to view industry publications as being important to innovation	-6.291***	1.160***	2.326***	2.805***
	0.409	0.084	0.159	0.185
Industry birth rate (%)	0.246***	-0.045***	-0.091***	-0.110***
	0.063	0.012	0.023	0.028
Industry concentration ratio (five-firm)	-0.621***	0.115***	0.230***	0.277***
	0.069	0.013	0.026	0.031
N	15657.000	15657.000	15657.000	15657.000
Chi-squared	4268.152	4268.152	4268.152	4268.152
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.126	0.126	0.126	0.126
bic	29732.757	29732.757	29732.757	29732.757

Table 2.20 (continued): Importance of Confidentiality Agreements – Homoscedastic ordered-probit model (marginal effects)

e. Average propensity within the industry to use informal knowledge protection/view informal methods as being important				
	Not important	**Low importance**	**Medium importance**	**High importance**
Employment (log)	-0.045***	0.008***	0.017***	0.020***
	0.002	0.000	0.001	0.001
Exporter (0/1)	-0.159***	0.025***	0.057***	0.077***
	0.009	0.001	0.003	0.005
Engaged in co-operation - any innovation activity (0/1)	-0.236***	0.027***	0.078***	0.131***
	0.010	0.001	0.003	0.007
Science graduates (% workforce)	-0.005***	0.001***	0.002***	0.002***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.003***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.163***	0.021***	0.056***	0.086***
	0.013	0.001	0.004	0.008
Av. propensity within the industry to use informal knowledge protection/view informal methods as being important	-0.822***	0.152***	0.304***	0.367***
	0.052	0.011	0.020	0.024
Industry birth rate (%)	-0.302***	0.056***	0.112***	0.135***
	0.070	0.013	0.026	0.031
Industry concentration ratio (five-firm)	-0.224***	0.041***	0.083***	0.100***
	0.057	0.011	0.021	0.025
N	15657.000	15657.000	15657.000	15657.000
Chi-squared	4275.827	4275.827	4275.827	4275.827
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.126	0.126	0.126	0.126
bic	29725.083	29725.083	29725.083	29725.083

f. Average propensity within the industry to use formal knowledge protection/view formal methods as being important				
	Not important	**Low importance**	**Medium importance**	**High importance**
Employment (log)	-0.045***	0.008***	0.017***	0.020***
	0.002	0.000	0.001	0.001
Exporter (0/1)	-0.159***	0.026***	0.057***	0.077***
	0.009	0.001	0.003	0.005
Engaged in co-operation - any innovation activity (0/1)	-0.235***	0.027***	0.078***	0.131***
	0.010	0.001	0.003	0.007
Science graduates (% workforce)	-0.005***	0.001***	0.002***	0.002***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.003***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.165***	0.021***	0.056***	0.087***
	0.013	0.001	0.004	0.008
Av. propensity within the industry to use formal knowledge protection/view formal methods as being important	-1.021***	0.189***	0.378***	0.454***
	0.063	0.013	0.025	0.029
Industry birth rate (%)	-0.250***	0.046***	0.093***	0.111***
	0.068	0.013	0.025	0.030
Industry concentration ratio (five-firm)	-0.308***	0.057***	0.114***	0.137***
	0.059	0.011	0.022	0.026
N	15657.000	15657.000	15657.000	15657.000
Chi-squared	4292.432	4292.432	4292.432	4292.432
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.127	0.127	0.127	0.127
bic	29708.478	29708.478	29708.478	29708.478

Notes: See Table 2.6
Coefficients are reported with standard errors below. Models contain wave dummies, * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2002 to 2012 and BSD 1997 to 2012.

Table 2.21: Importance of Copyright – Homoscedastic ordered-probit model (marginal effects)

a. Average propensity to be a product innovator within the industry				
	Not important	**Low importance**	**Medium importance**	**High importance**
Employment (log)	-0.029***	0.010***	0.009***	0.009***
	0.002	0.001	0.001	0.001
Exporter (0/1)	-0.130***	0.042***	0.043***	0.046***
	0.008	0.003	0.003	0.003
Engaged in co-operation - any innovation activity (0/1)	-0.099***	0.031***	0.032***	0.036***
	0.010	0.003	0.003	0.004
Science graduates (% workforce)	-0.003***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.003***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.078***	0.025***	0.026***	0.028***
	0.011	0.003	0.004	0.004
Average propensity to be a product innovator within the industry	-0.471***	0.162***	0.156***	0.153***
	0.050	0.018	0.017	0.016
Industry birth rate (%)	-0.020	0.007	0.007	0.006
	0.065	0.022	0.022	0.021
Industry concentration ratio (five-firm)	0.138***	-0.047***	-0.046***	-0.045***
	0.051	0.017	0.017	0.016
N	15657.000	15657.000	15657.000	15657.000
Chi-squared	2519.708	2519.708	2519.708	2519.708
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.099	0.099	0.099	0.099
bic	23024.492	23024.492	23024.492	23024.492

b. Average propensity to be a process innovator within the industry				
	Not important	**Low importance**	**Medium importance**	**High importance**
Employment (log)	-0.029***	0.010***	0.009***	0.009***
	0.002	0.001	0.001	0.001
Exporter (0/1)	-0.132***	0.042***	0.043***	0.046***
	0.008	0.003	0.003	0.003
Engaged in co-operation - any innovation activity (0/1)	-0.098***	0.031***	0.032***	0.036***
	0.010	0.003	0.003	0.004
Science graduates (% workforce)	-0.003***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.003***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.080***	0.025***	0.026***	0.028***
	0.011	0.003	0.004	0.004
Average propensity to be a process innovator within the industry	-0.592***	0.204***	0.196***	0.192***
	0.065	0.023	0.022	0.021
Industry birth rate (%)	0.039	-0.013	-0.013	-0.013
	0.063	0.022	0.021	0.020
Industry concentration ratio (five-firm)	0.160***	-0.055***	-0.053***	-0.052***
	0.050	0.017	0.017	0.016
N	15657.000	15657.000	15657.000	15657.000
Chi-squared	2512.866	2512.866	2512.866	2512.866
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.099	0.099	0.099	0.099
bic	23031.334	23031.334	23031.334	23031.334

Table 2.21 (continued): Importance of Copyright – Homoscedastic ordered-probit model (marginal effects)

c. Average propensity within the industry to view industry standards as being important to innovation

	Not important	Low importance	Medium importance	High importance
Employment (log)	-0.029***	0.010***	0.009***	0.009***
	0.002	0.001	0.001	0.001
Exporter (0/1)	-0.141***	0.045***	0.046***	0.050***
	0.008	0.003	0.003	0.003
Engaged in co-operation - any innovation activity (0/1)	-0.098***	0.030***	0.032***	0.036***
	0.010	0.003	0.003	0.004
Science graduates (% workforce)	-0.003***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.003***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.084***	0.026***	0.028***	0.030***
	0.011	0.003	0.004	0.004
Av. propensity within the industry to view industry standards as being important to innovation	-1.118***	0.383***	0.370***	0.365***
	0.171	0.060	0.057	0.057
Industry birth rate (%)	0.231***	-0.079***	-0.076***	-0.075***
	0.057	0.020	0.019	0.019
Industry concentration ratio (five-firm)	0.080	-0.027	-0.026	-0.026
	0.055	0.019	0.018	0.018
N	15657.000	15657.000	15657.000	15657.000
Chi-squared	2471.737	2471.737	2471.737	2471.737
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.097	0.097	0.097	0.097
bic	23072.464	23072.464	23072.464	23072.464

d. Average propensity within the industry to view industry publications as being important to innovation

	Not important	Low importance	Medium importance	High importance
Employment (log)	-0.029***	0.010***	0.009***	0.009***
	0.002	0.001	0.001	0.001
Exporter (0/1)	-0.132***	0.042***	0.043***	0.047***
	0.008	0.003	0.003	0.003
Engaged in co-operation - any innovation activity (0/1)	-0.099***	0.031***	0.032***	0.036***
	0.010	0.003	0.003	0.004
Science graduates (% workforce)	-0.003***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.003***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.081***	0.025***	0.027***	0.029***
	0.011	0.003	0.004	0.004
Av. propensity within the industry to view industry publications as being important to innovation	-3.032***	1.042***	1.005***	0.985***
	0.353	0.125	0.120	0.117
Industry birth rate (%)	0.322***	-0.111***	-0.107***	-0.105***
	0.055	0.019	0.018	0.018
Industry concentration ratio (five-firm)	-0.090	0.031	0.030	0.029
	0.063	0.022	0.021	0.020
N	15657.000	15657.000	15657.000	15657.000
Chi-squared	2503.190	2503.190	2503.190	2503.190
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.098	0.098	0.098	0.098
bic	23041.011	23041.011	23041.011	23041.011

Table 2.21 (continued): Importance of Copyright – Homoscedastic ordered-probit model (marginal effects)

e. Average propensity within the industry to use informal knowledge protection/view informal methods as being important				
	Not important	**Low importance**	**Medium importance**	**High importance**
Employment (log)	-0.029***	0.010***	0.009***	0.009***
	0.002	0.001	0.001	0.001
Exporter (0/1)	-0.131***	0.042***	0.043***	0.046***
	0.008	0.003	0.003	0.003
Engaged in co-operation - any innovation activity (0/1)	-0.099***	0.031***	0.032***	0.036***
	0.010	0.003	0.003	0.004
Science graduates (% workforce)	-0.003***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.003***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.079***	0.025***	0.026***	0.028***
	0.011	0.003	0.004	0.004
Av. propensity within the industry to use informal knowledge protection/view informal methods as being important	-0.415***	0.143***	0.137***	0.135***
	0.045	0.016	0.015	0.015
Industry birth rate (%)	0.035	-0.012	-0.012	-0.011
	0.063	0.022	0.021	0.020
Industry concentration ratio (five-firm)	0.092*	-0.032*	-0.030*	-0.030*
	0.052	0.018	0.017	0.017
N	15657.000	15657.000	15657.000	15657.000
Chi-squared	2512.810	2512.810	2512.810	2512.810
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.099	0.099	0.099	0.099
bic	23031.390	23031.390	23031.390	23031.390

f. Average propensity within the industry to use formal knowledge protection/view formal methods as being important				
	Not important	**Low importance**	**Medium importance**	**High importance**
Employment (log)	-0.028***	0.010***	0.009***	0.009***
	0.002	0.001	0.001	0.001
Exporter (0/1)	-0.131***	0.042***	0.043***	0.046***
	0.008	0.003	0.003	0.003
Engaged in co-operation - any innovation activity (0/1)	-0.098***	0.031***	0.032***	0.035***
	0.010	0.003	0.003	0.004
Science graduates (% workforce)	-0.003***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.003***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.081***	0.025***	0.026***	0.029***
	0.011	0.003	0.004	0.004
Av. propensity within the industry to use formal knowledge protection/view formal methods as being important	-0.507***	0.174***	0.168***	0.165***
	0.055	0.019	0.019	0.018
Industry birth rate (%)	0.070	-0.024	-0.023	-0.023
	0.061	0.021	0.020	0.020
Industry concentration ratio (five-firm)	0.055	-0.019	-0.018	-0.018
	0.053	0.018	0.018	0.017
N	15657.000	15657.000	15657.000	15657.000
Chi-squared	2515.071	2515.071	2515.071	2515.071
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.099	0.099	0.099	0.099
bic	23029.129	23029.129	23029.129	23029.129

Notes: See Table 2.6
Coefficients are reported with standard errors below. Models contain wave dummies, * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2002 to 2012 and BSD 1997 to 2012.

Table 2.22: Importance of Patents – Homoscedastic ordered-probit model (marginal effects)

a. Average propensity to be a product innovator within the industry				
	Not important	**Low importance**	**Medium importance**	**High importance**
Employment (log)	-0.031***	0.010***	0.009***	0.011***
	0.002	0.001	0.001	0.001
Exporter (0/1)	-0.145***	0.046***	0.044***	0.056***
	0.008	0.003	0.003	0.003
Engaged in co-operation - any innovation activity (0/1)	-0.084***	0.026***	0.025***	0.032***
	0.009	0.003	0.003	0.004
Science graduates (% workforce)	-0.003***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.001***	0.000***	0.000***	0.000***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.126***	0.037***	0.038***	0.052***
	0.011	0.003	0.003	0.005
Average propensity to be a product innovator within the industry	-0.452***	0.154***	0.138***	0.159***
	0.047	0.017	0.015	0.017
Industry birth rate (%)	0.335***	-0.114***	-0.103***	-0.118***
	0.064	0.022	0.020	0.023
Industry concentration ratio (five-firm)	0.221***	-0.075***	-0.068***	-0.078***
	0.049	0.017	0.015	0.017
N	15656.000	15656.000	15656.000	15656.000
Chi-squared	3063.060	3063.060	3063.060	3063.060
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.132	0.132	0.132	0.132
bic	20351.035	20351.035	20351.035	20351.035

b. Average propensity to be a process innovator within the industry				
	Not important	**Low importance**	**Medium importance**	**High importance**
Employment (log)	-0.031***	0.010***	0.009***	0.011***
	0.002	0.001	0.001	0.001
Exporter (0/1)	-0.147***	0.046***	0.044***	0.057***
	0.008	0.003	0.003	0.003
Engaged in co-operation - any innovation activity (0/1)	-0.083***	0.026***	0.025***	0.032***
	0.009	0.003	0.003	0.004
Science graduates (% workforce)	-0.003***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.001***	0.000***	0.000***	0.000***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.128***	0.038***	0.038***	0.052***
	0.011	0.003	0.003	0.005
Average propensity to be a process innovator within the industry	-0.557***	0.190***	0.171***	0.196***
	0.061	0.022	0.019	0.022
Industry birth rate (%)	0.398***	-0.136***	-0.122***	-0.140***
	0.061	0.021	0.019	0.022
Industry concentration ratio (five-firm)	0.245***	-0.084***	-0.075***	-0.086***
	0.049	0.017	0.015	0.017
N	15656.000	15656.000	15656.000	15656.000
Chi-squared	3052.023	3052.023	3052.023	3052.023
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.131	0.131	0.131	0.131
bic	20362.072	20362.072	20362.072	20362.072

Table 2.22 (continued): Importance of Patents – Homoscedastic ordered-probit model (marginal effects)

c. Average propensity within the industry to view industry standards as being important to innovation	Not important	Low importance	Medium importance	High importance
Employment (log)	-0.031***	0.010***	0.009***	0.011***
	0.002	0.001	0.001	0.001
Exporter (0/1)	-0.157***	0.049***	0.047***	0.061***
	0.008	0.003	0.003	0.004
Engaged in co-operation - any innovation activity (0/1)	-0.083***	0.026***	0.025***	0.032***
	0.009	0.003	0.003	0.004
Science graduates (% workforce)	-0.002***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.001***	0.000***	0.000***	0.000***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.133***	0.039***	0.039***	0.055***
	0.011	0.003	0.003	0.006
Av. propensity within the industry to view industry standards as being important to innovation	-0.972***	0.330***	0.297***	0.345***
	0.163	0.056	0.051	0.058
Industry birth rate (%)	0.599***	-0.203***	-0.183***	-0.212***
	0.055	0.020	0.018	0.020
Industry concentration ratio (five-firm)	0.184***	-0.063***	-0.056***	-0.065***
	0.054	0.018	0.016	0.019
N	15656.000	15656.000	15656.000	15656.000
Chi-squared	3004.015	3004.015	3004.015	3004.015
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.129	0.129	0.129	0.129
bic	20410.080	20410.080	20410.080	20410.080

d. Average propensity within the industry to view industry publications as being important to innovation	Not important	Low importance	Medium importance	High importance
Employment (log)	-0.031***	0.010***	0.009***	0.011***
	0.002	0.001	0.001	0.001
Exporter (0/1)	-0.149***	0.047***	0.045***	0.058***
	0.008	0.003	0.003	0.003
Engaged in co-operation - any innovation activity (0/1)	-0.083***	0.026***	0.025***	0.032***
	0.009	0.003	0.003	0.004
Science graduates (% workforce)	-0.002***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.001***	0.000***	0.000***	0.000***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.130***	0.038***	0.039***	0.053***
	0.011	0.003	0.003	0.005
Av. propensity within the industry to view industry publications as being important to innovation	-2.661***	0.907***	0.815***	0.940***
	0.339	0.118	0.106	0.121
Industry birth rate (%)	0.670***	-0.228***	-0.205***	-0.236***
	0.053	0.019	0.017	0.019
Industry concentration ratio (five-firm)	0.032	-0.011	-0.010	-0.011
	0.061	0.021	0.019	0.022
N	15656.000	15656.000	15656.000	15656.000
Chi-squared	3030.811	3030.811	3030.811	3030.811
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.130	0.130	0.130	0.130
bic	20383.284	20383.284	20383.284	20383.284

Table 2.22 (continued): Importance of Patents – Homoscedastic ordered-probit model (marginal effects)

e. Average propensity within the industry to use informal knowledge protection/view informal methods as being important

	Not important	Low importance	Medium importance	High importance
Employment (log)	-0.031***	0.010***	0.009***	0.011***
	0.002	0.001	0.001	0.001
Exporter (0/1)	-0.146***	0.046***	0.044***	0.056***
	0.008	0.003	0.003	0.003
Engaged in co-operation - any innovation activity (0/1)	-0.083***	0.026***	0.025***	0.032***
	0.009	0.003	0.003	0.004
Science graduates (% workforce)	-0.003***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.001***	0.000***	0.000***	0.000***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.127***	0.038***	0.038***	0.052***
	0.011	0.003	0.003	0.005
Av. propensity within the industry to use informal knowledge protection/view informal methods as being important	-0.406***	0.139***	0.124***	0.143***
	0.043	0.015	0.014	0.015
Industry birth rate (%)	0.382***	-0.130***	-0.117***	-0.134***
	0.061	0.021	0.019	0.022
Industry concentration ratio (five-firm)	0.173***	-0.059***	-0.053***	-0.061***
	0.050	0.017	0.015	0.018
N	15656.000	15656.000	15656.000	15656.000
Chi-squared	3058.162	3058.162	3058.162	3058.162
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.131	0.131	0.131	0.131
bic	20355.934	20355.934	20355.934	20355.934

f. Average propensity within the industry to use formal knowledge protection/view formal methods as being important

	Not important	Low importance	Medium importance	High importance
Employment (log)	-0.031***	0.010***	0.009***	0.011***
	0.002	0.001	0.001	0.001
Exporter (0/1)	-0.149***	0.046***	0.045***	0.058***
	0.008	0.003	0.003	0.003
Engaged in co-operation - any innovation activity (0/1)	-0.083***	0.026***	0.025***	0.032***
	0.009	0.003	0.003	0.004
Science graduates (% workforce)	-0.002***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.001***	0.000***	0.000***	0.000***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.130***	0.038***	0.039***	0.053***
	0.011	0.003	0.003	0.005
Av. propensity within the industry to use formal knowledge protection/view formal methods as being important	-0.430***	0.147***	0.132***	0.152***
	0.052	0.018	0.016	0.019
Industry birth rate (%)	0.452***	-0.154***	-0.138***	-0.160***
	0.060	0.021	0.019	0.021
Industry concentration ratio (five-firm)	0.164***	-0.056***	-0.050***	-0.058***
	0.052	0.018	0.016	0.018
N	15656.000	15656.000	15656.000	15656.000
Chi-squared	3036.974	3036.974	3036.974	3036.974
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.130	0.130	0.130	0.130
bic	20377.121	20377.121	20377.121	20377.121

Notes: See Table 2.6
Coefficients are reported with standard errors below. Models contain wave dummies, * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2002 to 2012 and BSD 1997 to 2012.

Table 2.23: Importance of Trademarks – Homoscedastic ordered-probit model (marginal effects)

a. Average propensity to be a product innovator within the industry	Not important	Low importance	Medium importance	High importance
Employment (log)	-0.038***	0.010***	0.013***	0.015***
	0.002	0.001	0.001	0.001
Exporter (0/1)	-0.149***	0.037***	0.050***	0.063***
	0.008	0.002	0.003	0.004
Engaged in co-operation - any innovation activity (0/1)	-0.083***	0.020***	0.028***	0.035***
	0.010	0.002	0.003	0.004
Science graduates (% workforce)	-0.002***	0.000***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.002***	0.000***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.087***	0.021***	0.029***	0.037***
	0.012	0.003	0.004	0.005
Average propensity to be a product innovator within the industry	-0.302***	0.081***	0.104***	0.118***
	0.051	0.014	0.018	0.020
Industry birth rate (%)	0.395***	-0.106***	-0.135***	-0.154***
	0.069	0.019	0.024	0.027
Industry concentration ratio (five-firm)	0.059	-0.016	-0.020	-0.023
	0.052	0.014	0.018	0.020
N	15658.000	15658.000	15658.000	15658.000
Chi-squared	2386.483	2386.483	2386.483	2386.483
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.088	0.088	0.088	0.088
bic	24714.528	24714.528	24714.528	24714.528

b. Average propensity to be a process innovator within the industry	Not important	Low importance	Medium importance	High importance
Employment (log)	-0.038***	0.010***	0.013***	0.015***
	0.002	0.001	0.001	0.001
Exporter (0/1)	-0.152***	0.037***	0.051***	0.064***
	0.008	0.002	0.003	0.004
Engaged in co-operation - any innovation activity (0/1)	-0.082***	0.020***	0.028***	0.035***
	0.010	0.002	0.003	0.004
Science graduates (% workforce)	-0.002***	0.000***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.002***	0.000***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.088***	0.021***	0.029***	0.038***
	0.012	0.003	0.004	0.005
Average propensity to be a process innovator within the industry	-0.333***	0.089***	0.114***	0.130***
	0.067	0.018	0.023	0.026
Industry birth rate (%)	0.455***	-0.122***	-0.156***	-0.177***
	0.066	0.018	0.023	0.026
Industry concentration ratio (five-firm)	0.078	-0.021	-0.027	-0.030
	0.052	0.014	0.018	0.020
N	15658.000	15658.000	15658.000	15658.000
Chi-squared	2376.202	2376.202	2376.202	2376.202
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.088	0.088	0.088	0.088
bic	24724.809	24724.809	24724.809	24724.809

Table 2.23 (continued): Importance of Trademarks – Homoscedastic ordered-probit model (marginal effects)

c. Average propensity within the industry to view industry standards as being important to innovation				
	Not important	**Low importance**	**Medium importance**	**High importance**
Employment (log)	-0.038***	0.010***	0.013***	0.015***
	0.002	0.001	0.001	0.001
Exporter (0/1)	-0.161***	0.039***	0.054***	0.069***
	0.008	0.002	0.003	0.004
Engaged in co-operation - any innovation activity (0/1)	-0.083***	0.020***	0.028***	0.035***
	0.010	0.002	0.003	0.004
Science graduates (% workforce)	-0.002***	0.000***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.002***	0.000***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.093***	0.022***	0.031***	0.040***
	0.012	0.003	0.004	0.006
Av. propensity within the industry to view industry standards as being important to innovation	-0.151	0.040	0.052	0.059
	0.175	0.047	0.060	0.068
Industry birth rate (%)	0.604***	-0.162***	-0.207***	-0.236***
	0.060	0.017	0.021	0.024
Industry concentration ratio (five-firm)	0.100*	-0.027*	-0.034*	-0.039*
	0.057	0.015	0.020	0.022
N	15658.000	15658.000	15658.000	15658.000
Chi-squared	2351.887	2351.887	2351.887	2351.887
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.087	0.087	0.087	0.087
bic	24749.124	24749.124	24749.124	24749.124

d. Average propensity within the industry to view industry publications as being important to innovation				
	Not important	**Low importance**	**Medium importance**	**High importance**
Employment (log)	-0.038***	0.010***	0.013***	0.015***
	0.002	0.001	0.001	0.001
Exporter (0/1)	-0.154***	0.038***	0.051***	0.065***
	0.008	0.002	0.003	0.004
Engaged in co-operation - any innovation activity (0/1)	-0.083***	0.020***	0.028***	0.035***
	0.010	0.002	0.003	0.004
Science graduates (% workforce)	-0.002***	0.000***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.002***	0.000***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.090***	0.022***	0.030***	0.039***
	0.012	0.003	0.004	0.005
Av. propensity within the industry to view industry publications as being important to innovation	-1.464***	0.393***	0.501***	0.570***
	0.362	0.098	0.124	0.141
Industry birth rate (%)	0.612***	-0.164***	-0.209***	-0.238***
	0.058	0.016	0.021	0.023
Industry concentration ratio (five-firm)	-0.035	0.009	0.012	0.014
	0.064	0.017	0.022	0.025
N	15658.000	15658.000	15658.000	15658.000
Chi-squared	2367.546	2367.546	2367.546	2367.546
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.088	0.088	0.088	0.088
bic	24733.465	24733.465	24733.465	24733.465

Table 2.23 (continued): Importance of Trademarks – Homoscedastic ordered-probit model (marginal effects)

e. Average propensity within the industry to use informal knowledge protection/view informal methods as being important				
	Not important	**Low importance**	**Medium importance**	**High importance**
Employment (log)	-0.038***	0.010***	0.013***	0.015***
	0.002	0.001	0.001	0.001
Exporter (0/1)	-0.151***	0.037***	0.050***	0.064***
	0.008	0.002	0.003	0.004
Engaged in co-operation - any innovation activity (0/1)	-0.082***	0.020***	0.028***	0.035***
	0.010	0.002	0.003	0.004
Science graduates (% workforce)	-0.002***	0.000***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.002***	0.000***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.088***	0.021***	0.029***	0.038***
	0.012	0.003	0.004	0.005
Av. propensity within the industry to use informal knowledge protection/view informal methods as being important	-0.240***	0.065***	0.082***	0.094***
	0.047	0.013	0.016	0.018
Industry birth rate (%)	0.447***	-0.120***	-0.153***	-0.174***
	0.066	0.018	0.023	0.026
Industry concentration ratio (five-firm)	0.037	-0.010	-0.013	-0.014
	0.053	0.014	0.018	0.021
N	15658.000	15658.000	15658.000	15658.000
Chi-squared	2377.598	2377.598	2377.598	2377.598
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.088	0.088	0.088	0.088
bic	24723.413	24723.413	24723.413	24723.413

f. Average propensity within the industry to use formal knowledge protection/view formal methods as being important				
	Not important	**Low importance**	**Medium importance**	**High importance**
Employment (log)	-0.038***	0.010***	0.013***	0.015***
	0.002	0.001	0.001	0.001
Exporter (0/1)	-0.152***	0.037***	0.051***	0.064***
	0.008	0.002	0.003	0.004
Engaged in co-operation - any innovation activity (0/1)	-0.082***	0.020***	0.028***	0.035***
	0.010	0.002	0.003	0.004
Science graduates (% workforce)	-0.002***	0.000***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.002***	0.000***	0.001***	0.001***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.089***	0.021***	0.030***	0.038***
	0.012	0.003	0.004	0.005
Av. propensity within the industry to use formal knowledge protection/view formal methods as being important	-0.289***	0.078***	0.099***	0.112***
	0.056	0.015	0.019	0.022
Industry birth rate (%)	0.468***	-0.126***	-0.160***	-0.182***
	0.065	0.018	0.022	0.025
Industry concentration ratio (five-firm)	0.017	-0.005	-0.006	-0.007
	0.055	0.015	0.019	0.021
N	15658.000	15658.000	15658.000	15658.000
Chi-squared	2377.377	2377.377	2377.377	2377.377
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.088	0.088	0.088	0.088
bic	24723.634	24723.634	24723.634	24723.634

Notes: See Table 2.6
Coefficients are reported with standard errors below. Models contain wave dummies, * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2002 to 2012 and BSD 1997 to 2012.

Table 2.24: Importance of Registered Designs – Homoscedastic ordered-probit model (marginal effects)

a. Average propensity to be a product innovator within the industry	Not important	Low importance	Medium importance	High importance
Employment (log)	-0.030***	0.010***	0.010***	0.010***
	0.002	0.001	0.001	0.001
Exporter (0/1)	-0.123***	0.039***	0.042***	0.042***
	0.008	0.003	0.003	0.003
Engaged in co-operation - any innovation activity (0/1)	-0.064***	0.021***	0.022***	0.022***
	0.009	0.003	0.003	0.003
Science graduates (% workforce)	-0.002***	0.001***	0.001***	0.000***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.001***	0.000***	0.000***	0.000***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.076***	0.024***	0.026***	0.026***
	0.011	0.003	0.004	0.004
Average propensity to be a product innovator within the industry	-0.400***	0.137***	0.137***	0.126***
	0.048	0.017	0.017	0.015
Industry birth rate (%)	0.387***	-0.132***	-0.133***	-0.122***
	0.065	0.023	0.023	0.021
Industry concentration ratio (five-firm)	0.195***	-0.067***	-0.067***	-0.061***
	0.050	0.017	0.017	0.016
N	15656.000	15656.000	15656.000	15656.000
Chi-squared	2151.914	2151.914	2151.914	2151.914
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.090	0.090	0.090	0.090
bic	21800.410	21800.410	21800.410	21800.410

b. Average propensity to be a process innovator within the industry	Not important	Low importance	Medium importance	High importance
Employment (log)	-0.030***	0.010***	0.010***	0.010***
	0.002	0.001	0.001	0.001
Exporter (0/1)	-0.126***	0.040***	0.043***	0.043***
	0.008	0.003	0.003	0.003
Engaged in co-operation - any innovation activity (0/1)	-0.064***	0.020***	0.022***	0.022***
	0.009	0.003	0.003	0.003
Science graduates (% workforce)	-0.002***	0.001***	0.001***	0.000***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.001***	0.000***	0.000***	0.000***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.077***	0.024***	0.026***	0.027***
	0.011	0.003	0.004	0.004
Average propensity to be a process innovator within the industry	-0.488***	0.167***	0.167***	0.154***
	0.062	0.022	0.022	0.020
Industry birth rate (%)	0.445***	-0.152***	-0.153***	-0.140***
	0.063	0.022	0.022	0.020
Industry concentration ratio (five-firm)	0.216***	-0.074***	-0.074***	-0.068***
	0.049	0.017	0.017	0.016
N	15656.000	15656.000	15656.000	15656.000
Chi-squared	2142.256	2142.256	2142.256	2142.256
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.090	0.090	0.090	0.090
bic	21810.068	21810.068	21810.068	21810.068

Table 2.24 (continued): Importance of Registered Designs – Homoscedastic ordered-probit model (marginal effects)

c. Average propensity within the industry to view industry standards as being important to innovation

	Not important	Low importance	Medium importance	High importance
Employment (log)	-0.030***	0.010***	0.010***	0.010***
	0.002	0.001	0.001	0.001
Exporter (0/1)	-0.134***	0.042***	0.045***	0.046***
	0.008	0.002	0.003	0.003
Engaged in co-operation - any innovation activity (0/1)	-0.063***	0.020***	0.022***	0.022***
	0.009	0.003	0.003	0.003
Science graduates (% workforce)	-0.001***	0.001***	0.001***	0.000***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.001***	0.000***	0.000***	0.000***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.081***	0.025***	0.028***	0.028***
	0.011	0.003	0.004	0.004
Av. propensity within the industry to view industry standards as being important to innovation	-0.848***	0.289***	0.290***	0.269***
	0.165	0.057	0.057	0.053
Industry birth rate (%)	0.620***	-0.211***	-0.212***	-0.196***
	0.057	0.020	0.020	0.019
Industry concentration ratio (five-firm)	0.163***	-0.056***	-0.056***	-0.052***
	0.054	0.019	0.019	0.017
N	15656.000	15656.000	15656.000	15656.000
Chi-squared	2107.142	2107.142	2107.142	2107.142
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.088	0.088	0.088	0.088
bic	21845.182	21845.182	21845.182	21845.182

d. Average propensity within the industry to view industry publications as being important to innovation

	Not important	Low importance	Medium importance	High importance
Employment (log)	-0.030***	0.010***	0.010***	0.010***
	0.002	0.001	0.001	0.001
Exporter (0/1)	-0.127***	0.040***	0.043***	0.044***
	0.008	0.003	0.003	0.003
Engaged in co-operation - any innovation activity (0/1)	-0.064***	0.021***	0.022***	0.022***
	0.009	0.003	0.003	0.003
Science graduates (% workforce)	-0.001***	0.001***	0.001***	0.000***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.001***	0.000***	0.000***	0.000***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.079***	0.025***	0.027***	0.028***
	0.011	0.003	0.004	0.004
Av. propensity within the industry to view industry publications as being important to innovation	-2.259***	0.771***	0.774***	0.714***
	0.341	0.118	0.119	0.109
Industry birth rate (%)	0.682***	-0.233***	-0.234***	-0.215***
	0.055	0.020	0.020	0.018
Industry concentration ratio (five-firm)	0.038	-0.013	-0.013	-0.012
	0.062	0.021	0.021	0.019
N	15656.000	15656.000	15656.000	15656.000
Chi-squared	2124.810	2124.810	2124.810	2124.810
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.089	0.089	0.089	0.089
bic	21827.514	21827.514	21827.514	21827.514

Table 2.24 (continued): Importance of Registered Designs – Homoscedastic ordered-probit model (marginal effects)

e. Average propensity within the industry to use informal knowledge protection/view informal methods as being important				
	Not important	**Low importance**	**Medium importance**	**High importance**
Employment (log)	-0.030***	0.010***	0.010***	0.010***
	0.002	0.001	0.001	0.001
Exporter (0/1)	-0.124***	0.040***	0.042***	0.043***
	0.008	0.003	0.003	0.003
Engaged in co-operation - any innovation activity (0/1)	-0.064***	0.021***	0.022***	0.022***
	0.009	0.003	0.003	0.003
Science graduates (% workforce)	-0.002***	0.001***	0.001***	0.000***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.001***	0.000***	0.000***	0.000***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.077***	0.024***	0.026***	0.027***
	0.011	0.003	0.004	0.004
Av. propensity within the industry to use informal knowledge protection/view informal methods as being important	-0.353***	0.121***	0.121***	0.111***
	0.044	0.015	0.015	0.014
Industry birth rate (%)	0.432***	-0.148***	-0.148***	-0.136***
	0.063	0.022	0.022	0.020
Industry concentration ratio (five-firm)	0.154***	-0.053***	-0.053***	-0.049***
	0.051	0.018	0.018	0.016
N	15656.000	15656.000	15656.000	15656.000
Chi-squared	2145.958	2145.958	2145.958	2145.958
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.090	0.090	0.090	0.090
bic	21806.367	21806.367	21806.367	21806.367

f. Average propensity within the industry to use formal knowledge protection/view formal methods as being important				
	Not important	**Low importance**	**Medium importance**	**High importance**
Employment (log)	-0.030***	0.010***	0.010***	0.010***
	0.002	0.001	0.001	0.001
Exporter (0/1)	-0.127***	0.040***	0.043***	0.043***
	0.008	0.003	0.003	0.003
Engaged in co-operation - any innovation activity (0/1)	-0.064***	0.020***	0.022***	0.022***
	0.009	0.003	0.003	0.003
Science graduates (% workforce)	-0.002***	0.001***	0.001***	0.000***
	0.000	0.000	0.000	0.000
Other graduates (% workforce)	-0.001***	0.000***	0.000***	0.000***
	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	-0.079***	0.025***	0.027***	0.027***
	0.011	0.003	0.004	0.004
Av. propensity within the industry to use formal knowledge protection/view formal methods as being important	-0.373***	0.127***	0.128***	0.118***
	0.053	0.018	0.018	0.017
Industry birth rate (%)	0.493***	-0.168***	-0.169***	-0.156***
	0.061	0.021	0.021	0.020
Industry concentration ratio (five-firm)	0.147***	-0.050***	-0.050***	-0.046***
	0.053	0.018	0.018	0.017
N	15656.000	15656.000	15656.000	15656.000
Chi-squared	2130.479	2130.479	2130.479	2130.479
p	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.089	0.089	0.089	0.089
bic	21821.845	21821.845	21821.845	21821.845

Notes: See Table 2.6
Coefficients are reported with standard errors below. Models contain wave dummies, * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2002 to 2012 and BSD 1997 to 2012.

Table 2.25: Use of Secrecy – Heteroscedastic probit model (marginal effects)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Employment (log)	0.002	0.002	0.002	0.002	0.002	0.002
	0.002	0.002	0.002	0.002	0.002	0.002
Exporter (0/1)	0.103***	0.104***	0.108***	0.106***	0.103***	0.104***
	0.009	0.009	0.009	0.009	0.009	0.009
Engaged in co-operation - any innovation activity (0/1)	0.158***	0.159***	0.159***	0.160***	0.158***	0.159***
	0.010	0.010	0.009	0.009	0.010	0.010
Science graduates (% workforce)	0.002***	0.002***	0.002***	0.002***	0.002***	0.002***
	0.000	0.000	0.000	0.000	0.000	0.000
Other graduates (% workforce)	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	0.107***	0.108***	0.106***	0.106***	0.107***	0.108***
	0.015	0.015	0.015	0.015	0.015	0.015
Industry birth rate (%)	0.302***	0.180*	-0.112	-0.127	0.185*	0.137
	0.115	0.107	0.102	0.102	0.107	0.105
Industry concentration ratio (five-firm)	0.216	0.145	0.048	-0.044	0.141	0.042
	0.135	0.128	0.125	0.114	0.132	0.119
Av. propensity to be a product innovator within the industry	0.384***					
	0.066					
Av. propensity to be a process innovator within the industry		0.461***				
		0.080				
Av. propensity within the industry to view industry standards as being important to innovation			0.929***			
			0.192			
Av. propensity within the industry to view industry publications as being important to innovation				1.610***		
				0.342		
Av. propensity within the industry to use informal knowledge protection/view informal methods as being important					0.320***	
					0.057	
Av. propensity within the industry to use formal knowledge protection/view formal methods as being important						0.376***
						0.064
N	8384.000	8384.000	8384.000	8384.000	8384.000	8384.000
Chi-squared	45.892	65.536	78.078	90.430	69.306	67.421
p	0.000	0.000	0.000	0.000	0.000	0.000
bic	5166.554	5167.011	5176.201	5178.252	5167.740	5165.827

Notes: See Table 2.6
Coefficients are reported with standard errors below. Models contain wave dummies, * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2002 to 2012 and BSD 1997 to 2012.

Table 2.26: Use of Lead-time Advantage – Heteroscedastic probit model (marginal effects)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Employment (log)	-0.002*	-0.002**	-0.002**	-0.002*	-0.002**	-0.002*
	0.001	0.001	0.001	0.001	0.001	0.001
Exporter (0/1)	0.018***	0.018***	0.018***	0.018***	0.017***	0.018***
	0.005	0.005	0.005	0.005	0.005	0.005
Engaged in co-operation - any innovation activity (0/1)	0.083***	0.083***	0.083***	0.082***	0.083***	0.082***
	0.007	0.007	0.007	0.007	0.007	0.007
Science graduates (% workforce)	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
	0.000	0.000	0.000	0.000	0.000	0.000
Other graduates (% workforce)	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	0.029***	0.030***	0.029***	0.029***	0.030***	0.029***
	0.008	0.008	0.008	0.008	0.008	0.008
Industry birth rate (%)	-0.130*	-0.175***	-0.318***	-0.300***	-0.176***	-0.205***
	0.068	0.063	0.061	0.061	0.063	0.062
Industry concentration ratio (five-firm)	-0.004	-0.019	-0.021	-0.097	-0.024	-0.084
	0.081	0.079	0.079	0.073	0.078	0.074
Av. propensity to be a product innovator within the industry	0.158***					
	0.040					
Av. propensity to be a process innovator within the industry		0.201***				
		0.050				
Av. propensity within the industry to view industry standards as being important to innovation			0.545***			
			0.126			
Av. propensity within the industry to view industry publications as being important to innovation				0.690***		
				0.209		
Av. propensity within the industry to use informal knowledge protection/view informal methods as being important					0.143***	
					0.034	
Av. propensity within the industry to use formal knowledge protection/view formal methods as being important						0.124***
						0.038
N	8384.000	8384.000	8384.000	8384.000	8384.000	8384.000
Chi-squared	36.975	50.170	50.327	71.326	51.023	55.134
p	0.000	0.000	0.000	0.000	0.000	0.000
bic	3179.377	3178.558	3174.649	3183.941	3176.844	3184.395

Notes: See Table 2.6
Coefficients are reported with standard errors below. Models contain wave dummies, * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2002 to 2012 and BSD 1997 to 2012.

Table 2.27: Use of Complexity of Design – Heteroscedastic probit model (marginal effects)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Employment (log)	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
	0.001	0.001	0.001	0.001	0.001	0.001
Exporter (0/1)	0.020***	0.020***	0.020***	0.020***	0.020***	0.020***
	0.004	0.004	0.004	0.004	0.004	0.004
Engaged in co-operation - any innovation activity (0/1)	0.042***	0.043***	0.043***	0.042***	0.042***	0.042***
	0.005	0.005	0.005	0.005	0.005	0.005
Science graduates (% workforce)	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
	0.000	0.000	0.000	0.000	0.000	0.000
Other graduates (% workforce)	0.000**	0.000**	0.000**	0.000***	0.000**	0.000***
	0.000	0.000	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	0.030***	0.030***	0.030***	0.029***	0.030***	0.029***
	0.006	0.006	0.006	0.006	0.006	0.006
Industry birth rate (%)	-0.023	-0.028	-0.042	-0.038	-0.027	-0.035
	0.051	0.048	0.048	0.047	0.047	0.046
Industry concentration ratio (five-firm)	-0.102*	-0.105*	-0.107*	-0.115**	-0.102*	-0.115**
	0.062	0.060	0.057	0.056	0.059	0.057
Av. propensity to be a product innovator within the industry	0.014					
	0.028					
Av. propensity to be a process innovator within the industry		0.020				
		0.035				
Av. propensity within the industry to view industry standards as being important to innovation			0.055			
			0.081			
Av. propensity within the industry to view industry publications as being important to innovation				0.013		
				0.140		
Av. propensity within the industry to use informal knowledge protection/view informal methods as being important					0.015	
					0.023	
Av. propensity within the industry to use formal knowledge protection/view formal methods as being important						0.006
						0.026
N	8384.000	8384.000	8384.000	8384.000	8384.000	8384.000
Chi-squared	41.377	57.077	66.274	78.313	60.186	59.728
p	0.000	0.000	0.000	0.000	0.000	0.000
bic	2481.094	2480.846	2479.222	2480.063	2480.242	2480.834

Notes: See Table 2.6
Coefficients are reported with standard errors below. Models contain wave dummies, * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2002 to 2012 and BSD 1997 to 2012.

Table 2.28: Use of Copyright – Heteroscedastic probit model (marginal effects)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Employment (log)	0.001	0.001	0.001	0.001	0.001	0.001
	0.001	0.001	0.001	0.001	0.001	0.001
Exporter (0/1)	0.037***	0.037***	0.038***	0.036***	0.037***	0.036***
	0.003	0.003	0.003	0.003	0.003	0.003
Engaged in co-operation - any innovation activity (0/1)	0.068***	0.068***	0.068***	0.065***	0.067***	0.067***
	0.004	0.004	0.004	0.004	0.004	0.004
Science graduates (% workforce)	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000	0.000	0.000
Other graduates (% workforce)	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	0.034***	0.034***	0.035***	0.032***	0.034***	0.034***
	0.005	0.005	0.005	0.005	0.005	0.005
Industry birth rate (%)	-0.022	-0.031	-0.061**	-0.081***	-0.028	-0.022
	0.030	0.029	0.027	0.027	0.029	0.028
Industry concentration ratio (five-firm)	-0.022	-0.026	-0.033	0.087	-0.013	0.012
	0.042	0.042	0.040	0.062	0.042	0.041
Av. propensity to be a product innovator within the industry	0.054**					
	0.022					
Av. propensity to be a process innovator within the industry		0.067**				
		0.028				
Av. propensity within the industry to view industry standards as being important to innovation			0.171***			
			0.065			
Av. propensity within the industry to view industry publications as being important to innovation				0.660***		
				0.131		
Av. propensity within the industry to use informal knowledge protection/view informal methods as being important					0.054***	
					0.019	
Av. propensity within the industry to use formal knowledge protection/view formal methods as being important						0.109***
						0.023
N	22653.000	22653.000	22653.000	22653.000	22653.000	22653.000
Chi-squared	155.237	206.239	215.661	259.689	201.723	191.257
p	0.000	0.000	0.000	0.000	0.000	0.000
bic	8549.117	8549.986	8549.759	8528.079	8546.705	8532.095

Notes: See Table 2.6
Coefficients are reported with standard errors below. Models contain wave dummies, * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2002 to 2012 and BSD 1997 to 2012.

Table 2.29: Use of Patents – Heteroscedastic probit model (marginal effects)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Employment (log)	0.004***	0.004***	0.004***	0.004***	0.004***	0.004***
	0.000	0.000	0.000	0.000	0.000	0.000
Exporter (0/1)	0.029***	0.029***	0.031***	0.030***	0.029***	0.029***
	0.003	0.003	0.003	0.003	0.003	0.003
Engaged in co-operation - any innovation activity (0/1)	0.034***	0.034***	0.035***	0.035***	0.034***	0.034***
	0.003	0.003	0.003	0.003	0.003	0.003
Science graduates (% workforce)	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
	0.000	0.000	0.000	0.000	0.000	0.000
Other graduates (% workforce)	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	0.028***	0.028***	0.029***	0.029***	0.028***	0.028***
	0.004	0.004	0.004	0.004	0.004	0.004
Industry birth rate (%)	-0.085***	-0.087***	-0.102***	-0.104***	-0.085***	-0.088***
	0.022	0.021	0.020	0.020	0.021	0.020
Industry concentration ratio (five-firm)	0.067	0.067	0.042	0.039	0.069	0.057
	0.054	0.054	0.049	0.047	0.052	0.051
Av. propensity to be a product innovator within the industry	0.013					
	0.017					
Av. propensity to be a process innovator within the industry		0.014				
		0.021				
Av. propensity within the industry to view industry standards as being important to innovation			0.055			
			0.049			
Av. propensity within the industry to view industry publications as being important to innovation				0.141		
				0.095		
Av. propensity within the industry to use informal knowledge protection/view informal methods as being important					0.015	
					0.014	
Av. propensity within the industry to use formal knowledge protection/view formal methods as being important						0.016
						0.017
N	22653.000	22653.000	22653.000	22653.000	22653.000	22653.000
Chi-squared	146.294	187.784	182.634	210.267	183.318	171.984
p	0.000	0.000	0.000	0.000	0.000	0.000
bic	6885.332	6885.131	6887.395	6884.658	6884.111	6885.185

Notes: See Table 2.6
Coefficients are reported with standard errors below. Models contain wave dummies, * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2002 to 2012 and BSD 1997 to 2012.

Table 2.30: Use of Trademarks – Heteroscedastic probit model (marginal effects)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Employment (log)	0.009***	0.009***	0.009***	0.009***	0.009***	0.009***
	0.001	0.001	0.001	0.001	0.001	0.001
Exporter (0/1)	0.046***	0.046***	0.046***	0.045***	0.046***	0.045***
	0.004	0.004	0.004	0.004	0.004	0.004
Engaged in co-operation - any innovation activity (0/1)	0.069***	0.069***	0.069***	0.068***	0.069***	0.068***
	0.004	0.004	0.004	0.004	0.004	0.004
Science graduates (% workforce)	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
	0.000	0.000	0.000	0.000	0.000	0.000
Other graduates (% workforce)	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	0.037***	0.037***	0.038***	0.038***	0.037***	0.037***
	0.006	0.006	0.006	0.006	0.006	0.006
Industry birth rate (%)	-0.235***	-0.228***	-0.200***	-0.197***	-0.230***	-0.216***
	0.034	0.033	0.031	0.031	0.033	0.032
Industry concentration ratio (five-firm)	0.133*	0.135*	0.088	0.153**	0.130*	0.168**
	0.074	0.072	0.061	0.064	0.071	0.068
Av. propensity to be a product innovator within the industry	-0.054**					
	0.027					
Av. propensity to be a process innovator within the industry		-0.074**				
		0.033				
Av. propensity within the industry to view industry standards as being important to innovation			-0.283***			
			0.075			
Av. propensity within the industry to view industry publications as being important to innovation				-0.273*		
				0.145		
Av. propensity within the industry to use informal knowledge protection/view informal methods as being important					-0.052**	
					0.022	
Av. propensity within the industry to use formal knowledge protection/view formal methods as being important						-0.022
						0.026
N	22653.000	22653.000	22653.000	22653.000	22653.000	22653.000
Chi-squared	182.542	235.757	216.483	248.993	227.118	213.976
p	0.000	0.000	0.000	0.000	0.000	0.000
bic	10250.143	10249.101	10232.782	10248.113	10248.794	10252.984

Notes: See Table 2.6
Coefficients are reported with standard errors below. Models contain wave dummies, * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2002 to 2012 and BSD 1997 to 2012.

Table 2.31: Use of Registered Designs – Heteroscedastic probit model (marginal effects)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Employment (log)	0.002***	0.001***	0.001***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000	0.000	0.000
Exporter (0/1)	0.009***	0.009***	0.009***	0.009***	0.009***	0.009***
	0.002	0.002	0.002	0.002	0.002	0.002
Engaged in co-operation - any innovation activity (0/1)	0.014***	0.014***	0.014***	0.014***	0.014***	0.014***
	0.002	0.002	0.002	0.002	0.002	0.002
Science graduates (% workforce)	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
	0.000	0.000	0.000	0.000	0.000	0.000
Other graduates (% workforce)	0.000*	0.000*	0.000**	0.000**	0.000*	0.000*
	0.000	0.000	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	0.006***	0.006***	0.006***	0.006***	0.006***	0.006***
	0.002	0.002	0.002	0.002	0.002	0.002
Industry birth rate (%)	-0.036***	-0.037***	-0.045***	-0.044***	-0.037***	-0.040***
	0.014	0.013	0.012	0.012	0.013	0.014
Industry concentration ratio (five-firm)	0.021	0.018	-0.005	0.002	0.020	0.019
	0.020	0.019	0.021	0.020	0.019	0.034
Av. propensity to be a product innovator within the industry	0.000					
	0.010					
Av. propensity to be a process innovator within the industry		-0.002				
		0.013				
Av. propensity within the industry to view industry standards as being important to innovation			-0.025			
			0.029			
Av. propensity within the industry to view industry publications as being important to innovation				-0.007		
				0.056		
Av. propensity within the industry to use informal knowledge protection/view informal methods as being important					0.000	
					0.009	
Av. propensity within the industry to use formal knowledge protection/view formal methods as being important						0.001
						0.010
N	22653.000	22653.000	22653.000	22653.000	22653.000	22653.000
Chi-squared	95.873	117.209	112.259	124.655	113.452	116.006
p	0.000	0.000	0.000	0.000	0.000	0.000
bic	3594.832	3595.344	3606.862	3606.265	3594.956	3605.344

Notes: See Table 2.6
Coefficients are reported with standard errors below. Models contain wave dummies, * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2002 to 2012 and BSD 1997 to 2012.

Table 2.32: Use of Secrecy – Homoscedastic probit model (marginal effects)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Employment (log)	0.001	0.001	0.001	0.002	0.001	0.001
	0.002	0.002	0.002	0.002	0.002	0.002
Exporter (0/1)	0.106***	0.107***	0.111***	0.110***	0.106***	0.106***
	0.009	0.009	0.009	0.009	0.009	0.009
Engaged in co-operation - any innovation activity (0/1)	0.164***	0.164***	0.165***	0.166***	0.164***	0.164***
	0.009	0.009	0.009	0.009	0.009	0.009
Science graduates (% workforce)	0.002***	0.002***	0.002***	0.002***	0.002***	0.002***
	0.000	0.000	0.000	0.000	0.000	0.000
Other graduates (% workforce)	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	0.113***	0.113***	0.112***	0.113***	0.113***	0.113***
	0.015	0.015	0.015	0.015	0.015	0.015
Industry birth rate (%)	0.228**	0.119	-0.179**	-0.212**	0.107	0.059
	0.104	0.096	0.090	0.091	0.095	0.092
Industry concentration ratio (five-firm)	0.092	0.050	-0.057	-0.134	0.040	-0.021
	0.121	0.116	0.112	0.105	0.116	0.109
Av. propensity to be a product innovator within the industry	0.372***					
	0.062					
Av. propensity to be a process innovator within the industry		0.459***				
		0.075				
Av. propensity within the industry to view industry standards as being important to innovation			0.909***			
			0.177			
Av. propensity within the industry to view industry publications as being important to innovation				1.596***		
				0.322		
Av. propensity within the industry to use informal knowledge protection/view informal methods as being important					0.310***	
					0.052	
Av. propensity within the industry to use formal knowledge protection/view formal methods as being important						0.374***
						0.060
N	8384.000	8384.000	8384.000	8384.000	8384.000	8384.000
Chi-squared	1910.971	1912.315	1901.245	1898.961	1911.336	1914.071
p	0.000	0.000	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.275	0.275	0.273	0.273	0.275	0.275
bic	5141.073	5139.728	5150.799	5153.083	5140.708	5137.973

Notes: See Table 2.6
Coefficients are reported with standard errors below. Models contain wave dummies, * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2002 to 2012 and BSD 1997 to 2012.

Table 2.33: Use of Lead-time Advantage – Homoscedastic probit model (marginal effects)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Employment (log)	-0.002**	-0.002**	-0.002**	-0.002*	-0.002**	-0.002**
	0.001	0.001	0.001	0.001	0.001	0.001
Exporter (0/1)	0.017***	0.017***	0.018***	0.018***	0.016***	0.018***
	0.005	0.005	0.005	0.005	0.005	0.005
Engaged in co-operation - any innovation activity (0/1)	0.081***	0.081***	0.081***	0.081***	0.081***	0.081***
	0.006	0.006	0.006	0.006	0.006	0.006
Science graduates (% workforce)	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
	0.000	0.000	0.000	0.000	0.000	0.000
Other graduates (% workforce)	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	0.029***	0.029***	0.028***	0.029***	0.028***	0.029***
	0.007	0.008	0.007	0.008	0.007	0.008
Industry birth rate (%)	-0.124*	-0.168***	-0.289***	-0.300***	-0.166***	-0.208***
	0.064	0.058	0.053	0.053	0.058	0.056
Industry concentration ratio (five-firm)	0.007	-0.013	-0.031	-0.092	-0.011	-0.072
	0.073	0.069	0.066	0.061	0.069	0.064
Av. propensity to be a product innovator within the industry	0.144***					
	0.036					
Av. propensity to be a process innovator within the industry		0.175***				
		0.044				
Av. propensity within the industry to view industry standards as being important to innovation			0.424***			
			0.102			
Av. propensity within the industry to view industry publications as being important to innovation				0.623***		
				0.186		
Av. propensity within the industry to use informal knowledge protection/view informal methods as being important					0.125***	
					0.030	
Av. propensity within the industry to use formal knowledge protection/view formal methods as being important						0.116***
						0.034
N	8384.000	8384.000	8384.000	8384.000	8384.000	8384.000
Chi-squared	632.544	632.710	634.167	627.714	634.322	627.724
p	0.000	0.000	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.172	0.172	0.172	0.171	0.172	0.171
bic	3144.693	3144.526	3143.070	3149.523	3142.915	3149.513

Notes: See Table 2.6
Coefficients are reported with standard errors below. Models contain wave dummies, * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2002 to 2012 and BSD 1997 to 2012.

Table 2.34: Use of Complexity of Design – Homoscedastic probit model (marginal effects)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Employment (log)	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
	0.001	0.001	0.001	0.001	0.001	0.001
Exporter (0/1)	0.022***	0.022***	0.022***	0.023***	0.022***	0.023***
	0.004	0.004	0.004	0.004	0.004	0.004
Engaged in co-operation - any innovation activity (0/1)	0.048***	0.048***	0.048***	0.048***	0.048***	0.048***
	0.005	0.005	0.005	0.005	0.005	0.005
Science graduates (% workforce)	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
	0.000	0.000	0.000	0.000	0.000	0.000
Other graduates (% workforce)	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
	0.000	0.000	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	0.033***	0.033***	0.032***	0.033***	0.032***	0.033***
	0.007	0.007	0.007	0.007	0.007	0.007
Industry birth rate (%)	-0.083*	-0.089**	-0.119***	-0.119***	-0.088**	-0.102**
	0.047	0.043	0.039	0.040	0.043	0.042
Industry concentration ratio (five-firm)	-0.146***	-0.145***	-0.139***	-0.167***	-0.144***	-0.163***
	0.053	0.052	0.049	0.047	0.051	0.048
Av. propensity to be a product innovator within the industry	0.030					
	0.026					
Av. propensity to be a process innovator within the industry		0.041				
		0.032				
Av. propensity within the industry to view industry standards as being important to innovation			0.134*			
			0.074			
Av. propensity within the industry to view industry publications as being important to innovation				0.113		
				0.133		
Av. propensity within the industry to use informal knowledge protection/view informal methods as being important					0.030	
					0.021	
Av. propensity within the industry to use formal knowledge protection/view formal methods as being important						0.021
						0.025
N	8384.000	8384.000	8384.000	8384.000	8384.000	8384.000
Chi-squared	654.886	655.300	657.020	654.317	655.591	654.302
p	0.000	0.000	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.218	0.218	0.218	0.218	0.218	0.218
bic	2452.493	2452.079	2450.359	2453.062	2451.788	2453.077

Notes: See Table 2.6
Coefficients are reported with standard errors below. Models contain wave dummies, * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2002 to 2012 and BSD 1997 to 2012.

Table 2.35: Use of Copyright – Homoscedastic probit model (marginal effects)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Employment (log)	0.001	0.001	0.001	0.001	0.001	0.001
	0.001	0.001	0.001	0.001	0.001	0.001
Exporter (0/1)	0.038***	0.039***	0.039***	0.037***	0.038***	0.037***
	0.003	0.003	0.003	0.003	0.003	0.003
Engaged in co-operation - any innovation activity (0/1)	0.068***	0.068***	0.068***	0.068***	0.068***	0.067***
	0.004	0.004	0.004	0.004	0.004	0.004
Science graduates (% workforce)	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000	0.000	0.000
Other graduates (% workforce)	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	0.035***	0.035***	0.035***	0.034***	0.034***	0.034***
	0.005	0.005	0.005	0.005	0.005	0.005
Industry birth rate (%)	-0.002	-0.012	-0.038*	-0.058***	-0.006	0.003
	0.026	0.025	0.022	0.022	0.025	0.023
Industry concentration ratio (five-firm)	-0.036	-0.041	-0.042	0.015	-0.025	0.007
	0.038	0.037	0.037	0.039	0.038	0.038
Av. propensity to be a product innovator within the industry	0.053**					
	0.021					
Av. propensity to be a process innovator within the industry		0.064**				
		0.026				
Av. propensity within the industry to view industry standards as being important to innovation			0.160**			
			0.062			
Av. propensity within the industry to view industry publications as being important to innovation				0.625***		
				0.125		
Av. propensity within the industry to use informal knowledge protection/view informal methods as being important					0.054***	
					0.019	
Av. propensity within the industry to use formal knowledge protection/view formal methods as being important						0.108***
						0.022
N	22653.000	22653.000	22653.000	22653.000	22653.000	22653.000
Chi-squared	2211.974	2211.263	2212.049	2230.871	2214.075	2229.272
p	0.000	0.000	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.209	0.209	0.209	0.210	0.209	0.210
bic	8512.371	8513.082	8512.297	8493.475	8510.270	8495.073

Notes: See Table 2.6
Coefficients are reported with standard errors below. Models contain wave dummies, * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2002 to 2012 and BSD 1997 to 2012.

Table 2.36: Use of Patents – Homoscedastic probit model (marginal effects)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Employment (log)	0.005***	0.005***	0.005***	0.005***	0.005***	0.005***
	0.001	0.001	0.001	0.001	0.001	0.001
Exporter (0/1)	0.037***	0.037***	0.038***	0.037***	0.037***	0.037***
	0.003	0.003	0.003	0.003	0.003	0.003
Engaged in co-operation - any innovation activity (0/1)	0.043***	0.043***	0.043***	0.043***	0.043***	0.043***
	0.003	0.003	0.003	0.003	0.003	0.003
Science graduates (% workforce)	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000	0.000	0.000
Other graduates (% workforce)	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	0.039***	0.039***	0.039***	0.038***	0.039***	0.039***
	0.005	0.005	0.005	0.005	0.005	0.005
Industry birth rate (%)	-0.120***	-0.125***	-0.143***	-0.150***	-0.118***	-0.124***
	0.021	0.020	0.017	0.017	0.020	0.019
Industry concentration ratio (five-firm)	-0.097***	-0.098***	-0.099***	-0.085***	-0.084***	-0.088***
	0.029	0.028	0.028	0.029	0.029	0.028
Av. propensity to be a product innovator within the industry	0.034**					
	0.015					
Av. propensity to be a process innovator within the industry		0.044**				
		0.020				
Av. propensity within the industry to view industry standards as being important to innovation			0.108**			
			0.046			
Av. propensity within the industry to view industry publications as being important to innovation				0.285***		
				0.093		
Av. propensity within the industry to use informal knowledge protection/view informal methods as being important					0.040***	
					0.014	
Av. propensity within the industry to use formal knowledge protection/view formal methods as being important						0.048***
						0.017
N	22653.000	22653.000	22653.000	22653.000	22653.000	22653.000
Chi-squared	2500.193	2500.347	2500.851	2504.868	2504.137	2503.786
p	0.000	0.000	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.270	0.270	0.270	0.270	0.270	0.270
bic	6885.054	6884.900	6884.395	6880.378	6881.109	6881.461

Notes: See Table 2.6
Coefficients are reported with standard errors below. Models contain wave dummies, * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2002 to 2012 and BSD 1997 to 2012.

Table 2.37: Use of Trademarks – Homoscedastic probit model (marginal effects)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Employment (log)	0.010***	0.010***	0.009***	0.010***	0.010***	0.010***
	0.001	0.001	0.001	0.001	0.001	0.001
Exporter (0/1)	0.048***	0.048***	0.048***	0.047***	0.048***	0.047***
	0.004	0.004	0.004	0.004	0.004	0.004
Engaged in co-operation - any innovation activity (0/1)	0.074***	0.074***	0.074***	0.073***	0.074***	0.073***
	0.004	0.004	0.004	0.004	0.004	0.004
Science graduates (% workforce)	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
	0.000	0.000	0.000	0.000	0.000	0.000
Other graduates (% workforce)	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***
	0.000	0.000	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	0.039***	0.039***	0.039***	0.039***	0.039***	0.038***
	0.006	0.006	0.006	0.006	0.006	0.006
Industry birth rate (%)	-0.251***	-0.240***	-0.198***	-0.190***	-0.238***	-0.213***
	0.033	0.031	0.029	0.029	0.031	0.030
Industry concentration ratio (five-firm)	-0.010	-0.008	-0.035	0.004	-0.010	0.027
	0.042	0.042	0.040	0.043	0.042	0.042
Av. propensity to be a product innovator within the industry	-0.077***					
	0.024					
Av. propensity to be a process innovator within the industry		-0.098***				
		0.030				
Av. propensity within the industry to view industry standards as being important to innovation			-0.352***			
			0.068			
Av. propensity within the industry to view industry publications as being important to innovation				-0.337**		
				0.142		
Av. propensity within the industry to use informal knowledge protection/view informal methods as being important					-0.064***	
					0.021	
Av. propensity within the industry to use formal knowledge protection/view formal methods as being important						-0.035
						0.025
N	22653.000	22653.000	22653.000	22653.000	22653.000	22653.000
Chi-squared	1668.925	1669.054	1684.390	1664.022	1667.926	1660.343
p	0.000	0.000	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.142	0.142	0.143	0.141	0.142	0.141
bic	10231.862	10231.732	10216.397	10236.765	10232.860	10240.443

Notes: See Table 2.6
Coefficients are reported with standard errors below. Models contain wave dummies, * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2002 to 2012 and BSD 1997 to 2012.

Table 2.38: Use of Registered Designs – Homoscedastic probit model (marginal effects)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Employment (log)	0.002***	0.002***	0.002***	0.002***	0.002***	0.002***
	0.000	0.000	0.000	0.000	0.000	0.000
Exporter (0/1)	0.011***	0.012***	0.012***	0.012***	0.011***	0.012***
	0.002	0.002	0.002	0.002	0.002	0.002
Engaged in co-operation - any innovation activity (0/1)	0.018***	0.018***	0.018***	0.018***	0.018***	0.018***
	0.002	0.002	0.002	0.002	0.002	0.002
Science graduates (% workforce)	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
	0.000	0.000	0.000	0.000	0.000	0.000
Other graduates (% workforce)	0.000**	0.000*	0.000**	0.000*	0.000*	0.000*
	0.000	0.000	0.000	0.000	0.000	0.000
Received public financial support for innovation (0/1)	0.009***	0.009***	0.009***	0.009***	0.009***	0.009***
	0.002	0.002	0.002	0.002	0.002	0.002
Industry birth rate (%)	-0.066***	-0.068***	-0.075***	-0.075***	-0.067***	-0.069***
	0.013	0.012	0.011	0.010	0.012	0.011
Industry concentration ratio (five-firm)	-0.026	-0.027*	-0.038**	-0.031**	-0.025	-0.028*
	0.016	0.016	0.015	0.016	0.016	0.016
Av. propensity to be a product innovator within the industry	0.012					
	0.009					
Av. propensity to be a process innovator within the industry		0.013				
		0.011				
Av. propensity within the industry to view industry standards as being important to innovation			-0.002			
			0.025			
Av. propensity within the industry to view industry publications as being important to innovation				0.037		
				0.053		
Av. propensity within the industry to use informal knowledge protection/view informal methods as being important					0.011	
					0.008	
Av. propensity within the industry to use formal knowledge protection/view formal methods as being important						0.011
						0.010
N	22653.000	22653.000	22653.000	22653.000	22653.000	22653.000
Chi-squared	832.843	832.516	831.040	831.523	833.030	832.377
p	0.000	0.000	0.000	0.000	0.000	0.000
R-squared (pseudo)	0.194	0.194	0.194	0.194	0.194	0.194
bic	3580.068	3580.395	3581.871	3581.387	3579.881	3580.534

Notes: See Table 2.6
Coefficients are reported with standard errors below. Models contain wave dummies, * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2002 to 2012 and BSD 1997 to 2012.

Chapter 3

Appropriability regimes and the complexity and variability of knowledge-protection strategies within industries

3.1 Introduction

Successful firm innovation, in the form of higher profits, increased market value, improved credit ratings or an increased chance of survival (Geroski et al., 1993; Hall, 2000; Czarnitzki and Kraft, 2004; Cefis and Marsili, 2005) is not guaranteed. Indeed, there are many reasons why innovative behaviour may fail to reward the innovator. In the case of technological innovations, for example, innovations may be unsuccessful because they are unreliable and imperfectly designed (Klein and Ralls, 1995); the newer the technology, the more likely it is to have bugs or break, or an innovation may be unsuccessful because it require users to acquire new technical knowledge and skills, for example, a requirement which may lower user satisfaction and adoption rates (Aiman-Smith and Green, 2002). Furthermore, a successful firm innovation does not necessarily guarantee higher profits, increased market value, improved credit ratings or an increased chance of survival for the innovating firm either. The outcome depends upon the firm's ability to appropriate the returns to its innovation i.e. the firm's ability to capture profits generated through innovation (Teece, 1986; Levin et al., 1987). The appropriability problem (Arrow, 1962) arises when an innovating firm is unable to limit other firms from imitating its innovations – the innovating firm fails to appropriate returns (Ceccagnoli and Rothaermel, 2008) and retain the value added it creates for its own benefit.

However, an innovating firm can guard against imitation by utilising knowledge-protection mechanisms – practical ways of making knowledge less transferable. Knowledge-protection mechanisms allow innovators to appropriate returns by making their innovative knowledge excludable. These mechanisms include both formal and informal methods of knowledge protection. Formal knowledge-protection mechanisms are implemented through regulation and are effective by legally excluding imitators, examples include patents and trademarks (Hall, 1992).

Informal protection methods are not based upon structures and statutory enforcement possibilities, examples include secrecy and lead-time (Hurmelinna-Laukkanen, 2014).

In order to profit from innovation, an innovator requires the ability to formulate an effective knowledge-protection strategy – encompassing different knowledge-protection mechanisms – to prevent or delay the imitation of its knowledge and technology (Hurmelinna-Laukkanen et al., 2008). Although a variety of protection mechanisms exist, not all protection mechanisms are available and effective for all firms. The industry appropriability regime – the environmental factors a firm faces (excluding firm and industry structure) – defines the knowledge-protection mechanisms that are available and effective within an industry to protect both innovations themselves and any increased rents which flow from them (Teece, 1986, 1998, 2000a; Levin et al., 1987; Teece and Pisano, 1998); it governs a firm's ability to capture profits from an innovation (Teece, 1986). Formal knowledge-protection mechanisms, for example patents, are more effective at protecting product innovations and knowledge in industries which specialise in the production of discrete products, for example in the pharmaceuticals and chemical industries (Mansfield, 1986; Harabi, 1995), and they therefore form part of the appropriability regime in these industries. Informal knowledge-protection mechanisms are more effective at protecting process innovations and knowledge in complex-product industries (Cohen et al., 2000), and as a result, they form part of the appropriability regime in these industries. Appropriability regimes also vary in strength across different industries. As the available and effective protection increases, the appropriability regime becomes stronger – innovation becomes easier to protect and firms are more able to appropriate returns.

Despite firms within a given industry being faced with identical knowledge-protection opportunities as defined by the industry appropriability regime, firms make different knowledge-protection choices. Firms within an industry are characterised by their resources and capabilities; indeed, each firm can be thought of as a collection of resources (Penrose, 1959). It is the heterogeneous nature of firm-specific resources and capabilities, for example the amount of finance a firm has available or its managerial capabilities, which gives rise to the variation in firms' knowledge-protection choices within an industry. Small firms, for instance, may lack the necessary resources and capabilities to protect innovation using formal methods – for example, they may lack the finance to apply for patents and to take court action if it becomes necessary to do so (Olander et al., 2009).

In summary, within any given industry, firms optimise their knowledge-protection choices according to their resources and capabilities and the available and effective knowledge-protection mechanisms within the industry which are defined by the industry appropriability regime.

The present study acknowledges that the complexity of firms' knowledge-protection choices (or strategies) within a given industry – in terms of the amount of knowledge-protection firms adopt – is jointly determined by the industry appropriability regime and firms' individual resources and capabilities. As the industry appropriability regime strengthens, firms have more effective knowledge-protection mechanisms available to them. The strategy space increases, and given that firms have the resources and capabilities to do so, they are able to increase the amount of protection that they adopt to protect their knowledge and innovations. In addition, this study acknowledges that the variability of firms' knowledge-protection choices within an industry is due to the heterogeneous nature of firms' resources and capabilities. As the industry appropriability regime strengthens, the increased strategy space leads to an increased variability in knowledge-protection choices amongst firms. The increased availability of effective protection options allows for a greater range of firm positioning and, in turn, an increase in the chance that firms will receive any added value for their own benefit. By being able to select a unique position relative to other firms within the industry, a firm reduces the competition that it faces and increases its chances of success in terms of performance (Deephouse, 1999).

Given the benefits to firms of more complex knowledge-protection choices and an increase in the variability of knowledge-protection choices within an industry, this study seeks to examine how relaxing the limit on the available and effective knowledge-protection mechanisms within an industry i.e. strengthening the knowledge-protection dimension of the industry appropriability regime, affects the complexity and variability of firms' knowledge-protection choices within the industry.

Previous studies examining the factors which affect firms' choice of knowledge-protection mechanisms are numerous. Many studies identify industry characteristics (for example, the level of technology and research and development – R&D – intensity) as being important determinants of the knowledge-protection mechanisms firms use to appropriate the returns to innovation (Mansfield, 1986; Levin et al., 1987; Harabi, 1995; Cohen et al., 2000). Others studies examine how the availability of firm resources (Kitching and Blackburn, 1998; Leiponen and Byma, 2009) and the novelty of an innovation (Thomas, 2003; Hanel, 2005; Hussinger, 2006) impact upon firms' knowledge-protection choices. Adding to these findings, Hurmelinna-Laukkanen et al. (2017) in their study identify three different appropriability profiles among firms (patterns of knowledge-protection choice) with industry factors and firm-resource factors jointly determining the profile group to which a firm belongs. Their findings suggest that firms are better to approach the appropriability problem by considering protection mechanisms as a whole rather than by comparing one protection mechanism with another, and they suggest that firms are likely to benefit from having a wide range of protection mechanisms available to them. The present study adds to this body of knowledge by taking a holistic view of knowledge protection and examining how strengthening the protection dimension of the industry appropriability regime impacts upon firms' protection choices within the industry. Rather than examining the nature of firms' knowledge-protection profiles across different industries, this study is concerned with firms' knowledge-protection profiles within an industry. In contrast to previous studies, it investigates how firms' knowledge-protection choices respond to changing industry appropriability conditions. Many previous studies acknowledge that industry characteristics have implications for firms' knowledge-protection choices, and the analysis here examines, quantitatively, the relationship between the strength of the protection dimension of the industry appropriability regime and the complexity and variability of knowledge-protection choices (or strategies) made by firms within the industry. In addition, the analysis considers whether the effects on firms' knowledge-protection choices differ across industries by undertaking a comparison of high-technology/knowledge-intensive industries and low-technology/less knowledge-intensive industries.

The remainder of this chapter is structured as follows. Section 3.2 introduces the concepts of the industry appropriability regime and a firm's knowledge-protection strategy. Knowledge protection in relation to the resource-based view of strategy is discussed along with the ways in which firms' knowledge-protection strategies are influenced by the industry appropriability regime. A description of the conceptual framework and hypotheses concludes this section. Section 3.3 profiles the data and methodology used in this study, Section 3.4 contains the empirical results and Section 3.5 includes discussion and conclusions.

3.2 Conceptual development

3.2.1 The industry appropriability regime

Appropriability – a firm's capacity to retain any added value it creates for its own benefit – represents the extent to which a firm can capture profits generated through innovation (Teece, 1986; Levin et al., 1987). The appropriability regime, the environmental factors a firm faces (excluding firm and industry structure) which govern its ability to capture profits from an innovation (Teece, 1986), has been identified, along with specialised complimentary assets, as an influence upon this appropriability (Teece, 1986); it affects a firm's ability to profit from its innovation (Pisano, 2006).

There are two important dimensions of the appropriability regime: the nature of the technology within the industry (for example, whether the industry is characterised by product or process technologies and whether technology is based upon tacit or codified knowledge), and the legal methods of knowledge protection available to protect both innovations themselves and any increased rents which flow from them (Teece, 1986, 1998, 2000a; Levin et al., 1987; Teece and Pisano, 1998). Some researchers extend this appropriability regime definition to include other formal (legally binding) knowledge-protection methods (for example, contracts and labour legislation) as well as less formal (not legally binding) knowledge-protection methods (for example secrecy and lead time) (Hurmelinna-Laukkanen and

Puumalainen, 2007b). For the purpose of this study, the appropriability regime is defined to include both formal and informal knowledge-protection mechanisms.

The first dimension of the appropriability regime – the nature of the technology within the industry – provides ‘natural protection against imitation’ (Pisano and Teece, 2007) and is an indication of the ease of its imitability (Pisano, 2006). For example, the accessibility of a technology – whether or not it can be obtained by and used by others – determines the likelihood of imitation (Jones Day, 2006). The level of accessibility varies across both product and process technologies and tacit and codified knowledge. Many process technologies, for example, are not generally observable and are therefore highly inaccessible. In contrast, new products are easily accessible to many, their technologies are observed and they can be re-created through techniques such as reverse engineering. Some technologies are based upon tacit knowledge and are very difficult to understand, making them particularly inaccessible. Other technologies use codified knowledge so that the technology is accessible to everyone. In summary, the less (more) generally accessible the technology, the less (more) likely it will be subject to imitation and the more (less) likely returns will be appropriated by the innovating firm. As the nature of the technology – or characteristics of the technology – varies across different industries, appropriability regimes become industry specific and defined by the technological profiles of the industry to which they apply.

The second dimension of the appropriability regime is the formal and informal methods of knowledge protection used by firms to protect their innovations and the rents which flow from them, for example patents, copyright and secrecy. It is the availability and enforceability of these protection methods which helps to shape the appropriability regime of a particular industry (Hurmelinna-Laukkanen and Jauhiainen, 2004). Levin et al. (1987) and Cohen et al. (2000) examine the extent to which firms in different industries choose formal and informal knowledge-protection methods to protect knowledge and innovation. Both studies find that a high percentage of firms rely on informal knowledge-protection mechanisms, for example, secrecy and lead time are found to be important protection methods for both product and process innovations; patents are found to be much less important, with the exception of the pharmaceutical and chemical industries. Patents, however, are identified as being more important for product innovations than for process innovations. One reason for this is that a patented process can easily be invented around once knowledge is disclosed. This is supported by Harabi (1995), who, in a study of Swiss firms, finds that firms are concerned about disclosing knowledge. Some firms believe disclosing knowledge allows competitors an opportunity to invent around their innovations. Patents, on the other hand, are identified as being important to firms in the pharmaceutical, chemical and machinery industries. Secrecy, an informal protection mechanism, is found to be important for process innovations; processes can be effectively retained within the firm and protected with trade secrets. In a survey of one hundred manufacturing firms, Mansfield (1986) also finds that firms in both the pharmaceutical and chemical industries use patent protection; at least 30 per cent of innovations are protected using this method. R&D intensive firms and science-based firms have been identified as being more likely to protect knowledge formally (Cohen et al., 2000; Leiponen and Byma, 2009), high-technology industries tend to rely more on formal methods (Brouwer and Kleinknecht, 1999), and the propensity to patent and the number of patent applications is significantly lower in services compared with manufacturing (Blind et al., 2003). The evidence shows that formal mechanisms are used more often than informal mechanisms in discrete product industries (Cohen et al., 2000), whereas in complex-product industries it is easier to invent around technologies, and consequently, firms rely on more informal methods of protection based upon secrecy.

The appropriability regime determines the barriers to imitation which exist within an industry and therefore the ease with which competitors can imitate an innovation (Ceccagnoli and Rothaermel, 2008). Appropriability regimes can be strong or weak (Teece, 1986), and their strength varies across industries. This is in part due to the effectiveness of knowledge-protection mechanisms – to achieve a desired or intended effect – varying significantly across industries (Levin et al., 1987).

An appropriability regime is 'strong' when innovations are easy to protect – knowledge about them is tacit or they are well protected by formal/informal knowledge-protection mechanisms. In a strong environment with tacit knowledge, innovations are hard to imitate because knowledge is embedded within firms' routines and capabilities. The technology in the software industry, for example, enjoys a relatively strong appropriability regime (Pisano and Teece, 2007). Here, imitation is difficult because it is technically possible to shield source code from users and competitors.

An appropriability regime is 'weak' when innovations are difficult to protect – knowledge is easily codified or formal/informal knowledge-protection mechanisms are ineffective. When technologies are easily observed and reverse engineering is possible, imitation is easy, and alternatives can be easily developed. The rate and volume of knowledge spillovers is higher in a weak appropriability regime compared with a strong regime. The effects of this are not all negative as there is a positive impact upon the rate of technological change; the technological opportunity for all firms within an industry is increased (Klevorick et al., 1995). On the downside, the knowledge embedded within firm innovations quickly diffuses to other firms, and the innovating firm's appropriated returns quickly diminish (Teece et al., 1997). For a firm to achieve continuous returns in a weak appropriability environment, it may need to innovate continuously (Roberts, 1999). In addition, the risk of knowledge spillovers in a weak regime means that there is a great uncertainty related to the returns from committing to long periods of resource development (Sakakibara, 2002). Firms may therefore need to develop new resources for innovation speedily. In a strong appropriability regime, however, firms are more able to commit to long periods of resource development due to the greater certainty of returns from their investment (Levin et al., 1987).

When faced with a weak appropriability regime, firms unable to use formal knowledge-protection mechanisms to protect their innovations and the returns which flow from them can strengthen their appropriability conditions by acquiring complementary assets (Gans and Stern, 2003) – the appropriability regime's counterpart in determining appropriability (Teece, 1986) – or by using less formal knowledge-protection mechanisms, for example a firewall to protect the leakage of confidential information (Markham et al., 2005). The soft drinks industry is an example where the appropriability regime is relatively weak. For example, Royal Crown Cola first developed a diet soft drink, yet its rivals – Pepsi and Coca-Cola – profited from the innovation (Dodgson et al., 2014). Within the soft-drinks industry, the use of patent protection would be short lived, and imitation would be relatively easy thereafter. The use of secrecy combined with trademarks and/or brand positioning – where the brand is perceived as being more favourable and credible in consumers' minds – is more suitable here.

In reality, appropriability regimes form a continuum, some emphasising knowledge-protection mechanisms over the nature of technology and some emphasising the nature of technology over knowledge protection (Teece, 1998, 2000a). A strong regime can be achieved by different means; some industries may rely upon knowledge-protection mechanisms while others may rely upon tacit knowledge embedded deep within the structure of firms (Levin et al., 1987). Whatever the chosen combination, a firm's aim is to create a first-mover advantage and earn higher than average returns. It follows from this that the industry appropriability regime can be strengthened by increasing the tacit nature of knowledge within an industry or by increasing the amount of effective and available knowledge protection within the industry for firms to use to help in the appropriation of innovation. The knowledge-protection dimension of the industry appropriability regime is the main focus of the study, with an increase in the amount of effective and available protection within an industry representing an increase in the strength of the appropriability regime.

3.2.2 A firm's knowledge-protection strategy

Knowledge, an intangible asset, typically entails higher risks than assets of a physical or financial nature. Mismanagement of, theft of and crime relating to knowledge requires firms to actively protect their knowledge, mitigating its risks and preserving its value. The protection of knowledge – whether using formal or informal protection mechanisms – limits imitation and helps firms gain a competitive advantage (Teece et al., 1997).

A strategy is defined as "a pattern in a stream of decisions" (Mintzberg, 1978, p. 934). A knowledge-protection strategy is a pattern in a stream of decisions relating to the protection of a firm's innovations – ideas, information and knowledge – and any income streams which flow from them. A prerequisite for profiting from innovation is that the innovator is able to prevent or delay the imitation of its intellectual assets and technology (Hurmelinna-Laukkanen et al., 2008). In formulating a knowledge-protection strategy, a firm attempts to prevent or delay the imitation of its intellectual assets. A firm's knowledge-protection strategy represents just one part of its overall appropriability strategy[8], which is its approach to protecting knowledge against imitation and to ensuring that the returns from innovative activities are appropriated (Laursen and Salter, 2014).

For many firms, knowledge is a primary source of market value, and by making knowledge-protection strategies an integrated process rather than allowing technology or legal departments to make protection decisions (Reitzig, 2004), knowledge protection can be managed alongside the overall business model design and corporate strategy of the firm. Top management personnel can ensure that the decisions relating to knowledge protection are integrated into corporate strategy with guidance from R&D/technology managers. By managing knowledge-protection strategy in this way, the commercial success of the firm is more likely (Al-Aali and Teece, 2013).

There are a number of knowledge-protection mechanisms available to firms which allow them to capture returns from their intellectual property (Laursen and Salter, 2014) or knowledge assets. A firm's knowledge-protection strategy may include the use of formal protection methods implemented through regulation, such as patents and trademarks (Hall, 1992), and informal protection methods, such as secrecy and lead-time. Other protection mechanisms, such as the complex nature of databases, networks and reputation, can be used to curb imitation in the short term (Fahy and Smithee, 1999). The protection mechanisms which make up a firm's knowledge-protection strategy reflect the importance the firm attributes to the various protection mechanisms available: the more concerned a firm is with appropriability, the more importance it attributes to the different protection mechanisms (Laursen and Salter, 2014).

The use of knowledge-protection mechanisms to appropriate the returns from innovation requires considerable firm resources, for example managerial and

[8] A firm's appropriability strategy also includes decisions relating to its technology and the acquisition of complementary assets.

financial resources are needed to apply for patents and keep technologies secret from competitors (Teece, 1986; Arora and Ceccagnoli, 2006; Ceccagnoli, 2009). These required resources influence a firm's approach to the external environment in relation to who it works with, where it looks for ideas and how it organises its own innovative activities (Gans and Stern, 2003; Chesbrough, 2006; Laursen and Salter, 2014).

As knowledge protection often represents a cost to the firm, it is important that a firm's chosen strategy is an efficient option. Choosing to patent, for example, can be more expensive than first envisaged as during times of dispute, expensive court costs are inevitable, or firms may attempt to retain knowledge embodied within employees by offering high salaries. Both of these protection strategies may be at the expense of firm profit (Hurmelinna-Laukkanen and Puumalainen, 2007b).

In formulating its knowledge-protection strategy, a firm may choose complementary protection mechanisms, for example trademarks and registered designs – many formal and informal protection mechanisms have a tendency to be compliments (Cohen et al., 2000). Given this, one firm's knowledge-protection strategy may inform other firms, and this may lead to the acquisition of complementary forms of protection through collaborative activities (Cohen et al., 2000). Individual knowledge-protection mechanisms interact with others to generate complementarities. Some protection mechanisms are pre-requisites or supportive of other forms of protection, for example, encryption to prevent unauthorised disclosures (a so-called technical mean) may be a pre-requisite for keeping a trade secret, and patents or secrecy may help to create lead-time advantages (Hurmelinna-Laukkanen and Puumalainen, 2007a). Also, different protection mechanisms may be more suited to different stages of the innovation process, for example, prior to commercialisation, firms may rely upon secrecy. Later, firms may apply for a patent and/or use lead-time strategies. In addition to this, more than one protection mechanism may be used at the same time for a given innovation when there are separately protectable components or features (Cohen et al., 2000) or when legislation allows for more than one protection mechanism for the same innovation.

3.2.3 A firm's knowledge-protection strategy – a resource-based approach

A firm's resources and capabilities, and its position relative to other firms' resources and capabilities, provide useful information on ways in which a firm can formulate an effective knowledge-protection strategy and create barriers against imitation. In this study, a firm's knowledge-protection strategic position is supported by its resources and capabilities, reflecting the idea that resources and positions are closely related (Wernerfelt, 1984). Firms differ in the mechanisms that they use to protect the knowledge which they create, and these differences mainly relate to firm-specific factors such as size, finance and managerial capabilities. Thus, it is assumed here that the heterogeneous nature of firms' resources and capabilities gives rise to differences in firms' knowledge-protection strategies. The origins of such a resource-based view (RBV) of strategy lie with Penrose (1959) who describes a firm as a collection of resources. In this view of strategy determination, each firm is unique due to the heterogeneity of the services it extracts from its resources. Firm-specific resources, or firm-specific assets, allow for diversification and enable a firm to create a cost or differentiation advantage. Individual firm resources are assumed to be immobile – tied to the firm – and encompass both tangible and intangible assets (Wernerfelt, 1984), and it is upon these heterogeneous, immobile resources that this theory of competitive advantage is based (Penrose, 1959; Rumelt, 1984; Wernerfelt, 1984): they are a source of heterogeneity in firm performance (Lu et al., 2008).

Firm resources are defined as "all assets, capabilities, organizational processes, firm attributes, information, knowledge, etc. controlled by a firm that enable the firm to conceive of and implement strategies that improve its efficiency and effectiveness" (Barney, 1991, p.101). A firm's capabilities are its ability to utilise these resources effectively. They allow firms to make better use of their resources as mere possession of resources is not sufficient (Penrose 1959). These internal resources and capabilities are the source of firm profitability; they lead to a cost or differentiation advantage and in turn a competitive advantage. Heterogeneous and immobile resources are an essential requirement for firms to be able to achieve a competitive advantage, but in order to achieve a sustained competitive advantage, the resources need to be valuable (V), rare (R), costly to imitate or inimitable (I) (by embedding capabilities within firm routines, for example) and non-substitutable (N) – characteristics collectively known as VRIN (Barney, 1991). Barney (1995) later extended VRIN to include resources that are organised (O) in such a way so as to capture value (VRIO).

Teece et al. (1997) draw on and extend the RBV in their dynamic capabilities approach. Here, firms constantly adapt, renew, reconfigure and re-create their resources and capabilities in line with the competitive environment which they face. In a highly dynamic business environment, the original RBV proposition is static and neglects the influence of market dynamism, something the dynamic capabilities approach aims to address (Eisenhardt and Martin, 2000).

In order to sustain a competitive advantage, a firm develops a business strategy to make use of its resources and capabilities (Grant, 1991). A firm's available resources and capabilities may therefore provide an insight into its ability to successfully implement a strategy, or for the purpose of the present study, a knowledge-protection strategy. For example, firms require the capabilities to handle fragile protection mechanisms such as tacitness: once it is lost, it cannot be retrieved (Winter, 1995; Zander and Kogut, 1995), firms may lack the know-how to acquire knowledge protection (Olander et al., 2014) and firms may lack the required finance to protect knowledge – patent protection, for example, is associated with high costs, and this often deters firms from using them (Lerner, 1995; Arundel and Kabla 1998). Generally, many types of resources are required to implement and maintain an effective knowledge-protection strategy (Hurmelinna-Laukkanen and Puumalainen, 2007b) and to ensure the efficacy (or perceived strength) of protection mechanisms. A firm's ability to protect knowledge represents a capability (Gold et al., 2001), and in order to protect knowledge, a firm requires both a knowledge-infrastructure capability and a knowledge-process capability. The knowledge protection itself is part of the knowledge-process capability, a capability which is essential for a firm to be able to generate new knowledge and competitive advantage.

A firm's managerial capabilities have a strong impact upon its knowledge-protection strategy. Managers are required to know how and when to implement protection (Hurmelinna-Laukkanen and Puumalainen, 2007b), and the decision on whether or not to protect depends upon a manager's perceived strength of the mechanisms (Hurmelinna-Laukkanen and Puumalainen, 2007a). Managers have to take into account the efficiency of protection mechanisms, and when considering a range of knowledge-protection options, they have to compare the benefits of protection with the costs (Al-Aali and Teece, 2013). Choosing to patent, for example, can be more expensive than first envisaged and be at the expense of firm profit. In contrast, undertaking an expensive protection strategy may be justified when protecting technologies that underlie a core competency or are critical for the firm's competitive advantage (Al-Aali and Teece, 2013). Managers need the ability to select appropriate protection mechanisms and choose the best ways of exploiting them according to the strategic goals of the firm. A firm's resources, both in terms of money and capabilities, are important when considering the firm's ability to protect knowledge using the various protection mechanisms available.

Management capabilities vary across firms and are important factors affecting the knowledge-protection strategies of firms within an industry. Managers are called upon to identify effective protection mechanisms and to assess their strength in protecting knowledge and innovations before any appropriate protection mechanisms can be selected and exploited to achieve the strategic goals of the firm (Hurmelinna and Puumalainen, 2005). They are required to understand the protection mechanisms and their applicability before making an informed strategic choice. Not all protection mechanisms are at the firm's disposal, and those that are, may not be effective. Availability and efficacy (Hurmelinna and Puumalainen, 2005) are the necessary and sufficient conditions for a strong knowledge-protection strategy that is effective in preventing imitation, and managers need an understanding of both availability and efficacy to make an informed choice.

Formal protection mechanisms may be difficult to obtain, and consequently, not all of them are available to the firm (Hurmelinna-Laukkanen, 2009). Patent protection requires a complicated and lengthy process of research, application and correspondence, and it is a costly process. Small firms, for example, may have limited resources and find it difficult to implement patent protection, and service-sector firms may find it difficult to protect their innovations with knowledge-protection mechanisms more traditionally associated with product innovations (Olander et al., 2009). Furthermore, even if a firm possesses the resources and capabilities to implement protection, for example patent protection, the firm may not have an enforcing and monitoring capacity (Olander et al., 2014).

There is a need for managers to be able to acknowledge the constraints related to attaining protection mechanisms and gaining adequate protective power (Hurmelinna-Laukkanen and Puumalainen, 2007b). For example, at the theoretical level, there are reasons to expect that small firms may find patents more valuable than large firms, but there are also arguments that imply the opposite. While small firms could use patents to create a temporary barrier against competitors in order to build the capabilities required to become a successful innovator, patent application costs and the costs of protecting patents from infringement could cause them to value secrecy more highly (Arundel, 2001). Large firms often have knowledge-protection departments which might lead them to have a greater propensity to patent. Large firms often have the resources to enforce intellectual property rights and ensure the efficacy of protection mechanisms, although organisational barriers, such as a lack of knowledge, may also exist in large firms and hinder the integration of a firm's knowledge-protection strategy and its corporate strategy (Al-Aali and Teece, 2013).

Firms require the capabilities 'to sense and then to seize new opportunities, and to reconfigure and protect knowledge assets, competences, and complementary assets and technologies to achieve sustainable competitive advantage' (Teece, 2000b, p. 26), i.e. they are required to find the most efficient uses for the protection mechanisms (Hurmelinna-Laukkanen and Puumalainen, 2007b). In addition, careful firm management is required to successfully protect knowledge assets in the presence of emerging opportunities and threats (Teece, 2000b). Firm strategies may therefore be dynamic in nature and be required to adjust to changing conditions, in line with the dynamic capabilities theory proposed by Teece et al. (1997).

Firms continuously seek to maximise the value of their resources and capabilities, and their strategic choices relating to knowledge protection are made in line with this maximisation process. However, in any given industry, the technology opportunities and protection possibilities available to the firm are defined by the industry appropriability regime.

3.2.4 The industry appropriability regime and a firm's knowledge-protection strategy

Section 3.2.1 above describes how firms' knowledge-protection choices within a given industry or sector – both formal and informal – are shaped by the industry appropriability regime. As a consequence of this, a firm's knowledge-protection strategy – or appropriability profile (Hurmelinna- Laukkanen et al., 2017) – is not only determined by firm-specific resources and capabilities as discussed in Section 3.2.3 above, but is also contingent upon the appropriability regime of the industry within which the firm operates.

Contingency has emerged as an important concept in both strategic management and organisational research (Venkatraman and Prescott, 1990). The degree of fit between strategy and the environment (Hofer, 1975; Prescott, 1986) or strategy and structure (Chandler, 1962; Rumelt, 1974) has significant positive implications for performance. In his research, Hofer (1975) develops a contingency theory of firm strategy. Economic conditions, demographic trends, political and legal factors, industry structure variables and competitor variables are all identified as being strategically significant environmental and organisational variables. Operationally, a firm is required to find a match between the environment, its available resources and its strategy. Given this, a firm within a particular industry is required to find a match between the industry appropriability regime (part of the industry environment), its resources and capabilities and its knowledge-protection strategy.

The availability and efficacy of knowledge-protection mechanisms within a specific industry are 'given' determinants of the industry's appropriability regime, and both this availability and efficacy set the limits on a firm's knowledge-protection strategy (Hurmelinna-Laukkanen and Puumalainen, 2007a). The appropriability regime places constraints upon the knowledge-protection choices individual firms make and has an important influence upon a firm's strategic behaviour. Therefore, in order to fully understand a firm's knowledge-protection strategy, it is first necessary to understand the appropriability regime of the industry to which the firm belongs.

The industry within which a firm is located is an important factor determining a firm's appropriability profile (Hurmelinna- Laukkanen et al., 2017) – the combination of protection mechanisms used by a firm to appropriate the benefits from innovation. The nature of the technology and innovations, for example whether they are incremental or radical, defines the ways in which they can be protected (Hurmelinna-Laukkanen and Puumalainen, 2007b). In addition to this, other factors such as legal restrictions (Rao and Klein, 1994) and a high mobility of labour (leading to a high risk of knowledge leakage) (Atkins, 1998) for example, may determine the protection mechanisms that a firm uses. This is the case in the information and communications technology (ICT) sector where secrecy, lead time and human-resource practices are the most effective protection mechanisms and feature in the industry appropriability regime. In technology-intensive industries with a high rate of new inventions, formal knowledge protection is too slow and too costly to effectively protect innovations (Deakin and Wilkinson, 1998), and because protecting knowledge formally is time-consuming, formal knowledge protection is inefficient in industries that are developing quickly (Hurmelinna-Laukkanen and Puumalainen, 2007b). Firms of this type are strategically constrained to choose less formal protection methods from the available and effective set given by the industry appropriability regime. Older and more established industries, such as the metal industry, pharmaceuticals and chemical industry, have a longer tradition of using formal knowledge protection (Teece, 1986), and more formal protection mechanisms, for example patents, are characteristic of their industry appropriability regimes.

Within a particular industry, a firm makes decisions about its knowledge-protection strategy based upon the appropriability regime it faces in its environment and its individual resources and capabilities. As industry appropriability regimes become stronger, firms within an industry have more effective knowledge-protection mechanisms available to them. The number of tools available to protect knowledge and innovation within an industry increases creating a larger strategy space for firms to work within the bounds of. As firms are less limited in terms of the effective protection mechanisms which are available, one would expect firms' knowledge-protection strategies to be more complex – comprised of more knowledge-protection mechanisms – within industries characterised by strong appropriability regimes.

Firms' heterogeneous resources and capabilities mean that, in any given industry, firms may implement different knowledge-protection strategies despite the industry appropriability regime being common to all: firms seek to position themselves optimally subject to the appropriability regime which they face. For example, small firms with limited resources may find it difficult to use complex and expensive patent protection – the resources of the firm determine whether the firm can pay patent fees or not, and with limited resources, it is difficult to establish strong protection (Kitching and Blackburn, 1998; Leiponen and Byma, 2009). As firms within an industry are differently equipped to make use of any effective and available protection mechanisms (Hurmelinna- Laukkanen et al., 2017), variability exists in firms' knowledge-protection strategies within an industry. In an industry characterised by a strong appropriability regime, the increased availability of effective protection options gives more strategic options and allows for a greater range of firm positioning and, in turn, an increase in the chance that firms will receive any added value which they create for their own benefit. Firms in such an industry are more able to select a unique position relative to other firms (given their available resources and capabilities), and are therefore more able to reduce the competition which they face, increasing their chance of performance success (Deephouse, 1999). It follows that there may be more variability in knowledge-protection strategies within an industry characterised by a strong appropriability regime compared with one characterised by a weak appropriability regime.

3.2.5 Conceptual framework and hypothesis development

The conceptual model at the centre of this study seeks to explain how firms' value-maximising knowledge-protection strategies are determined and, more importantly, how firms' value-maximising knowledge-protection strategies are influenced by the appropriability regime of the industry to which the firm belongs.

Section 3.2.4 above describes how a firm, when formulating a knowledge-protection strategy, chooses protection mechanisms in line with its own resources and capabilities and the appropriability regime of the industry to which it belongs. Rather than seeking to maximise protection itself, the firm seeks to maximise the *value* of its protection; it seeks to maximise the expected net profits from its knowledge assets (Shapiro and Varian, 1999; Hurmelinna-Laukkanen and

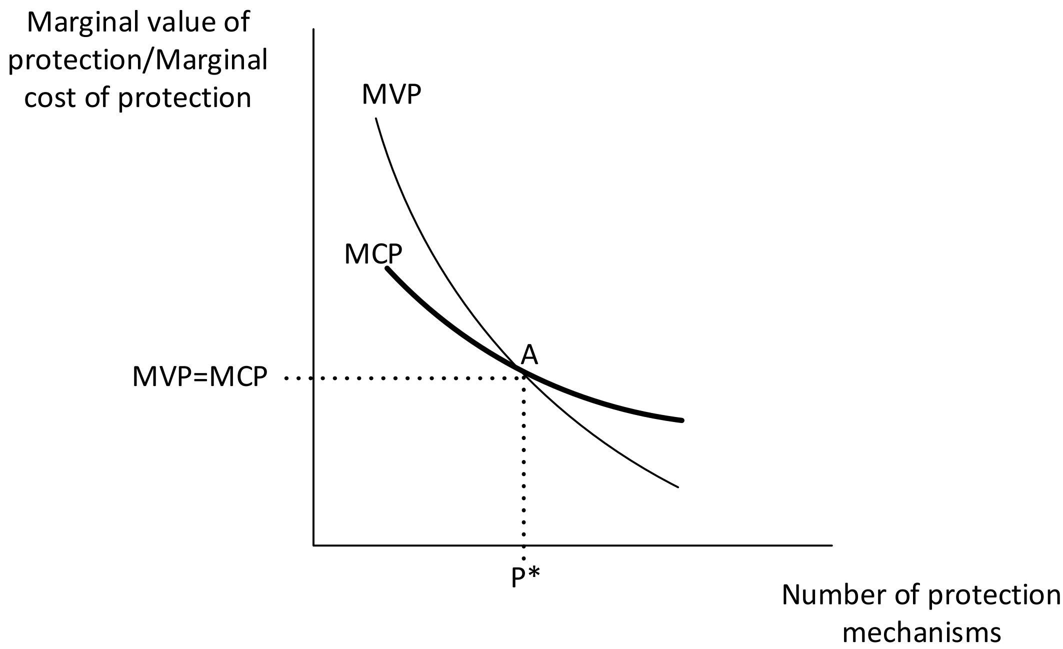
Puumalainen, 2007b). In order to implement a value-maximising knowledge-protection strategy, the firm not only assesses the benefits of each protection mechanism but also assesses the costs of implementation.

When assessing the value or benefit of different knowledge-protection mechanisms, firms are concerned with the marginal value of protection i.e. the extra benefit or value received from adopting one extra protection mechanism. The model assumes that the marginal value of protection falls as the number of protection mechanisms adopted increases – firms choose to adopt the protection mechanism which provides the greatest value or benefit first. Figure 3.1 shows the marginal-value-of-protection (MVP) schedule sloping downwards in the marginal-value-of-protection/number-of-protection-mechanisms space.

The additional cost to the firm of obtaining one more protection mechanism is the marginal cost of protection. The model assumes that the marginal cost of protection falls as the number of protection mechanisms adopted by a firm increases. Typically, initial costs of protection are high as obtaining protection can be a timely, costly and complicated process. As the number of protection mechanisms used by a firm increases, the firm becomes more familiar with the protection process. Proprietary knowledge, skills and capabilities useful for protecting knowledge increase so that the protection process is easier and less costly for the firm. Figure 3.1 shows the downward-sloping marginal-cost-of-protection (MCP) schedule in the marginal-cost-of-protection/number-of-protection-mechanisms space.

The model assumes that the marginal value a firm receives from implementing its first protection mechanism is greater than the cost to the firm of adopting that mechanism. This assumption reflects a firm’s initial incentive to protect. The firm believes that there is some value or benefit to be gained from protecting; otherwise protection would not take place. This incentive is represented by the marginal-value-of-protection schedule being higher than the marginal-cost-of-protection schedule, initially.

Figure 3.1: A firm's value-maximising knowledge-protection position



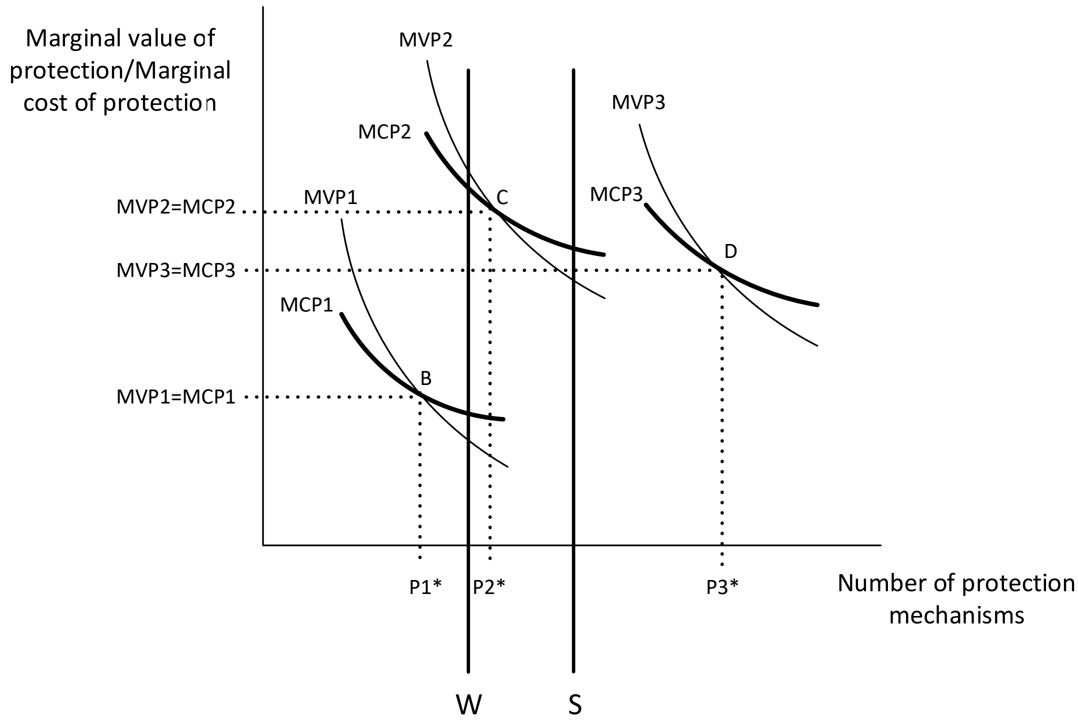
In an unconstrained world, it is assumed that rational firms make decisions about the amount of knowledge protection they adopt based upon the marginal value and marginal cost of protection – firms undertake a costs verses benefits comparison. A firm continues to add to its protection up to the point where the marginal value of protection is equal to the marginal cost of protection (point A in Figure 3.1). Once the additional value received is at a greater cost per benefit, it is no longer reasonable for the firm to increase the number of protection mechanisms it uses: the firm's value of protection is maximised. The firm's optimal knowledge-protection strategy is thus given by P* in Figure 3.1.

The value a firm gains from using a protection mechanism varies across firms within a given industry. 'Value' is determined by firm-specific factors such as firm presence in international markets, size, age and firm goals, for example (Hurmelinna-Laukkenen et al., 2017). From this, it follows that each firm has its own individual marginal-value-of-protection schedule. Similarly, the marginal cost of protection is determined by a firm's individual resources and capabilities, and therefore each firm has its own marginal-cost-of-protection schedule. Given that each firm has its own individual marginal-value-of-protection and marginal-cost-of-protection schedules, the value of protection is maximised at a different point for each firm. Figure 3.2 shows the value-maximising knowledge-protection positions for three different firms within a given industry (points B, C and D), with the number of knowledge-protection mechanisms maximising value being different for each firm (P_1*, P_2* and P_3*, respectively).

In a constrained world, the model assumes that rational firms make decisions about the amount of knowledge protection they adopt based upon the marginal value of protection and the marginal cost of protection, subject to a constraint. Firms assess the potential of and the restrictions related to the use of each available protection mechanism – in terms of its availability, efficacy and efficiency (Hurmelinna-Laukkanen and Puumalainen, 2007b) – before deciding upon which protection mechanisms to implement. They reach optimising decisions by considering the constraint which they face i.e. the appropriability regime, itself the object of their calculating considerations (Vanberg, 1994). This results in a range of knowledge-protection choices – or profiles (Hurmelinna- Laukkanen et al., 2017).

In an industry characterised by a weak appropriability regime, the knowledge-protection mechanisms available to a firm are more limited than in an industry characterised by a strong appropriability regime. In Figure 3.2, W represents the maximum number of effective knowledge-protection mechanisms available to firms in a weak appropriability regime. When faced with the weak regime, Firm 1 is able to optimise and maximise the value of its knowledge protection given the constraint (where MVP1=MCP1), but Firm 2 and Firm 3 are limited and are forced to adopt the sub-optimal knowledge-protection strategy given by W. In an industry characterised by a strong appropriability regime, the knowledge-protection mechanisms available to a firm are less limited. The maximum number of effective knowledge-protection mechanisms available to firms in a strong appropriability regime is given by S. When faced with the strong regime, Firm 2 is no longer constrained; it is able to maximise the value of its knowledge protection (where MVP2=MCP2). Firm 3 continues to be limited and is forced to adopt the sub-optimal knowledge-protection strategy given by S.

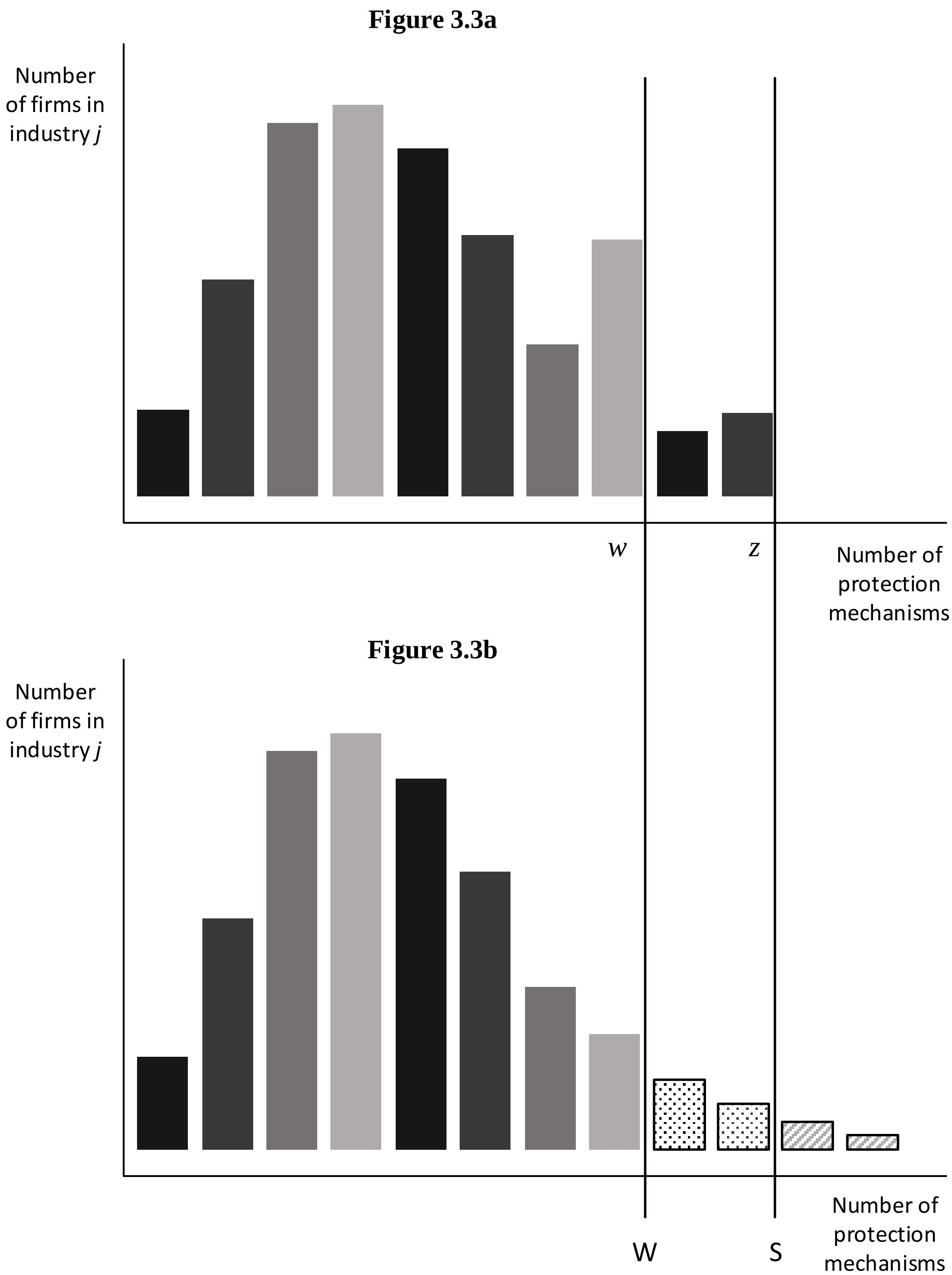
Figure 3.2: The value-maximising knowledge-protection positions for three different firms within a given industry



To see the effects of this more clearly, Figure 3.3 shows both the constrained and the unconstrained industry-level distribution of firms' value-maximising knowledge-protection choices or strategies within industry *j*. Figure 3.3a illustrates the constrained industry-level distribution of individual-firm knowledge-protection strategies, given a weak (W) and a strong (S) appropriability regime constraint. The unconstrained industry-level distribution in Figure 3.3b illustrates how knowledge-protection strategies within industry *j* vary due to firm-specific factors, resources and capabilities when there is no appropriability regime constraint in place.

In a weak appropriability regime (W), the constrained proportion of firms within the industry adopt the knowledge-protection strategy given by *w*. Firms choose the protection strategy given by *w* rather than any protection strategy below *w* because they seek to implement the protection strategy which is closest to their optimum level. Up to point *w*, the industry distribution of knowledge-protection strategies is the same as in the unconstrained case (Figure 3.3b), but at *w*, there is a concentration of firms adopting the knowledge-protection strategy given by *w*. This concentration includes those firms limited by the weak appropriability regime. The dotted and hatched areas in Figure 3.3b represents the proportion of firms within the industry that are constrained by the weak appropriability regime.

Figure 3.3: The constrained and unconstrained distribution of firms' value-maximising knowledge-protection strategies within industry *j*



In a strong appropriability regime, the constrained proportion of firms within the industry adopts the knowledge-protection strategy given by *z*. Again, the constrained firms choose to implement the knowledge-protection strategy which is closest to their optimum level i.e. a protection strategy given by *z*. In the strong appropriability regime case, the industry distribution of knowledge-protection strategies is the same as in the unconstrained case (Figure 3.3b) up to point *z*. At this point, there is a concentration of firms adopting the knowledge-protection strategy given by *z*. This concentration includes those firms limited by the strong appropriability regime. The hatched area in Figure 3.3b represents the proportion of firms within the industry that are constrained by the strong appropriability regime.

Within an industry, the proportion of firms limited in terms of their knowledge-protection strategy when the appropriability regime is weak is greater than that when the appropriability regime is strong (the dotted and hatched area combined is greater than the hatched area alone in Figure 3.3b). The industry appropriability regime places limits on a firm's knowledge-protection choices; the stronger the appropriability regime, the less limited firms are in terms of their knowledge-protection strategy.

3.2.5.1 Hypotheses

The conceptual framework discussed in Section 3.2.5 above describes how a firm's knowledge-protection strategy – or choice of knowledge-protection mechanisms – depends upon the value to the firm and the cost to the firm of protecting its knowledge, both of which depend upon the appropriability regime of the industry to which the firm belongs.

Firms' protection choices depend upon the efficacy of the available protection mechanisms i.e. the perceived strength (Hurmelinna-Laukkanen and Puumalainen, 2007b). The firm's perceived strength of protection is related to the value the firm believes it will receive from using the protection mechanisms to protect its knowledge. For example, firm managers often take the viewpoint that patents do not prevent imitation and it is therefore pointless pursuing them (Harabi, 1995; Cohen et al., 2000), and hence they do not use patents, whereas firms that perceive mechanisms to be effective, use them, for example Arundel (2001) finds that firms use trade secrets because they perceive them to be an effective knowledge-protection mechanism.

The conceptual framework here illustrates how a firm determines its value-maximising protection decision; it compares its marginal value and marginal cost of protection. The model shows that the industry appropriability regime can, for some firms within an industry, act as a constraint upon this value-maximising protection decision; the appropriability regime limits the range of potential strategic options available for protecting knowledge (Hurmelinna-Laukkanen and Puumalainen, 2007b). The present study is concerned with the effects of this appropriability regime limit on firms' protection choices and the distribution of firms' protection choices within an industry setting. In particular, the analysis examines the effects of an increase in the strength of an industry's appropriability regime on the average protection strategy and the variability of protection strategies within an industry.

An increase in the strength of the industry appropriability regime is represented by a rightwards shift of the vertical line at point W to point S in Figures 3.2 and 3.3. The stronger appropriability regime leads to fewer constrained firms within the industry. More firms are able to maximise the value of their protection and use a higher number of protection mechanisms. Figure 3.3 shows that a smaller proportion of firms within the industry are constrained in a strong appropriability regime than are in a weak appropriability regime. The area of the distribution in Figure 3.3b between the constraint at W and the constraint at S represents the proportion of firms who are no longer constrained once the industry appropriability regime is strengthened.

As the regime strengthens, there are more effective protection options available to the firms within the industry. Firms previously limited by the appropriability regime can now, given their resources and capabilities, maximise the value of their knowledge protection. They are able to adopt more protection mechanisms, given the cost of adopting. The stronger appropriability regime creates more strategic options for the firm and increases a firm's flexibility. As there are more effective protection mechanisms available to them within the industry, the firm will, given its resources and capabilities, choose to adopt more mechanisms. By adopting more protection mechanisms, a firm increases the strength of its knowledge-protection strategy (Laursen and Salter, 2005), and the probability that its protection will be effective increases.

As more firms within the industry are able to use a higher number of knowledge-protection mechanisms, it is expected that, on average, firms' protection strategies within the industry will be stronger when the strength of the industry appropriability regime increases. This leads to the first hypothesis that:

Hypothesis 1: *On average, firms' knowledge-protection strategies are strengthened when the knowledge-protection dimension of the industry appropriability regime strengthens.*

At any given point in time, a finite level of resources and capabilities exists. If firms target similar resources using similar capabilities, the industry approaches a situation of perfect competition and the opportunity to earn economic rents disappears. A firm that conforms to the strategies of others has many similar competitors; this limits performance and increases failure rates (Henderson, 1981; Hannan et al., 1990; Baum and Singh, 1994). Competition within the industry is reduced and firm performance is improved through firms' rational differentiation, 'the firm must stake out a distinct position from its rivals. Imitation almost ensures a lack of competitive advantage and hence mediocre performance,' (Porter, 1991, p102). Taking a different position to competitors enables a firm to earn higher economic rents; they face less competition (Porter, 1980, 1991; Hannan et al., 1990; Baum and Mezias, 1992; Baum and Singh, 1994). Firms therefore have an incentive to be different, because by being different, they are able to reduce the competition they face for resources (Deephouse, 1999).

The heterogeneous nature of firms' resources and capabilities gives rise to variability in firms' knowledge-protection strategies. These resources and capabilities are the source of firm profitability as they lead to a cost or differentiation advantage and in turn a competitive advantage. In a weak appropriability regime, some firms are unable to maximise the value of their knowledge protection given their resources and capabilities. These firms are limited by the industry appropriability regime and are forced to conform to the strategies of others. They implement sub-optimal knowledge-protection strategies, face higher levels of competition and are less able to earn returns. In a strong appropriability regime, more protection mechanisms are available; fewer firms are constrained and more are able to maximise the value of their knowledge protection. The previously constrained firms no longer have to conform to the strategies of others but instead are able to use their resources and capabilities to take a different strategic position to competitors. Overall, firms within the industry have access to a greater range of strategic options. More firms are able to implement optimal knowledge-protection strategies, competition is lower and there are more opportunities for firms to earn returns. From this it can be hypothesised that:

Hypothesis 2: *When the knowledge-protection dimension of the industry appropriability regime strengthens, firms have access to a wider range of strategic options, and this leads to more variable knowledge-protection strategies within the industry.*

3.3 Data and methods

The empirical analysis in this study is based upon four waves of the United Kingdom (UK) Community Innovation Survey (CIS) covering the period 2002 to 2010 (CIS 4 to CIS 7) and data from the Business Structure Database (BSD) covering the period 1997 to 2008.

3.3.1 The UK Community Innovation Survey (CIS)

Innovation surveys are conducted by many governments and agencies around the world: they are the main source of innovation data within the UK and Europe. Background and motivation for the UK's innovation survey – the UK counterpart of the European Union Community Innovation Survey – can be found in the Organisation for Economic Co-operation and Development's (OECD) Oslo manual (OECD, 2005), along with a description of the type of questions and definitions used. In the UK, the Office for National Statistics (ONS) – the UK official government statistical office – manages the administration of and data collection for the UK CIS.

The UK CIS provides detailed information on firms' innovation activity. It provides an insight into the objectives of this innovation activity and firms' external innovation connections. Questions relating to firm size and structure, customer base, firm product and process innovation activity, the sources of innovation, perceived barriers to innovation, the levels of public support and basic economic information about the firm are included. The surveys contain up to approximately 16,000 firms with 10 or more employees and are designed to be statistically representative of the 12 regions of the UK, most industrial sectors and all sizes of firms. The sampling frame is taken from the Inter-departmental Business Register (IDBR), a UK-Government compiled register of all UK businesses based on tax and payroll records. The survey is conducted every two years by means of a postal questionnaire and follow-up telephone interviews. For the waves analysed here, the non-compulsory interviews achieved a response rate ranging between 50 per cent in 2010 (CIS 7) and 58 per cent in 2004 (CIS 4). [9]

3.3.2 The Business Structure Database (BSD)

The BSD is derived primarily from the IDBR, a live register of data collected by Her Majesty's Revenue and Customs via Value Added Tax (VAT) and Pay As You Earn (PAYE) records. In 2004 it was estimated that businesses listed on the IDBR accounted for almost 99 per cent of economic activity in the UK. Only very small businesses, such as the self-employed, are not included. The BSD represents the IDBR at one particular moment in time and provides a version of the IDBR for research use. The reporting period is the financial year, and there are up to approximately 5.5 million firms included. The dataset contains a small number of variables for almost all UK firms, including employment, turnover, foreign ownership, Standard Industrial Classification (SIC) codes, start-up dates and termination dates.

3.3.3 Dependent variables

Two dependent variables are defined using data related to the protection of innovation and intellectual property. To investigate how the strength of firms' knowledge-protection strategies change when the strength of the appropriability

[9] See: https://www.gov.uk/government/collections/community-innovation-survey

regime changes, the first dependent variable is defined as *the average knowledge-protection strategy within an industry.* To investigate how the range or variability of strategic options available to a firm changes when the strength of the appropriability regime changes, the second dependent variable is defined as the *variability of knowledge-protection strategies within an industry.* The nature and detail of the innovation survey question addressing the protection of innovation and intellectual property differs across the different waves of CIS data. Of the waves available, the 2008 to 2010 dataset (CIS 7) provides the most detailed insight into firms' new knowledge protection for the purpose of this study – both legal (formal) and non-legal (informal) knowledge-protection mechanisms are explored, with emphasis placed on new protection which has taken place during the previous three years.

The CIS 7 survey asked the firm whether, during the 2008 to 2010 period, it protected innovation and intellectual property. The survey listed seven protection types: the application for a patent, the registration of an industrial design, the registration of a trademark, the use of copyright, the use of secrecy (including non-disclosure agreements), the use of complexity of design and the use of lead-time on competitors. Addressing each protection mechanism separately, firms were asked to indicate whether or not they engaged in the protection activity during the previous three-year period. Firm responses are recorded in the CIS 7 dataset as a 0/1 binary variable, with a 1 denoting that the protection took place.

The seven knowledge-protection mechanisms have a high degree of internal consistency (Cronbach Alpha Coefficient = 0.75), and in light of this, the individual firm responses indicating whether or not the protection type took place can be summed to create a single *cumulative knowledge-protection variable* for each firm (Laursen and Salter, 2005). The cumulative knowledge-protection variable is a count variable having a minimum value of 0 (no new protection took place during the previous three-year period) and a maximum value of 7 (all seven protection mechanisms were used to protect knowledge during the previous three-year period). In line with Laursen and Salter (2005), this cumulative variable represents the *strength* of the firm's knowledge-protection strategy.

This study is concerned with the knowledge-protection behaviour of firms within an industry setting. To conduct the analysis, the 14,342 firms within CIS 7 are separated into industry groups. Initially, firms are divided into 188 industry groups according to their three-digit UK Standard Industrial Classification (SIC) code in 2003.[10] Those industry groups with only a small number of firms are combined with others (according to their two-digit SIC code in 2003) to give a final 103 industry groups for the analysis – the smallest group having 29 firms and the largest group having 1005 firms.

Two dependent variables are constructed using the newly-defined firm-level cumulative knowledge-protection variable and the 103 industry groups.

i. *Dependent variable 1*

The average knowledge-protection strategy within an industry: To calculate the average knowledge-protection strategy within an industry, the mean of firms' cumulative knowledge-protection responses within each of the 103 industries is found.

ii. *Dependent variable 2*

The variability of knowledge-protection strategies within an industry: To calculate the variability of knowledge-protection strategies within an industry, the variance of firms' cumulative knowledge-protection responses within each of the 103 industries is found.

3.3.4 Explanatory variables

The explanatory variables in the model represent the industry appropriability regime. The most important dimensions of the industry appropriability regime are the nature of the industry technology (i.e. whether the industry is characterised by product or process technologies and whether technology is based upon tacit or codified knowledge), the legal methods of knowledge protection (Teece, 1986, 1998, 2000a; Levin et al., 1987; Teece and Pisano, 1998), other formal methods of knowledge

[10] The use of SIC codes for segmenting firms by industry has served as a mainstay methodology: Bhojraj et al. (2003) survey seven journals from the 2000 and 2001 period and find 116 studies using SIC codes for the purpose of industry segmentation.

protection (for example, contracts and labour legislation) and less formal knowledge-protection methods (for example, the use of secrecy and lead time) used to protect firms' innovations and any increased rents which flow from (Hurmelinna-Laukkanen and Puumalainen, 2007a).

For each of the 103 industry groups, seven explanatory variables representing the industry appropriability regime are defined – four variables represent the nature of the technology within each industry group and three variables represent available and effective knowledge-protection mechanisms within each industry group.

i. *The nature of the industry technology*

a. *The industry average propensity for a firm to be a product innovator*

The industry average propensity for a firm to be a product innovator is calculated using the CIS 4, CIS 5 and CIS 6 datasets.[11] The binary 0/1 data indicating whether or not a firm is a product innovator is taken, and the average of the firm-level responses across the three CIS waves is calculated for each of the 103 industry groups. The calculated values provide an indication of the breadth or extension of product innovation within each industry group.

b. *The industry average propensity for a firm to be a process innovator*

The industry average propensity for a firm to be a process innovator is calculated using the CIS 4, CIS 5 and CIS 6 datasets. The binary 0/1 data indicating whether or not a firm is a process innovator is taken, and the average of the firm-level responses across the three CIS waves is calculated for each of the 103 industry groups. The calculated values provide an indication of the breadth or extension of process innovation within each industry group.

c. *The industry average propensity for a firm to view technical, industry or service standards as being important to innovation activities*

The industry average propensity for a firm to view technical, industry or service standards as being important to innovation activities is calculated using the CIS 4, CIS 5 and CIS 6 datasets. Knowledge is assumed to be codified if firms identify

[11] CIS7 data is used to construct the two dependent variables, it is therefore excluded from the construction of any explanatory variables.

technical, industry or service standards as being of medium or high importance to their innovation activities. If technical, industry or service standards are not used or are of low importance to firms, knowledge is assumed to be tacit. A 0/1 binary variable is generated for all firms across the three waves of data. This variable is set equal to 1 if the sources are of medium or high importance to firm innovation activities and set equal to 0 if they are not used or are of low importance. The average of the firm-level responses across the three CIS waves is then calculated for each of the 103 industry groups. This yields the industry average propensities for firms to view technical, industry or service standards as being important to innovation activities.

d. The industry average propensity for a firm to view scientific journals and trade/technical publications as being important to innovation activities

The industry average propensity for a firm to view scientific journals and trade/technical publications as being important to innovation activities is calculated using the CIS 4, CIS 5 and CIS 6 datasets. Knowledge is assumed to be codified if firms identify scientific journals and trade/technical publications as being of medium or high importance to their innovation activities. If scientific journals and trade/technical publications are not used or are of low importance to firms, knowledge is assumed to be tacit. A 0/1 binary variable is generated for all firms across the three waves of data. This variable is set equal to 1 if the sources are of medium or high importance to firm innovation activities and set equal to 0 if they are not used or are of low importance. The average of the firm-level responses across the three CIS waves is then calculated for each of the 103 industry groups. This yields the industry average propensities for firms to view scientific journals and trade/technical publications as being important to innovation activities.

ii. The effective and available knowledge-protection mechanisms within the industry

Three variables are constructed to represent effective and available knowledge-protection mechanisms within the industry. The variables encompass both the importance of protection mechanisms within the industry and the extent to which knowledge-protection mechanisms are adopted within the industry.

As the nature and detail of the CIS survey question addressing the protection of innovation and intellectual property differs across the different waves of CIS data, different waves of the data are used to construct each variable: CIS 4 and CIS 5 ask firms about the importance of various protection mechanisms to their innovations, whereas CIS 6 asks firms about any new protection which may have taken place during the survey period.

a. *The industry average propensity for a firm to view formal knowledge-protection mechanisms as being important to innovations*

Using the data from CIS 4 and CIS 5, a formal-protection importance binary variable is created using responses to the formal-protection mechanism questions (i.e. the questions asking firms about the importance of the use of design registration, trademarks, patents, confidentiality agreements and copyright). The formal-protection importance variable is set equal to 1 if any of the formal mechanisms is of medium or high importance and 0 otherwise. For each of the 103 industry groups, the average of the firm-level responses across the two CIS waves is then calculated. This yields the industry average propensities for firms to view formal knowledge-protection mechanisms as being important to innovations.

b. *The industry average propensity for a firm to view informal knowledge-protection mechanisms as being important to innovations*

Using data from CIS 4 and CIS 5, an informal-protection importance binary variable is created using responses to the informal protection mechanism questions (i.e. the questions asking firms about the importance of the use of secrecy, complexity of design and lead-time advantage on competitors). The informal protection importance variable is set equal to 1 if any of the informal protection mechanisms is of medium or high importance and 0 otherwise. For each of the 103 industry groups, the average of the firm-level responses across the two CIS waves is then calculated. This yields the industry average propensities for firms to view informal knowledge-protection mechanisms as being important to innovations.

c. The industry average propensity for a firm to adopt new formal knowledge-protection mechanisms

A new formal-protection binary variable is created using data from CIS 6. Firms are asked if they applied for a patent, registered a design, registered a trademark or produced materials eligible for copyright during the survey period. The new formal-protection variable is set equal to 1 if any of the four formal protection mechanisms were adopted and 0 otherwise. For each of the 103 industry groups, the average of the firm-level responses is then calculated. This yields the industry average propensities for firms to adopt new formal knowledge-protection mechanisms.

3.3.5 Control variables

A series of industry-level control variables are included in the model. These variables represent factors other than the appropriability regime which may impact upon the average knowledge-protection strategy and the variability of knowledge-protection strategies within an industry. They include collaboration, internationalisation, firm size and market structure.

i. Collaboration: Industry engagement in cooperation on any innovation activity

In recent decades there has been a tendency towards collaboration in firms' R&D strategy (Olander et al., 2014). An increase in the complexity of technological development, the pace of innovation cycles and higher risks and costs has led to more firms using external partners in their R&D (Bader, 2008). During collaboration, a firm reveals knowledge to collaboration partners and, due to this increased openness, is at risk of knowledge theft (Gans and Stern, 2003; Chesborough, 2006). It follows that firms need to protect knowledge when engaging in external collaboration (Cassiman and Veugelers, 2002).

The literature illustrates conflicting views regarding the relationship between a firm's level of openness and its knowledge-protection strategy. Firm-level openness is viewed by some as being negatively linked with a strong level of knowledge protection. Chesbrough (2003) promotes firm openness and encourages firms to become less concerned about protecting ideas. Firms who implement strong protection eliminate any opportunities to exchange knowledge with other firms (von Hippel, 2005) – they become overly concerned with the legalities of protection and less concerned about new innovations themselves (Bessen and Maskin, 2009). Firms overly concerned with knowledge protection are unable to share the ideas and benefits of their innovations with others (Laursen and Salter, 2005). They become obsessed with secrecy and legal protection. Rather than becoming open and collaborative, they become inward and afraid that outsiders may steal their "precious" technology (Laursen and Salter, 2005).

In contrast to this view, Chesbrough (2006) describes how firm-level openness can be positively linked with a firm's knowledge-protection strategy. Firms who protect their knowledge may be more willing to engage with external firms as they are protected against others' opportunistic behaviour (Teece, 2000b). Cohen et al. (2000) view a firm's knowledge-protection strategy as being important to ensure that knowledge is not stolen and to inform negotiations over collaboration with a range of external parties.

Laursen and Salter (2014) provide evidence which supports both views. They examine how a firm's appropriability strategy is connected to the openness of the firm and find that firm attitudes to openness and knowledge protection are very closely connected – without providing any direct evidence of causality. Their study suggests a concave relationship between the strength of a firm's appropriability strategy and collaboration as very strong knowledge-protection strategies are found to reduce formal collaborations.

The specific knowledge-protection mechanisms a firm uses may depend upon the specific knowledge in the R&D collaboration. Knowledge protection allows firms to safely participate in knowledge sharing collaboration, and it may also protect the outputs of the knowledge exchange from imitation. A broad range of protection mechanisms may therefore be preferred in order to protect knowledge during the collaboration and any outputs which exist as a result of the collaboration. Collaboration is therefore expected to be positively related to the number of protection mechanisms used by the firm (Olander et al., 2014), and therefore positively related to the industry's average knowledge-protection strategy.

An *industry engagement in cooperation* variable is constructed to represent collaboration in the model. CIS 4 and CIS 5 asked firms if they cooperated (on any innovation activity) with any other enterprises or institutes during the previous three-year period. The resulting 0/1 binary response data is combined with a 0/1 binary variable created from the response data obtained from the question addressing cooperation in the CIS 6 survey. In the CIS 6 survey, firms were not asked a general yes/no cooperation question but were only asked about specific types of cooperation. The newly-created binary variable for CIS 6 was set equal to 1 if the firm cooperated in any of the stated ways in any part of the world and set equal to 0 if no cooperation took place. Using the 0/1 binary cooperation data for CIS 4, CIS 5 and CIS 6, the average propensity for a firm to cooperate on any innovation activity is created for each of the 103 industries by averaging the firm-level responses across the three CIS waves. Using these values, a 0/1 binary industry engagement in cooperation variable is created to indicate whether the industry displays a high or low average propensity for a firm to cooperate on any innovation activity. The industry engagement in cooperation variable is set equal to 1 if the industry average propensity for a firm to cooperate is greater than or equal to 40 per cent and set equal to 0 if the industry average propensity for a firm to cooperate is less than 40 per cent.

ii. Internationalisation: Extent of internationalisation within the industry

While knowledge flow is required for both innovation and internationalisation (Martin and Salomon, 2003; Feinberg and Gupta, 2004), protection of knowledge and innovations is important (Hurmelinna-Laukkanen, 2014). Internationalisation entails risk (Hurmelinna-Laukkanen, 2014). It increases the risk of imitation by competing firms (Olander et al., 2010) because it involves the replication of routines and procedures in foreign locations (Martin and Salomon, 2003). The increased risk of imitation means that firms operating in international markets often require protection mechanisms in order to manage in those markets (de Faria and Sofka, 2010). Firms operating in international markets without protection mechanisms in place to protect against imitation and theft of knowledge face competition that could otherwise be avoided (Zoltan et al., 1997).

Some informal protection mechanisms become more effective when used by firms who internationalise (Hurmelinna-Laukkanen, 2014). For example, language barriers encountered can be effective in strengthening lead-time and practical means of concealment. Characteristics specific to foreign markets can themselves act as a barrier to the theft of knowledge and imitation – unfamiliarity can lead firms to misinterpret information creating a barrier to imitation (Cohen and Levinthal, 1990).

Institutional protection varies across countries (Acs et al., 1997), and this leads firms who internationalise to form different knowledge-protection strategies to those who do not operate in foreign markets. Firms with access to a wide range of knowledge-protection mechanisms are better prepared for internationalisation (Hurmelinna-Laukkanen, 2014). When firms enter foreign markets, the structure of the industry appropriability regime may differ to that in the domestic industry. The availability and effectiveness of knowledge-protection mechanisms may be different in the foreign regime (Keupp et al., 2012). For this reason, an exporting firm may benefit from gaining access to additional protection mechanisms. A firm with access to a wide range of knowledge-protection mechanisms is likely to be more able to adjust to the foreign appropriability regime (Hurmelinna-Laukkanen, 2014).

For these reasons, it is expected that a firm's engagement in exporting will be positively related to its cumulative knowledge protection, increasing the industry's average knowledge-protection strategy and variability of knowledge-protection strategies.

An *industry engagement in exporting* variable is constructed to represent internationalisation within the model. CIS 4, CIS 5 and CIS 6 asked firms if they sold goods and/or services to other European Union (EU) and non-EU countries during the previous three years. The response data is used to create a 0/1 binary variable set equal to 1 if the firm exported goods and/or services elsewhere and set equal to 0 otherwise. For each of the 103 industry groups, the firm-level responses are averaged across the three waves of data creating the industry average propensities for a firm to be an exporter. Using these values, a 0/1 binary industry engagement in exporting variable is created to indicate whether the industry displays a high or low average propensity for a firm to be an exporter. The industry engagement in exporting variable is set equal to 1 if the industry average propensity for a firm to be an exporter is greater than or equal to 50 per cent and set equal to 0 if the industry average propensity for a firm to be an exporter is less than 50 per cent.

iii. Firm size: Average firm employment within the industry

It is assumed that small firms lack resources (Olander, 2009). Employment is included in the model to represent the level of firm resources that can be used for knowledge protection. Previous studies find that the use of knowledge and innovation protection varies across large and small firms (Arundel and Kabla, 1998; Kitching and Blackburn, 1998; Brouwer and Kleinknecht, 1999; Davis, 2006). There is a relatively low usage of formal protection mechanisms in small and medium sized enterprises (SMEs) compared with larger firms. Larger firms invest in more of all forms of protection of innovation; 2.1 per cent of small firms protected an innovation with a patent during the 2008 to 2010 period, compared with 6.3 per cent of large firms (Hargreaves, 2011). SMEs view the use of formal mechanisms as a complex process. Owner-managers of small firms lack the knowledge and information required to pursue such protection. They are reluctant to adopt formal mechanisms because they perceive protection-related costs (both money and time) to be high, for example dealing with patent offices and patent lawyers and gaining the knowledge/skills required to enforce protection. Administering and enforcing protection is problematic for SMEs, especially when they are in dispute with larger firms. In practice, SMEs are found to rely more on informal methods of protection (Leiponen and Byma, 2009).

Firm employment is expected to be positively related to a firm's cumulative knowledge protection, and therefore an increase in average firm employment within an industry is expected to have a positive impact upon the average knowledge-protection strategy and the variability of knowledge-protection strategies within the industry.

An *industry average firm employment variable* is constructed to indicate the average level of firm resources within an industry. In CIS 4, CIS 5 and CIS 6, firms were asked how many employees they had in the year prior to the survey taking place. For each of the 103 industry groups, response data is averaged across the three waves of data creating an industry average firm employment variable.

iv. Market structure: Industry birth rate

The birth rate within an industry reflects the proportion of young firms present. The firm resources and capabilities required to protect firm knowledge and innovations may not be present during the early years of a firm's life, whereas older firms may have accumulated resources and capabilities over time and be better equipped to use a wide range of knowledge-protection mechanisms. Given this, it may be expected that the average knowledge-protection strategy and the variability of protection strategies within an industry falls as the birth rate increases. In contrast, new firms within an industry also represent new competition for incumbents. Firm knowledge and innovations may require protection from this new threat meaning that both the average protection strategy and the variability of protection strategies within an industry increase when the industry birth rate is higher. Given the two contrasting views, the effect of a change in the industry birth rate on the distribution of knowledge-protection strategies within the industry is ambiguous.

An *industry birth rate variable* is constructed using the pooled BSD dataset. The number of firms born during the 2006 to 2008 period – consistent with the years covered in the CIS 6 survey – is counted for each of the 103 industry groups. Using the same dataset, the total number of firms in each of the 103 industries in 2008 is counted using birth data for the 1997 to 2008 period (firms born prior to 1997 are given a 1997 birth date in the pooled BSD dataset). A birth rate is then calculated for each of the 103 industry groups.

v. Market structure: Industry five-firm concentration ratio

Industry competitiveness impacts upon a firm's knowledge and innovation protection decisions. For example, if a monopolist controls the industry, it is inefficient for other firms to use costly protection methods (Granstrand, 1999). The manner in which firms protect knowledge assets differs across industries due to the different competitive dynamics that exist. It follows that as competition within an industry increases, the use of knowledge-protection mechanisms is expected to increase. In the model, the industry five-firm concentration ratio (CR5) is included to capture the effects of industrial concentration and firms' market power. The industry CR5 is the combined market share of the five largest firms within the industry. As the industry CR5 increases, competition within the industry falls and knowledge protection is also expected to fall. An increase in the industry CR5 is therefore expected to lead to a fall in the industry average knowledge-protection strategy and a fall in the variability of the industry's knowledge-protection strategies.

A *five-firm concentration ratio variable* is constructed for each of the 103 industry groups. Using the pooled BSD dataset, 2008 turnover data – a year consistent with the final year of the CIS 6 survey – is sorted into the 103 industry groups, and the total turnover for each of the 103 industry groups is calculated. Within each industry group, each firm's turnover share is calculated. The five largest turnover shares are then summed to give the five-firm concentration ratio for each of the 103 industry groups.

3.3.6 Estimation method

The estimation method adopted is dictated largely by the nature of the two dependent variables under investigation. The first dependent variable – the mean of firms' cumulative knowledge-protection choices within an industry (or the average knowledge-protection strategy within an industry) is bounded between the values of 0 and 7. The average knowledge-protection strategy within an industry takes on the value 0 with positive probability; for some industries, the optimal average protection strategy is equal to 0 i.e. the model includes a corner solution outcome (Wooldridge, 2010). In addition to this, the average protection strategy within an industry is censored from above. The knowledge-protection questions in the UK CIS 2008 to 2010 survey restrict the average knowledge-protection strategy within an industry to have a threshold value which is equal to 7. A data problem arises because the average knowledge-protection strategy within an industry is censored above this value. The Tobit regression model (Tobin, 1958) – a censored regression application – is an appropriate estimation method for response data of this kind. The relationship between an independent variable and a censored-dependent variable is inherently nonlinear (Tobin, 1958; Greene, 1993) making the use of ordinary least squares (OLS) inappropriate. OLS regression may yield biased parameter estimates and standard errors, predicted values that fall below zero and heteroskedastic error terms (Greene, 1993). Log transformation of the OLS model – a method commonly employed to eliminate such statistical issues – is inappropriate here due to zero values in the dependent variable data. The Tobit model uses the maximum-likelihood estimation procedure to model the nonlinear relationship between the independent variable and the censored-dependent variable. It takes into account both the qualitative (probability of a zero response) and the continuous components (magnitude of a non-zero response) of the dependent variable avoiding the problems associated with OLS estimation (Tobin, 1958; Greene, 1993; Frone et al., 1994).

The second dependent variable – the variance of firms' cumulative knowledge-protection choices within an industry (or the variability of knowledge-protection strategies within an industry) – has a minimum value of 0. For some industries, the optimal variability of knowledge-protection strategy will be 0. Thus, the response variable includes a corner solution outcome. Again, the Tobit censored regression model (or the more appropriately named corner solution model) is an appropriate estimation method for response data of this kind.

Unfortunately, many of the variables representing the industry appropriability regime are highly correlated with one another leading to multicollinearity problems. Therefore it is not possible to examine their impact upon intangibles strategy in the same estimated equation. As a solution, each element of the industry appropriability regime is analysed separately. This method has been used by other researchers when faced with a similar issue (see for example Hall and Sena (2017) who estimated separate productivity equations when faced with process and product innovation probabilities that were highly correlated with one another).

3.4 Results

3.4.1 Descriptive results

Descriptive statistics and correlation coefficients are given in Tables 3.1 and 3.2. Table 3.1 shows the mean, standard deviation, minimum and maximum values for each of the variables described in Section 3.3 above and used in the empirical analysis. UK CIS data for the 2008 to 2010 period indicates that across the 103 industries, on average, the average number of knowledge-protection mechanisms used within an industry (i.e. the average knowledge-protection strategy) is 0.41 protection mechanisms; the minimum average knowledge protection strategy across the industries is 0 mechanisms and the maximum is 1.38 mechanisms. On average, the variance of knowledge-protection strategies within an industry is 0.99; the minimum and maximum values of the protection-strategy variance across the 103 industries are 0 and 3.66 respectively.

UK CIS data for the 2002 to 2008 period is used to formulate the variables that represent the industry appropriability regime in the analysis. On average, across all industry groups, 31 per cent of firms within an industry are product innovators; the smallest proportion of product innovators within an industry is 11 per cent and the largest proportion is 64 per cent. On average, 19 per cent of firms within an industry are process innovators; the smallest proportion of process innovators within an industry is 4 per cent and the largest proportion is 44 per cent. On average, across all industry groups, 7 per cent of firms within an industry view technical, industry or service standards as being important to innovation activities; the smallest proportion within an industry is 2 per cent of firms and the largest proportion is 21 per cent of firms. On average, 3 per cent of firms within an industry view scientific journals and trade/technical publications as being important to innovation activities; the smallest proportion within an industry is 0 per cent and the largest proportion is 17 per cent.

Examining the three variables that represent the effective and available knowledge-protection mechanisms within an industry shows that first, on average, 39 per cent of firms within an industry view formal knowledge-protection mechanisms as being important to innovations; the smallest proportion within an industry is 7 per cent and the largest proportion is 80 per cent, second, on average, 40 per cent of firms within an industry view informal or strategic knowledge-protection mechanisms as being important to innovations; the smallest proportion within an industry is 10 per cent and the largest proportion is 77 per cent, and third, on average, 15 per cent of firms within an industry adopt formal protection mechanisms; the smallest proportion within an industry is 1 per cent and the largest proportion is 48 per cent.

As for the control variables, the mean of each binary (0/1) independent variable indicates the proportion of industries that have a positive response: UK CIS data from the 2002 to 2008 period indicates that 7 per cent of industries have 40 per cent or more firms co-operating on any innovation activity and 41 per cent of industries have 50 per cent or more firms engaging in exporting. The same data indicates that on average, the average firm employment within an industry is approximately 311 employees; the minimum average employment in an industry is around 37 employees and the maximum average employment within an industry is around 2,630 employees. Turnover data for 2008 in the BSD indicates that across the 103 industries, on average, 28 per cent of an industry's market share is attributable to the largest five firms (in terms of their individual market shares); the minimum CR5 is 2 per cent and the maximum CR5 is 77 per cent. The industry birth rate data indicates that on average, 0.17 per cent of firms in an industry are born during the 2006 to 2008 period; the minimum birth rate is 0.06 per cent and the maximum birth rate is 0.51 per cent.

Table 3.2 shows the correlation coefficients for all variables included in the analysis. Many of the variables included to represent the industry appropriability regime are highly correlated, for example, the correlation between the industry propensity to view formal knowledge-protection mechanisms as being important and the industry propensity to view informal knowledge-protection mechanisms as being important is 0.96. The high correlation between many of these variables is not surprising given that they essentially measure similar attributes, for example the knowledge-protection variables measure the protection of knowledge and innovation (Hurmelinna-Laukkanen et al. (2017). Due to these high correlations, the two models are estimated seven times – each estimation including a different variable from the industry appropriability regime. This is quite often the approach undertaken when estimating highly correlated variables (for example, Hall and Sena, 2017).

3.4.2 Econometric results

The estimation results are given in Tables 3.3 to 3.8. As the proportion of industries having zero scores for the mean of firms' cumulative knowledge-protection choices within an industry and the variance of firms' cumulative knowledge-protection choices within an industry is low, and there is no clear indication as to the proportion of zero responses required to justify the use of the Tobit regression model, both Tobit (Table 3.3 and Table 3.4) and OLS (Table 3.5 and Table 3.6) regression results are reported here for comparison purposes.

The Tobit regression analysis estimates the latent dependent variable rather than the observed outcome. Consequently, the coefficients indicate the linear effect of a one unit change in the independent variable upon the uncensored latent variable, *ceteris paribus*. The Tobit model coefficients are therefore not readily interpretable as size effects, and the discussion of results focuses upon the sign of the coefficient (whether positive or negative) and whether or not the coefficient is statistically significant.

i. *The mean or average number of knowledge-protection mechanisms used by firms within an industry*

Table 3.3 shows the results for the Tobit regression to investigate how the strength of the industry appropriability regime affects the mean number of knowledge-protection mechanisms used by firms within an industry i.e. the average strength of knowledge-protection strategies (Laursen and Salter, 2005) within an industry. In total, there are seven variables which represent the different elements of the industry appropriability regime. Four variables represent the first dimension of the industry appropriability regime – the nature of technology within an industry (the industry average propensity to be a product/process innovator and the industry average propensity to view technical, industry or service standards/scientific journals and trade or technical publications as being important to innovation activities) and three variables represent the second dimension of the industry appropriability regime – the available and effective knowledge-protection mechanisms within an industry (the industry average propensity to view formal/informal knowledge-protection mechanisms as being important and the industry average propensity to adopt new formal knowledge-protection mechanisms).

The industry average propensity to be a product innovator and the industry average propensity to be a process innovator have significant, positive effects (at the 1 per cent level) on the mean number of knowledge-protection mechanisms used within an industry. As expected, when innovation becomes more popular within an industry – be it product or process innovation – the mean or average number of protection mechanisms used by firms within that industry increases, although the positive impact upon protection is slightly stronger when an industry's average propensity to be a product innovator increases. This may be due to knowledge that is linked to process innovations being more tacit in nature and more effectively retained within firms than knowledge linked to product innovations (product innovations may be subject to reverse engineering, for example). For this reason, the average number of knowledge-protection mechanisms required to retain knowledge increases by more when the average propensity to be a product innovator increases than when the average propensity to become a process innovator increases.

The industry average propensity to view technical, industry or service standards, and scientific journals and trade or technical publications as being important to innovation activities has a significant, positive effect (at the 1 per cent and 10 per cent levels respectively) on the average number of protection mechanisms used by firms within an industry. As these two variables increase, the knowledge that the industry technology is based upon becomes more codified and open to imitation. Thus, the average number of knowledge-protection mechanisms used by firms within an industry may increase in an attempt to protect innovations and combat any risk of imitation.

The three variables which represent the knowledge-protection dimension of the industry appropriability regime i.e. the available and effective knowledge-protection methods within an industry, have a significant, positive effect (at the 1 per cent level) on the average number of knowledge-protection mechanisms used by firms within an industry. The industry average propensity to adopt new formal knowledge-protection mechanisms has the strongest effect with a parameter equal to 1.458 compared with 1.262 and 1.195 for the industry average propensity to view informal knowledge-protection mechanisms as being important and the industry average propensity to view formal knowledge-protection mechanisms as being important, respectively. When the industry appropriability regime strengthens, the number of available and effective knowledge-protection mechanisms increases. This represents an increase in the three variables which represent available and effective knowledge-protection mechanisms within an industry in the model. Firms within the industry that were previously limited by knowledge-protection mechanisms defined by the appropriability regime are now able to maximise the value of their knowledge protection and protect their knowledge and innovations using a higher number of knowledge-protection mechanisms (see Figure 3.2). The heterogeneous nature of firm resources and capabilities allow some firms within the industry to utilise the extra available and effective knowledge-protection mechanisms following the appropriability regime shift. Consequently, the mean number of knowledge-protection mechanisms used by firms within an industry increases i.e. the average knowledge-protection strategy within the industry strengthens. Therefore, the estimation results support Hypothesis 1which states that on average, firms' knowledge-protection strategies are strengthened when the knowledge-protection dimension of the industry appropriability regime strengthens.

ii. The variance or variability of cumulative knowledge-protection mechanisms used by firms within an industry

Table 3.4 shows the results for the Tobit regression to investigate how the strength of the industry appropriability regime affects the variance of cumulative knowledge-protection mechanisms used by firms within an industry. The industry average propensity to be a product innovator and the industry average propensity to be a process innovator have significant, positive effects (at the 1 per cent level) on the variance of cumulative knowledge-protection mechanisms used by firms within an industry. The industry average propensity to be a product innovator has a stronger, positive effect on the variance than the industry average propensity to be a process innovator. As the propensity to innovate within an industry increases, the average amount of protection used by firms within the industry increases. The heterogeneous nature of firms' resources and capabilities leads to an increase in the variance of the cumulative knowledge-protection mechanisms used by firms within the industry. The industry average propensity to view technical, industry or service standards as being important to innovation activities has a significant, positive effect (at the 5 per cent level) on the variance of cumulative knowledge-protection mechanisms used by firms within an industry, whereas the industry average propensity to view scientific journals and trade or technical publications as being important to innovation activities has an insignificant effect. As the codified nature of knowledge increases, the average amount of protection used by firms within the industry increases, and the heterogeneous nature of firms' resources and capabilities leads to an increase in the variance of the cumulative knowledge-protection mechanisms used by firms.

The three variables which represent available and effective knowledge-protection mechanisms within an industry have a significant, positive effect (at the 1 per cent level) on the variance of cumulative knowledge-protection mechanisms used by firms within an industry. The industry average propensity to adopt new formal knowledge-protection mechanisms has the strongest effect with a parameter equal to 3.305 compared with 2.819 and 2.533 for the industry average propensity to view informal knowledge-protection mechanisms as being important and the industry average propensity to view formal knowledge-protection mechanisms as being important, respectively. As the three knowledge-protection propensities increase, the effective and available protection options for firms within an industry increases. Firms that were previously limited by the appropriability regime are able to maximise the value of their knowledge protection given their resources and capabilities and the new, stronger appropriability regime. The variance of firms' cumulative knowledge-protection choices increases because firms choose to optimise the value of their knowledge protection. As more strategic options exist, the previously constrained firms choose to no longer conform to the strategies of others; they have an incentive to differentiate their protection strategies. By taking a different position to their rivals, these rational firms within the industry face less competition and increase their chances of success. These results provide evidence in support of Hypothesis 2 which states that firms are faced with a wider range of strategic options when the knowledge-protection dimension of the industry appropriability strengthens, and in turn, this leads to more variable knowledge-protection strategies within the industry.

Table 3.5 and Table 3.6 show the estimation results when using OLS regression. The sign and significance level of the estimated parameters is the same as in the Tobit regression case. Given the presence of high correlations between some control variables and appropriability regime variables (Table 3.2), variance inflation factor (VIF) tests are carried out following the OLS regressions to test for the presence of multicollinearity. The VIF values in Table 3.7 and Table 3.8 are all below 2.5 suggesting that there are no serious concerns in relation to multicollinearity here.

3.4.3 High-technology/knowledge-intensive industries and low-technology/less knowledge-intensive industries: a comparison

The estimations discussed in Section 3.4.3 above assume that the model parameters are the same for all of the industries included in the analysis. The question therefore remains as to whether the strength of the industry appropriability regime affects the mean number of knowledge-protection mechanisms used by firms within an industry and the variance of cumulative knowledge-protection mechanisms within an industry to the same extent across different industry groups.

To investigate this, two different industry types are defined – high-technology/knowledge-intensive industries and low-technology/less knowledge-intensive industries. First, following the OECD in 2011, manufacturing industries are categorised into four groups based upon their level of technology: high-technology industries, medium-high-technology industries, medium-low-technology industries or low-technology industries. In its classification, the OECD uses expenditure on R&D to determine the technological input of each manufacturing industry. Both direct and indirect expenditure on R&D are considered, including the purchase of machinery, equipment and intermediary inputs (Hatzichronoglou, 1997). For the purpose of this study, each industry's economic activity is classified according to the level of technology and knowledge given by its SIC code.

Second, the service industries are sorted into six categories based upon the OECD's proposal for knowledge-intensive services (Eurostat, 2007) – each is identified as belonging to one of the industry types: knowledge-intensive high-technology services, knowledge-intensive market services, knowledge-intensive financial services, other knowledge-intensive services, less knowledge-intensive market services or other less knowledge-intensive services. The most knowledge-intensive services generally show higher investment in R&D, a greater use of information technology and a tendency to hire highly qualified personnel. Each service industry's economic activity is classified according to the level of technology and knowledge given by its SIC code.

Third, in order to obtain two groups of industries with contrasting technology/knowledge levels, industries belonging to the high-technology and medium high-technology manufacturing groups are merged with those belonging to the four knowledge-intensive service-sector groups – forming a group of high-technology/knowledge-intensive industries, and industries belonging to the medium low-technology and low-technology manufacturing groups are merged with those belonging to the two less knowledge-intensive service groups – forming a group of low-technology/less knowledge-intensive industries.

A new binary 0/1 variable signalling each industry's technology/knowledge level is generated using this information: the variable is set equal to 1 if the industry belongs to the high-technology/knowledge-intensive group and set equal to 0 if the industry belongs to the low-technology/less knowledge-intensive group.

The Tobit and OLS regressions are once again estimated, incorporating this added information. The estimated model is given by equation (1):

$$MKP_i \; or \; VKP_i = \beta_0 + \beta_1 C_i + \beta_2 \, TECH_i AR_i + \beta_3 \, (AR_i - TECH_i AR_i) + \mu_i \qquad (1)$$

where *MKPi* is the mean number of knowledge-protection mechanisms used by firms in industry *i*, *VKPi* is the variance of cumulative knowledge-protection mechanisms used by firms in industry *i*, *Ci* is a set of industry-level control variables, *TECHi* is the binary technology/knowledge indicator for industry *i*, *ARi* is the appropriability regime of industry *i* and *μi* is the error term. The β_2 parameter indicates how the strength of the appropriability regime in a high-technology/knowledge-intensive industry affects the mean number of knowledge-protection mechanisms used by firms and the variance of cumulative knowledge-protection mechanisms used by firms in that industry, and the β_3 parameter indicates how the strength of the appropriability regime in a low-technology/less knowledge-intensive industry affects the mean number of knowledge-protection mechanisms used by firms and the variance of cumulative knowledge-protection mechanisms used by firms within that industry. An F-test is performed to test the null hypothesis that β_2 is equal to β_3 i.e. that there is no significant difference between the effect the strength of the appropriability regime has on the dependent variable across the two industry types (the alternative hypothesis being that the two parameters are significantly different from one another, and that the effect on the dependent variable varies across the two industry types).

Tables 3.9 to 3.12 show the regression results which allow for the comparison of the two industry types. Again, Tobit regression (Tables 3.9 and 3.10) and OLS regression (Tables 3.11 and 3.12) results are presented here for comparison purposes.

i. *The mean or average number of knowledge-protection mechanisms used by firms within an industry*

Table 3.9 shows the results for the Tobit regression to investigate how the strength of the industry appropriability regime affects the mean number of knowledge-protection mechanisms used by firms within a high-technology/knowledge-intensive industry and a low-technology/less knowledge-intensive industry. The industry average propensity to be a product innovator has a significant, positive effect (at the 1 per cent level) on the mean number of knowledge-protection mechanisms used by firms in both a high-technology/knowledge-intensive industry and a low-technology/less knowledge-intensive industry. The F statistic indicates that there is no significant difference at the 5 per cent level between the parameters of the two industry groups, but that there is a significant difference between the parameters of the two industry groups at the 10 per cent level.

The industry average propensity to be a process innovator has a significant, positive effect on the mean number of knowledge-protection mechanisms used by firms in both a high-technology/knowledge-intensive industry and a low-technology/less knowledge-intensive industry, although the level of significance is higher for the high-technology/knowledge-intensive industry group (significant at the 1 per cent level compared with the 5 per cent level for the low-technology/less knowledge-intensive industry group). The F statistic indicates that the null hypothesis stating that the parameters are equal to one another should be rejected – there is a significant difference (at the 5 per cent level) between the parameters of the two industry groups.

The industry average propensity to view technical, industry or service standards, and scientific journals and trade or technical publications as being important to innovation activities has a significant, positive effect (at the 1 per cent level) on the mean number of protection mechanisms used by firms within a high-technology/knowledge-intensive industry – the effect in a low-technology/less knowledge-intensive industry is insignificant. The F statistic indicates that the null hypothesis stating that the parameters are equal to one another should be rejected – there is a significant difference (at the 5 per cent level) between the parameters of the two industry groups.

The extent to which knowledge is codified within an industry is an important determinant of the mean number of knowledge-protection mechanisms used by firms within a high-technology/knowledge intensive industry but not in a low-technology/less knowledge-intensive industry. This result is unsurprising given that firms in high-technology/knowledge-intensive industries face a higher risk of imitation – they have more knowledge to lose. Firms in these industries are therefore more inclined to increase the number of knowledge-protection mechanisms which they use to protect knowledge when knowledge within the industry becomes more codified. In turn, the mean number of knowledge-protection mechanisms used by firms within the high-technology/knowledge intensive industry increases.

The three variables which represent available and effective knowledge-protection mechanisms within an industry have a significant, positive effect (at the 1 per cent level) on the mean number of knowledge-protection mechanisms used by firms within a high-technology/knowledge-intensive industry and a low-technology/less knowledge-intensive industry. The F statistic indicates that the null hypothesis stating that the parameters are equal to one another cannot be rejected for the industry average propensity to view informal knowledge-protection mechanisms as being important variable and the industry average propensity to view formal knowledge-protection mechanisms as being important variable – there is no significant difference (at the 5 per cent level) between the parameters for the two industry groups in both cases. In contrast, the F statistic indicates that the null hypothesis stating that the parameters are equal to one another should be rejected for the industry average propensity to adopt new formal knowledge-protection mechanisms variable – the parameters for the two industry groups are significantly different to one another at the 5 per cent level. The difference in these results may be explained by the fact that a change in the propensity to adopt new formal knowledge-protection mechanisms within an industry represents an actual change in the strength of the industry appropriability regime, whereas a change in the industry average propensity to view informal knowledge-protection mechanisms as being important or the industry average propensity to view formal knowledge-protection mechanisms as being important represents a subjective change in the strength of the appropriability regime. When the average propensity to adopt new formal knowledge-protection mechanisms within an industry increases, the appropriability regime strengthens, and the number of available and effective knowledge-protection mechanisms increases. Some firms in high-technology/knowledge-intensive industries and low-technology/less knowledge-intensive industries that were previously limited by the industry appropriability regime are now able to optimise and maximise the value of their knowledge protection. But it is likely that more firms in high-technology/knowledge intensive industries will adopt the newly available knowledge-protection mechanisms as firms in these industries undertake more knowledge-intensive innovations. Thus, there is a significant difference (at the 5 per cent level) between the parameters for the two industry types.

ii. The variance or variability of cumulative knowledge-protection mechanisms used by firms within an industry

Table 3.10 shows the results for the Tobit regression to investigate how the strength of the industry appropriability regime affects the variance of cumulative knowledge-protection mechanisms used by firms within a high-technology/knowledge-intensive industry and a low-technology/less knowledge-intensive industry. The industry average propensity to be a product innovator has a significant, positive effect (at the 1 per cent level) on the variance of cumulative knowledge-protection mechanisms used by firms in both a high-technology/knowledge-intensive industry and a low-technology/less knowledge-intensive industry. The F statistic indicates that there is no significant difference at the 5 per cent level between the parameters of the two industry groups. The null hypothesis that the parameters are the same cannot be rejected.

The industry average propensity to be a process innovator has a significant, positive effect on the variance of cumulative knowledge-protection mechanisms used by firms in both a high-technology/knowledge-intensive industry and a low-technology/less knowledge-intensive industry, although the level of significance is higher for the high-technology/knowledge intensive industry group (significant at the

1 per cent level compared with the 5 per cent level for the low-technology/less knowledge-intensive industry group). The F statistic indicates that there is a significant difference (at the 5 per cent level) between the parameters of the two industry groups, and therefore the null hypothesis that the parameters are equal to one another is rejected in favour of the alternative hypothesis that they are significantly different from one another.

The industry average propensities to view technical, industry or service standards, and scientific journals and trade or technical publications as being important to innovation activities have insignificant effects on the variance of cumulative knowledge-protection mechanisms used by firms within both industry types.

The extent to which knowledge is codified within an industry does not impact upon the variance of cumulative knowledge-protection mechanisms used by firms within an industry as much as it does on the mean number of knowledge-protection mechanisms used by firms within an industry. It is only when the industry average propensity to be a process innovator increases that the parameters for the high-technology/knowledge-intensive industry group and the low-technology/less knowledge-intensive industry group differ from one another. As the mean number of knowledge-protection mechanisms used by firms in a high-technology/knowledge-intensive industry increases by more than the mean number of knowledge-protection mechanisms used by firms in a low-technology/less knowledge-intensive industry when the industry average propensity to be a process innovator increases, it is not surprising that the variance of cumulative knowledge-protection mechanisms used by firms within a high-technology/knowledge-intensive industry is also higher. As more knowledge-protection options exist for a high-technology/knowledge-intensive industry and firms have an incentive to differentiate their protection strategies in order to reduce the competition which they face and increase their chances of success, the variability or variance of knowledge-protection strategies within a high-technology/knowledge-intensive industry will be higher.

The three variables which represent available and effective knowledge-protection mechanisms within an industry have a significant, positive effect (at the 1 per cent level) on the variance of cumulative knowledge-protection mechanisms in a high-technology/knowledge- intensive industry and a low-technology/less knowledge-intensive industry. The F statistic indicates that there is no significant difference between the two industry group's estimated parameters on two of these protection variables – the industry average propensity to view informal knowledge-protection mechanisms as being important and the industry average propensity to view formal knowledge-protection mechanisms as being important. In both cases, the null hypothesis that the parameters are equal to one another cannot be rejected. As with the analysis of the mean number of knowledge-protection mechanisms used by firms within high-technology/knowledge-intensive and low-technology/less knowledge-intensive industries, an increase in the industry average propensity to adopt new formal knowledge-protection mechanisms is the only protection variable to have parameters which are significantly different from one another for the two industry groups, although the null hypothesis stating that the parameters are equal to one another is rejected here at the 10 per cent level rather than the 5 per cent level.

As the knowledge-protection dimension of the appropriability regime strengthens within an industry, the number of effective and available knowledge-protection mechanisms increases. In turn, the mean number of knowledge-protection mechanisms adopted by firms in a high-technology/knowledge-intensive industry increases by more than in a low-technology/less knowledge-intensive industry. As a result of this, the number of additional strategic options available to firms in a high-technology/knowledge intensive industry is greater than that in a low-technology/less knowledge-intensive industry. Previously constrained firms – in both industries – choose to no longer conform to the strategies of others; they have an incentive to differentiate their protection strategies as by taking a different position to their rivals, these rational firms within the industry face less competition and increase their chances of success. As the number of strategic options is higher in a high-technology/knowledge intensive industry, the variability or variance of knowledge-protection strategies within a high-technology/knowledge-intensive will be greater than in a low-technology/less knowledge-intensive industry.

Tables 3.11 and 3.12 show the estimation results for the two industry types when using OLS regression. The sign and significance level of the estimated parameters is the same as in the Tobit regression case.

3.5 Discussion and conclusions

When a firm successfully innovates, success – in terms of higher firm profits, increased market value, improved credit ratings or an increased chance of survival – is not assured (Geroski et al., 1993; Hall, 2000; Czarnitzki and Kraft, 2004; Cefis and Marsili, 2005); it is the innovating firm's ability to appropriate innovation returns which determines the outcome (Teece, 1986; Levin et al., 1987). In order to aid appropriation and guard against imitation, a firm can formulate an effective knowledge-protection strategy – incorporating formal, legally-enforceable protection mechanisms and informal knowledge-protection mechanisms based upon secrecy and non-disclosure – to prevent or delay the imitation of its knowledge and technology (Hurmelinna-Laukkanen et al., 2008). In this study, it is assumed that a firm's chosen knowledge-protection strategy is determined by two factors: the appropriability regime of the industry to which the firm belongs, defining the available and effective knowledge-protection mechanisms within the industry (Teece, 1986, 1998, 2000a; Levin et al., 1987; Teece and Pisano, 1998), and the individual resources and capabilities that the firm has available to aid in the protection of its knowledge.

The present study acknowledges that firms in an industry with a strong appropriability regime have more knowledge-protection options available to them than firms in an industry with a weak appropriability regime. It is therefore expected that firms faced with a strong appropriability environment are likely, given that they have the resources and capabilities available to do so, to make more complex knowledge-protection choices i.e. implement stronger knowledge-protection strategies – in terms of the amount of protection that they use – than firms faced with a weak appropriability environment. It is also expected that the increased availability of effective knowledge-protection options in an industry with a strong appropriability regime will lead to more variability in knowledge-protection choices amongst firms than in an industry with a weak appropriability regime. Given that they have the resources and capabilities available to do so, firms in an industry with a strong appropriability regime will seek to position themselves differently to other firms within the industry in an attempt to increase their chances of success (Deephouse, 1999).

This industry-level study examines the knowledge-protection dimension of the industry appropriability regime and asks how relaxing the limit on the available and effective knowledge-protection mechanisms within an industry i.e. strengthening the knowledge-protection dimension of the industry appropriability regime, affects the complexity (or strength) and variability of firms' knowledge-protection choices within the industry. Using UKCIS data covering the period 2002 to 2010 (CIS4 to CIS7) and BSD data covering the period 1997 to 2008, Tobit models are estimated to investigate how firms' knowledge-protection choices, or strategies, change when the industry appropriability regime they face strengthens, and how the variability of firms' knowledge-protection choices or strategies change when the industry appropriability regime they face strengthens. Initially, the analysis examines all industries and then moves on to examine and compare the results for high-technology/knowledge-intensive industries and low-technology/less knowledge-intensive industries.

This study adds to the existing literature on the determinants of firms' knowledge-protection strategies by asking how increasing the strength of the knowledge-protection dimension of an industry appropriability regime affects the complexity and variability of firms' knowledge-protection choices or strategies within the industry. Previous studies identify industry characteristics (Mansfield, 1986; Levin et al., 1987; Harabi, 1995; Cohen et al., 2000), firm resources (Kitching and Blackburn, 1998; Leiponen and Byma, 2009) and the novelty of the innovation (Thomas, 2003; Hanel, 2005; Hussinger, 2006) as being important determinants of a firm's knowledge-protection strategy. In their study, Hurmelinna-Laukkanen et al. (2017) identify three types of firm appropriability profile with industry factors and firm-resource factors jointly determining the profile group to which a firm belongs. Building upon this study and adding to the existing body of knowledge, this study examines the nature of firms' knowledge-protection profiles within an industry setting (rather than across different industries). It assumes that industry factors and resources are behind firms' knowledge-protection profiles and investigates how firms' knowledge-protection choices or strategies respond to an increase in strength of the knowledge-protection dimension of the industry appropriability regime.

This study deepens our understanding of how the knowledge-protection dimension of the industry appropriability regime influences the complexity and variability of firms' knowledge-protection strategies within an industry. The empirical analysis leads to a number of key findings.

i. First, the results suggest that the average protection strategy within an industry strengthens – or the complexity of firms' knowledge-protection strategies increases – when the knowledge-protection dimension of the industry appropriability regime strengthens. When the knowledge-protection dimension of the industry appropriability regime strengthens, firms equipped with the necessary resources and capabilities to do so are able to increase the number of knowledge-protection mechanisms that they use in order to optimise their knowledge-protection strategies. The results suggest that increasing the strategy space within an industry, or the number of effective and available protection mechanisms within an industry, allows more firms to optimise their knowledge-protection strategies, increasing firms' chances of appropriating innovation returns. As the chances of appropriating returns to innovation increase within an industry, the incentive for firms to innovate within the industry also increases because firms' decisions to invest in innovation depend upon expected post-innovation returns (Du et al., 2007). A firm's ability to appropriate or capture the benefits of an innovation is central to a firm being able to gain and sustain a competitive advantage (Laursen and Salter, 2005).
By optimising their use of knowledge-protection mechanisms, firms within an industry are able to capture the private benefits or returns to innovation (Laursen and Salter, 2005; Greenhalgh and Rogers, 2007), reduce competition and be incentivised to carry out further innovations (Granstrand, 1999).

ii. Second, the analysis suggests that the diversity or variability of firms' knowledge-protection strategies within an industry increases when the knowledge-protection dimension of the industry appropriability regime strengthens. As the knowledge-protection dimension of the industry appropriability regime strengthens, some firms within the industry are able to increase the number of protection mechanisms that they use, given their resources and capabilities, and maximise the value of their knowledge protection. As the industry strategy space increases and more effective knowledge-protection options exist for firms within an industry, some firms (with the necessary resources and capabilities to do so) are able to position themselves differently to other firms and are no longer forced to conform to the protection strategies of others. The variability of firms' protection strategies within the industry therefore increases, firms face less competition and in turn, their chances of success increase.

iii. Third, results suggest that the increase in strength – or complexity – of the average protection strategy within an industry following an increase in the strength of the knowledge-protection dimension of the industry appropriability regime (in terms of formal mechanisms) is not the same across all industries. Results show that it is likely that the strength of the average protection strategy within high-technology/knowledge intensive industries will increase by more than the strength of the average protection strategy within the low-technology/less knowledge-intensive industries. This result is not surprising given that firms in high-technology/knowledge intensive industries are more likely to undertake knowledge-intensive innovations and, in turn, have more knowledge to protect.

iv. Fourth, results suggest that the increase in the diversity or variability of protection strategies within an industry following an increase in the strength of the knowledge-protection dimension of the industry appropriability regime (in terms of formal mechanisms) is not the same across all industries. Results show that it is likely that the variability of protection strategies within high-technology/knowledge intensive industries will increase by more than the variability of protection strategies within the low-technology/less knowledge-intensive industries, although the difference between the two groups of industries is less significant than in the average protection strategy case. As the knowledge-protection dimension of the industry appropriability regime strengthens, the average protection strategy within high-technology/knowledge-intensive industries increases by more than the

> average protection strategy in low-technology/less knowledge-intensive industries. Firms in high-technology/knowledge-intensive industries have more strategic options available to them to protect knowledge and therefore more opportunities to act differently to other firms within the industry, reducing competition and improving their chances of success.

Policy surrounding firms' use of knowledge-protection mechanisms is very much focused on formal knowledge protection. However, the results of this study suggest that, within an industry, the average knowledge-protection strategy is strengthened and the diversity of knowledge-protection strategies is increased when the importance of informal knowledge-protection mechanisms increases as well as when the importance of formal knowledge-protection mechanisms increases – the availability of both formal and informal knowledge-protection mechanisms matter for a firm's strategic choice. It is important, therefore, that in addition to the current policy which surrounds formal knowledge protection, new policy initiatives are directed towards the promotion and use of informal protection mechanisms across all firms. This will enable firms to seize valuable, strategic opportunities by engaging in informal protection practices. The likelihood of a firm finding a strategic opportunity is increased if it is able to use its resources and capabilities in a unique way – differentiating itself from other firms. Therefore, government policy aimed at promoting the use of informal protection will enable those firms that face barriers to the use of formal mechanisms to position themselves differently to other firms when new opportunities arise. In doing so, a firm is more likely to receive the benefits from its positioning (Denrell et al., 2003). Government policy supporting informal protection will increase firms' chances of receiving the returns to its innovation, increase the probability of further innovative investment and, in turn, promote long-run growth. Government policy supporting informal knowledge protection will encourage firms that do have the resources and capabilities to use formal knowledge protection to also invest in informal protection. This may allow both the innovations and the knowledge-protection to be used more widely (Hurmelinna-Laukkanen, 2014). A wide set of knowledge-protection mechanisms will give firms the readiness to change direction and, at the same time, it will increase their chances of performance success in new ventures – given that performance outcomes depend upon a firm's ability to protect assets.

Examples of ways in which government policy initiatives can support firms to increase their informal protection include: designating an individual within the firm to identify intellectual property and implement and enforce secrecy compliance. The individual should keep records, distribute and collect operations manuals, conduct exit interviews and respond to questions relating to the protection of the firm's IP; making IP protection part of the employees' orientation and training program, and informing those employees who have access to firm-specific knowledge and confidential information of their continuing duty to prevent disclosure; prohibiting individuals from making copies of confidential information unless it is necessary for them to perform their duties; and prohibiting employees from downloading proprietary software onto portable computers without prior authorisation and maintain detailed records of employees permitted to download proprietary software. The Intellectual Property Office (IPO) (the official UK government body responsible for intellectual property rights) should, in the same way as they do for formal protection, provide events, tool-kits, case studies and guidance to help firms use these and other informal strategies as a way of protecting their knowledge in an informal way.

In addition, the results suggest that government policies supporting formal knowledge-protection will have stronger positive effects upon the average knowledge-protection strategy and the diversity of knowledge-protection strategies in high-technology/knowledge intensive industries than in low-technology/less knowledge-intensive industries. Government policy should provide extra formal-protection support for firms in high-technology/knowledge-intensive industries. The IPO should target high-technology/knowledge-intensive firms – particularly those that may find it difficult to engage in formal knowledge protection (small firms, for example) and help them to identify their intellectual property (through tool-kits, for example) and suggest appropriate formal protection mechanisms. Resource-constrained high-technology/knowledge-intensive firms should also be directed towards any financial help that is available to them (innovation vouchers, for example).

3.5.1 Limitations and future work

There are several limitations to this study. First, the high degree of correlation between the variables designed to represent the industry appropriability regime means that each element of the regime is analysed in a separate regression model – it is not possible to examine the impact of the industry appropriability regime on a firm's intangibles strategy in a single estimated equation. Future work will aim to address this issue and seek ways to create a single measure representing the industry appropriability regime. Second, the analysis here examines how changing the strength of the knowledge-protection dimension of the industry appropriability regime affects the average knowledge-protection strategy within the industry and the diversity or variability of knowledge-protection strategies within the industry. Rather than examining individual protection mechanisms, this study is concerned with firms' *cumulative* protection choices, and therefore provides no understanding as to how the strength of the industry appropriability affects firms' use of individual mechanisms nor any indication as to which mechanisms formulate firms' protection strategies. Future work may examine the responses of particular mechanisms to a change in strength of the industry appropriability regime so that complementarities and connections between particular protection mechanisms can be identified. Third, the study examines how the results differ across high-technology/knowledge-intensive industries and low-technology/less knowledge-intensive industries. Ideally, a comparison across individual industries is preferred, but the analysis here is limited by the number of observations in the dataset. As the nature of the knowledge-protection questions changes across different waves of the UK CIS surveys, further waves of the data could not be used to formulate the dependent variables. Future work aims to link other formal knowledge-protection data to the UKCIS and BSD datasets so that the response of firms' formal knowledge-protection strategies to a change in strength of the industry appropriability regime within particular industries can be examined. Fourth, the analysis considers UK data only. Knowledge-protection availability and effectiveness varies across countries, and therefore the findings here may not be observed in other countries. Future work aims to carry out a similar analysis in other countries, providing that the data is available.

Table 3.1: Descriptive statistics

Variable	Number of observations	Mean	Standard Deviation	Minimum	Maximum
Average knowledge-protection strategy within an industry	103	0.41	0.33	0	1.38
Variability of knowledge-protection strategies within an industry	103	0.99	0.88	0	3.66
Industry average propensity to be a product innovator	100	0.31	0.13	0.11	0.64
Industry average propensity to be a process innovator	100	0.19	0.09	0.04	0.44
Industry average propensity to view standards as being important to innovation	100	0.07	0.04	0.02	0.21
Industry average propensity to view publications as being important to innovation	100	0.03	0.03	0.00	0.17
Industry average propensity to view formal knowledge-protection mechanisms as being important to innovation	100	0.39	0.17	0.07	0.80
Industry average propensity to view informal knowledge-protection mechanisms as being important to innovation	100	0.40	0.17	0.10	0.77
Industry average propensity to adopt new formal knowledge-protection mechanisms	100	0.15	0.11	0.01	0.48
Industry engagement in cooperation on any innovation activity	103	0.07	0.25	0	1
Extent of internationalisation within the industry	103	0.41	0.49	0	1
Average firm employment within the industry	100	310.81	343.91	36.98	2629.94
Industry five-firm concentration ratio **	103	0.28	0.18	0.02	0.77
Industry birth rate *	102	0.17	0.08	0.06	0.51

Notes: * The proportion of new firms entering the industry group during the three-year CIS period
** The share of industry-group turnover accounted for by the five largest firms within the industry group – in terms of turnover (individual year values are averaged across the CIS wave)
Source: UK CIS 2002 to 2010 and BSD 1997 to 2008

Table 3.2: Correlation matrix (N=98)

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14
(1) Average knowledge-protection strategy within an industry	1.00													
(2) Variability of knowledge-protection strategies within an industry	0.94	1.00												
(3) Industry average propensity to be a product innovator	0.83	0.76	1.00											
(4) Industry average propensity to be a process innovator	0.68	0.62	0.86	1.00										
(5) Industry average propensity to view standards as being important to innovation	0.56	0.48	0.64	0.63	1.00									
(6) Industry average propensity to view publications as being important to innovation	0.46	0.37	0.54	0.58	0.56	1.00								
(7) Industry average propensity to view formal knowledge-protection mechanisms as being important to innovation	0.81	0.73	0.91	0.81	0.63	0.54	1.00							
(8) Industry average propensity to view informal knowledge-protection mechanisms as being important to innovation	0.83	0.77	0.92	0.83	0.62	0.43	0.96	1.00						
(9) Industry average propensity to adopt new formal knowledge-protection mechanisms	0.74	0.68	0.73	0.62	0.44	0.67	0.78	0.70	1.00					
(10) Industry engagement in cooperation on any innovation activity	0.47	0.42	0.39	0.43	0.41	0.64	0.34	0.32	0.47	1.00				
(11) Extent of internationalisation within the industry	0.71	0.69	0.68	0.53	0.39	0.26	0.69	0.75	0.56	0.26	1.00			
(12) Average firm employment within the industry	-0.17	-0.17	-0.03	-0.01	-0.07	-0.07	-0.04	-0.12	-0.11	0.01	-0.21	1.00		
(13) Ind. five-firm concentration ratio **	0.22	0.18	0.27	0.33	0.23	0.20	0.30	0.25	0.15	0.13	0.07	0.35	1.00	
(14) Industry birth rate *	-0.27	-0.28	-0.29	-0.27	-0.01	0.03	-0.19	-0.29	-0.16	-0.02	-0.31	0.07	-0.08	1.00

Notes: * The proportion of new firms entering the industry group during the three-year CIS period
** The share of industry-group turnover accounted for by the five largest firms within the industry group – in terms of turnover (individual year values are averaged across the CIS wave)
Source: UK CIS 2002 to 2010 and BSD 1997 to 2008

Table 3.3: The mean or average number of knowledge-protection mechanisms used by firms within an industry – Tobit model

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Ind. cooperation on any innovation activity	0.286***	0.332***	0.395***	0.350**	0.361***	0.380***	0.250**
	(0.09)	(0.11)	(0.12)	(0.14)	(0.09)	(0.09)	(0.11)
Ind. extent of internationalisation	0.132***	0.279***	0.319***	0.361***	0.112**	0.08	0.237***
	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)
Av. firm employment within industry	-0.000**	-0.000*	0.00	0.00	-0.000**	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Industry birth rate	-0.05	-0.12	-0.46	-0.40	-0.399*	-0.14	-0.32
	(0.24)	(0.28)	(0.30)	(0.30)	(0.24)	(0.24)	(0.26)
Industry five-firm concentration ratio	0.09	0.14	0.22	0.256*	0.04	0.06	0.229**
	(0.11)	(0.13)	(0.13)	(0.13)	(0.11)	(0.11)	(0.11)
Industry average propensity to be a product innovator	1.597***						
	(0.19)						
Industry average propensity to be a process innovator		1.356***					
		(0.29)					
Industry average propensity to view standards as being important to innovation			2.209***				
			(0.68)				
Ind. av. propensity to view publications as being important to innovation				2.111*			
				(1.10)			
Ind. av. propensity to view formal protection as important					1.195***		
					(0.15)		
Ind. av. propensity to view informal protection as important						1.262***	
						(0.15)	
Ind. av. propensity to adopt new formal protection							1.458***
							(0.23)
Constant	-0.125*	0.05	0.168**	0.229***	-0.02	-0.10	0.120*
	(0.07)	(0.08)	(0.08)	(0.08)	(0.07)	(0.07)	(0.07)
N	99.00	99.00	99.00	99.00	99.00	99.00	99.00
Chi-squared	137.98	104.44	94.91	88.64	135.32	138.07	118.66
p	0.00	0.00	0.00	0.00	0.00	0.00	0.00
R-squared (Pseudo)	2.02	1.53	1.39	1.30	1.98	2.02	1.74
bic	-32.90	0.64	10.17	16.44	-30.24	-32.99	-13.58

Notes: See Table 3.2
Coefficients are reported with standard errors in parentheses. * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2002 to 2010 and BSD 1997 to 2008.

Table 3.4: The variance or variability of cumulative knowledge-protection mechanisms used by firms within an industry – Tobit model

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Ind. cooperation on any innovation activity	0.683**	0.772**	0.952***	1.038**	0.857***	0.883***	0.583*
	(0.30)	(0.33)	(0.34)	(0.41)	(0.29)	(0.29)	(0.32)
Ind. extent of internationalisation	0.448***	0.763***	0.870***	0.961***	0.420**	0.316*	0.667***
	(0.15)	(0.15)	(0.15)	(0.14)	(0.16)	(0.16)	(0.14)
Av. firm employment within industry	-0.000*	0.00	0.00	0.00	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Industry birth rate	-0.52	-0.67	-1.38	-1.21	-1.284*	-0.71	-1.11
	(0.75)	(0.82)	(0.85)	(0.86)	(0.76)	(0.74)	(0.78)
Industry five-firm concentration ratio	0.18	0.26	0.47	0.60	0.09	0.10	0.47
	(0.33)	(0.37)	(0.37)	(0.38)	(0.34)	(0.33)	(0.34)
Industry average propensity to be a product innovator	3.487***						
	(0.61)						
Industry average propensity to be a process innovator		3.047***					
		(0.85)					
Industry average propensity to view standards as being important to innovation			4.289**				
			(1.96)				
Ind. av. propensity to view publications as being important to innovation				1.92			
				(3.11)			
Ind. av. propensity to view formal protection as important					2.533***		
					(0.47)		
Ind. av. propensity to view informal protection as important						2.819***	
						(0.48)	
Ind. av. propensity to adopt new formal protection							3.305***
							(0.69)
Constant	-0.16	0.21	0.499**	0.653***	0.09	-0.13	0.360*
	(0.23)	(0.24)	(0.22)	(0.21)	(0.21)	(0.23)	(0.20)
N	99.00	99.00	99.00	99.00	99.00	99.00	99.00
Chi-squared	103.11	86.43	78.98	74.70	100.01	104.71	95.10
p	0.00	0.00	0.00	0.00	0.00	0.00	0.00
R-squared (Pseudo)	0.40	0.33	0.31	0.29	0.39	0.41	0.37
bic	192.48	209.16	216.61	220.89	195.58	190.88	200.50

Notes: See Table 3.2
Coefficients are reported with standard errors in parentheses. * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2002 to 2010 and BSD 1997 to 2008.

Table 3.5: The mean or average number of knowledge-protection mechanisms used by firms within an industry – OLS model

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Ind. cooperation on any innovation activity	0.285***	0.333***	0.393***	0.349**	0.360***	0.380***	0.251**
	(0.10)	(0.12)	(0.12)	(0.15)	(0.10)	(0.09)	(0.11)
Ind. extent of internationalisation	0.137***	0.283***	0.322***	0.363***	0.118**	0.09	0.242***
	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)
Av. firm employment within industry	-0.000**	-0.000*	0.00	0.00	-0.000**	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Industry birth rate	-0.04	-0.12	-0.45	-0.40	-0.39	-0.13	-0.31
	(0.24)	(0.29)	(0.30)	(0.31)	(0.25)	(0.24)	(0.27)
Industry five-firm concentration ratio	0.10	0.14	0.22	0.257*	0.05	0.07	0.231*
	(0.11)	(0.13)	(0.13)	(0.14)	(0.11)	(0.11)	(0.12)
Industry average propensity to be a product innovator	1.583***						
	(0.20)						
Industry average propensity to be a process innovator		1.336***					
		(0.30)					
Industry average propensity to view standards as being important to innovation			2.205***				
			(0.70)				
Ind. av. propensity to view publications as being important to innovation				2.101*			
				(1.13)			
Ind. av. propensity to view formal protection as important					1.180***		
					(0.15)		
Ind. av. propensity to view informal protection as important						1.244***	
						(0.16)	
Ind. av. propensity to adopt new formal protection							1.439***
							(0.24)
Constant	-0.12	0.05	0.166**	0.227***	-0.02	-0.10	0.120*
	(0.08)	(0.08)	(0.08)	(0.08)	(0.07)	(0.07)	(0.07)
N	99.00	99.00	99.00	99.00	99.00	99.00	99.00
p	0.00	0.00	0.00	0.00	0.00	0.00	0.00
bic	-42.83	-9.06	0.10	6.50	-39.87	-42.46	-23.26

Notes: See Table 3.2
Coefficients are reported with standard errors in parentheses. * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2002 to 2010 and BSD 1997 to 2008.

Table 3.6: The variance or variability of cumulative knowledge-protection mechanisms used by firms within an industry – OLS model

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Ind. cooperation on any innovation activity	0.682**	0.773**	0.945***	1.033**	0.855***	0.880***	0.586*
	(0.30)	(0.34)	(0.35)	(0.42)	(0.30)	(0.29)	(0.33)
Ind. extent of internationalisation	0.464***	0.777***	0.878***	0.970***	0.441***	0.340**	0.682***
	(0.16)	(0.15)	(0.15)	(0.15)	(0.16)	(0.17)	(0.15)
Av. firm employment within industry	-0.000*	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Industry birth rate	-0.51	-0.66	-1.36	-1.19	-1.26	-0.69	-1.09
	(0.77)	(0.84)	(0.87)	(0.89)	(0.78)	(0.76)	(0.80)
Industry five-firm concentration ratio	0.19	0.27	0.47	0.61	0.10	0.12	0.48
	(0.34)	(0.38)	(0.38)	(0.39)	(0.35)	(0.34)	(0.35)
Industry average propensity to be a product innovator	3.438***						
	(0.62)						
Industry average propensity to be a process innovator		2.981***					
		(0.87)					
Industry average propensity to view standards as being important to innovation			4.276**				
			(2.02)				
Ind. av. propensity to view publications as being important to innovation				1.89			
				(3.20)			
Ind. av. propensity to view formal protection as important					2.483***		
					(0.48)		
Ind. av. propensity to view informal protection as important						2.760***	
						(0.49)	
Ind. av. propensity to adopt new formal protection							3.243***
							(0.71)
Constant	-0.16	0.21	0.492**	0.646***	0.09	-0.12	0.358*
	(0.24)	(0.24)	(0.23)	(0.22)	(0.22)	(0.23)	(0.21)
N	99.00	99.00	99.00	99.00	99.00	99.00	99.00
p	0.00	0.00	0.00	0.00	0.00	0.00	0.00
bic	185.10	201.79	208.91	213.25	188.40	183.84	193.20

Notes: See Table 3.2
Coefficients are reported with standard errors in parentheses. * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2002 to 2010 and BSD 1997 to 2008.

Table 3.7: Variance inflation factor tests - mean or average knowledge-protection regressions

Variable	VIF	1/VIF		Variable	VIF	1/VIF
Industry average propensity to be a product innovator	2.17	0.460414		**Ind. av. propensity to view formal protection as important**	2.16	0.463455
Ind. extent of internationalisation	1.93	0.519115		**Ind. extent of internationalisation**	2.07	0.482158
Industry five-firm concentration ratio	1.26	0.790934		**Industry five-firm concentration ratio**	1.31	0.764883
Av. firm employment within industry	1.21	0.825603		**Av. firm employment within industry**	1.21	0.825431
Ind. cooperation on any innovation activity	1.2	0.834716		**Ind. cooperation on any innovation activity**	1.14	0.875184
Industry birth rate	1.14	0.878466		**Industry birth rate**	1.12	0.896315
MEAN VIF	**1.49**			**MEAN VIF**	**1.5**	
Industry average propensity to be a process innovator	1.76	0.568692		**Ind. av. propensity to view informal protection as important**	2.42	0.412418
Ind. extent of internationalisation	1.48	0.677417		**Ind. extent of internationalisation**	2.26	0.443057
Industry five-firm concentration ratio	1.3	0.768626		**Industry five-firm concentration ratio**	1.29	0.777716
Av. firm employment within industry	1.25	0.799946		**Av. firm employment within industry**	1.22	0.819097
Ind. cooperation on any innovation activity	1.21	0.825015		**Ind. cooperation on any innovation activity**	1.13	0.885632
Industry birth rate	1.15	0.873317		**Industry birth rate**	1.13	0.888226
MEAN VIF	**1.36**			**MEAN VIF**	**1.57**	
Industry average propensity to view standards as being important to innovation	1.42	0.70204		**Ind. av. propensity to adopt new formal protection**	1.7	0.586778
Ind. extent of internationalisation	1.38	0.723219		**Ind. extent of internationalisation**	1.55	0.646287
Industry five-firm concentration ratio	1.25	0.799638		**Industry five-firm concentration ratio**	1.2	0.830404
Av. firm employment within industry	1.22	0.81862		**Av. firm employment within industry**	1.22	0.819183
Ind. cooperation on any innovation activity	1.22	0.818897		**Ind. cooperation on any innovation activity**	1.29	0.772226
Industry birth rate	1.13	0.883027		**Industry birth rate**	1.11	0.897195
MEAN VIF	**1.27**			**MEAN VIF**	**1.35**	
Ind. av. propensity to view publications as being important to innovation	1.81	0.552704				
Ind. extent of internationalisation	1.26	0.795647				
Industry five-firm concentration ratio	1.24	0.806885				
Av. firm employment within industry	1.24	0.809357				
Ind. cooperation on any innovation activity	1.73	0.577708				
Industry birth rate	1.13	0.885032				
MEAN VIF	**1.4**					

Notes: See Table 3.2
Source: UK CIS 2002 to 2010 and BSD 1997 to 2008.

Table 3.8: Variance inflation factor tests – variance or variability of knowledge-protection regressions

Variable	VIF	1/VIF		Variable	VIF	1/VIF
Industry average propensity to be a product innovator	2.17	0.460414		**Ind. av. propensity to view formal protection as important**	2.16	0.463455
Ind. extent of internationalisation	1.93	0.519115		**Ind. extent of internationalisation**	2.07	0.482158
Industry five-firm concentration ratio	1.26	0.790934		**Industry five-firm concentration ratio**	1.31	0.764883
Av. firm employment within industry	1.21	0.825603		**Av. firm employment within industry**	1.21	0.825431
Ind. cooperation on any innovation activity	1.2	0.834716		**Ind. cooperation on any innovation activity**	1.14	0.875184
Industry birth rate	1.14	0.878466		**Industry birth rate**	1.12	0.896315
MEAN VIF	**1.49**			**MEAN VIF**	**1.5**	
Industry average propensity to be a process innovator	1.76	0.568692		**Ind. av. propensity to view informal protection as important**	2.42	0.412418
Ind. extent of internationalisation	1.48	0.677417		**Ind. extent of internationalisation**	2.26	0.443057
Industry five-firm concentration ratio	1.3	0.768626		**Industry five-firm concentration ratio**	1.29	0.777716
Av. firm employment within industry	1.21	0.825015		**Av. firm employment within industry**	1.22	0.819097
Ind. cooperation on any innovation activity	1.25	0.799946		**Ind. cooperation on any innovation activity**	1.13	0.885632
Industry birth rate	1.15	0.873317		**Industry birth rate**	1.13	0.888226
MEAN VIF	**1.36**			**MEAN VIF**	**1.57**	
Industry average propensity to view standards as being important to innovation	1.42	0.70204		**Ind. av. propensity to adopt new formal protection**	1.7	0.586778
Ind. extent of internationalisation	1.38	0.723219		**Ind. extent of internationalisation**	1.55	0.646287
Industry five-firm concentration ratio	1.25	0.799638		**Industry five-firm concentration ratio**	1.2	0.830404
Av. firm employment within industry	1.22	0.81862		**Av. firm employment within industry**	1.22	0.819183
Ind. cooperation on any innovation activity	1.22	0.818897		**Ind. cooperation on any innovation activity**	1.29	0.772226
Industry birth rate	1.13	0.883027		**Industry birth rate**	1.11	0.897195
MEAN VIF	**1.27**			**MEAN VIF**	**1.35**	
Ind. av. propensity to view publications as being important to innovation	1.81	0.552704				
Ind. extent of internationalisation	1.26	0.795647				
Industry five-firm concentration ratio	1.24	0.806885				
Av. firm employment within industry	1.24	0.809357				
Ind. cooperation on any innovation activity	1.73	0.577708				
Industry birth rate	1.13	0.885032				
MEAN VIF	**1.4**					

Notes: See Table 3.2
Source: UK CIS 2002 to 2010 and BSD 1997 to 2008.

Table 3.9: The mean or average number of knowledge-protection mechanisms in high-technology/knowledge-intensive industries and low-technology/less knowledge-intensive industries – Tobit model

		Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Ind. cooperation on any innovation activity		0.258***	0.245**	0.366***	0.243*	0.330***	0.349***	0.13
		(0.09)	(0.11)	(0.11)	(0.14)	(0.09)	(0.09)	(0.11)
Ind. extent of internationalisation		0.150***	0.280***	0.330***	0.352***	0.131**	0.100*	0.246***
		(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)
Av. firm employment within industry		-0.000**	-0.000**	-0.000*	0.00	-0.000**	-0.000*	0.00
		0.00	0.00	0.00	0.00	0.00	0.00	0.00
Industry birth rate		-0.14	-0.30	-0.522*	-0.559*	-0.449*	-0.21	-0.438*
		(0.24)	(0.27)	(0.29)	(0.30)	(0.24)	(0.24)	(0.25)
Industry five-firm concentration ratio		0.08	0.10	0.215*	0.220*	0.04	0.05	0.17
		(0.10)	(0.12)	(0.13)	(0.13)	(0.11)	(0.11)	(0.11)
Industry average propensity to be a product innovator	GP1	1.544***						
		(0.19)						
	GP2	1.334***						
		(0.24)						
F statistic		3.23						
prob>F		0.08						
Industry average propensity to be a process innovator	GP1		1.492***					
			(0.28)					
	GP2		0.835**					
			(0.32)					
F statistic			10.84					
prob>F			0.00					
Industry average propensity to view standards as being important to innovation	GP1			1.809***				
				(0.68)				
	GP2			0.07				
				(1.08)				
F statistic				6.26				
prob>F				0.01				

Table 3.9 (continued): The mean or average number of knowledge-protection mechanisms in high-technology/knowledge-intensive industries and low-technology/less knowledge-intensive industries – Tobit model

		Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Ind. av. propensity to view publications as being important to innovation	GP1				2.874***			
					(1.09)			
	GP2				-0.89			
					(1.51)			
F statistic					7.76			
prob>F					0.01			
Ind. av. propensity to view formal protection as important	GP1					1.165***		
						(0.15)		
	GP2					1.015***		
						(0.18)		
F statistic						2.59		
prob>F						0.11		
Ind. av. propensity to view informal protection as important	GP1						1.225***	
							(0.15)	
	GP2						1.073***	
							(0.19)	
F statistic							2.86	
prob>F							0.09	
Ind. av. propensity to adopt new formal protection	GP1							1.710***
								(0.23)
	GP2							0.946***
								(0.26)
F statistic								11.74
prob>F								0.00
Constant		-0.06	0.13	0.261***	0.298***	0.03	-0.05	0.170**
		(0.08)	(0.08)	(0.08)	(0.08)	(0.07)	(0.08)	(0.07)
N		99.00	99.00	99.00	99.00	99.00	99.00	99.00
Chi-squared		141.15	114.71	100.97	96.10	137.87	140.88	129.74
p		0.00	0.00	0.00	0.00	0.00	0.00	0.00
R-squared (pseudo)		2.07	1.68	1.48	1.41	2.02	2.06	1.90
bic		-31.47	-5.03	8.70	13.57	-28.20	-31.21	-20.06

Notes: See Table 3.2
Coefficients are reported with standard errors in parentheses. * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
GP1=High-technology/knowledge-intensive firms
GP2=Low-technology/less knowledge-intensive firms
Source: UK CIS 2002 to 2010 and BSD 1997 to 2008.

Table 3.10: The variance or variability of knowledge-protection mechanisms in high-technology/knowledge-intensive industries and low-technology/less knowledge-intensive industries – Tobit model

		Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Ind. cooperation on any innovation activity		0.643**	0.595*	0.876***	0.825*	0.803***	0.833***	0.40
		(0.30)	(0.33)	(0.33)	(0.42)	(0.30)	(0.29)	(0.33)
Ind. extent of internationalisation		0.473***	0.765***	0.898***	0.944***	0.454***	0.350**	0.680***
		(0.16)	(0.14)	(0.14)	(0.14)	(0.17)	(0.17)	(0.14)
Av. firm employment within industry		-0.000*	-0.000*	0.00	0.00	0.00	0.00	0.00
		0.00	0.00	0.00	0.00	0.00	0.00	0.00
Industry birth rate		-0.65	-1.03	-1.551*	-1.516*	-1.372*	-0.82	-1.297*
		(0.77)	(0.82)	(0.83)	(0.86)	(0.76)	(0.75)	(0.77)
Industry five-firm concentration ratio		0.16	0.19	0.47	0.53	0.07	0.08	0.38
		(0.33)	(0.36)	(0.36)	(0.37)	(0.34)	(0.33)	(0.34)
Industry average propensity to be a product innovator	GP1	3.411***						
		(0.61)						
	GP2	3.111***						
		(0.76)						
F statistic		0.64						
prob>F		0.42						
Industry average propensity to be a process innovator	GP1		3.323***					
			(0.84)					
	GP2		1.992**					
			(0.95)					
F statistic			5.01					
prob>F			0.03					
Industry average propensity to view standards as being important to innovation	GP1			3.26				
				(1.97)				
	GP2			-1.21				
				(3.12)				
F statistic				4.97				
prob>F				0.03				

Table 3.10 (continued): The variance or variability of knowledge-protection mechanisms in high-technology/knowledge-intensive industries and low-technology/less knowledge-intensive industries – Tobit model

		Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Ind. av. propensity to view publications as being important to innovation	GP1				3.43			
					(3.16)			
	GP2				-4.02			
					(4.37)			
F statistic					3.61			
prob>F					0.06			
Ind. av. propensity to view formal protection as important	GP1					2.479***		
						(0.47)		
	GP2					2.214***		
						(0.59)		
F statistic						0.79		
prob>F						0.38		
Ind. av. propensity to view informal protection as important	GP1						2.761***	
							(0.48)	
	GP2						2.519***	
							(0.59)	
F statistic							0.71	
prob>F							0.40	
Ind. av. propensity to adopt new formal protection	GP1							3.697***
								(0.72)
	GP2							2.510***
								(0.82)
F statistic								2.92
prob>F								0.09
Constant		-0.08	0.38	0.737***	0.789***	0.16	-0.04	0.437**
		(0.26)	(0.24)	(0.24)	(0.22)	(0.23)	(0.25)	(0.20)
N		99.00	99.00	99.00	99.00	99.00	99.00	99.00
Chi-squared		103.75	91.31	83.83	78.24	100.80	105.42	97.98
p		0.00	0.00	0.00	0.00	0.00	0.00	0.00
R-squared (pseudo)		0.40	0.35	0.32	0.30	0.39	0.41	0.38
bic		196.44	208.87	216.36	221.95	199.39	194.77	202.21

Notes: See Table 3.2
Coefficients are reported with standard errors in parentheses. * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
GP1=High-technology/knowledge-intensive firms
GP2=Low-technology/less knowledge-intensive firms
Source: UK CIS 2002 to 2010 and BSD 1997 to 2008.

Table 3.11: The mean or average number of knowledge-protection mechanisms in high-technology/knowledge-intensive industries and low-technology/less knowledge-intensive industries – OLS model

		Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Ind. cooperation on any innovation activity		0.257***	0.245**	0.364***	0.24	0.329***	0.347***	0.13
		(0.10)	(0.11)	(0.12)	(0.15)	(0.10)	(0.09)	(0.11)
Ind. extent of internationalisation		0.154***	0.283***	0.332***	0.354***	0.137**	0.107*	0.250***
		(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)
Av. firm employment within industry		-0.000**	-0.000**	-0.000*	0.00	-0.000**	0.00	0.00
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Industry birth rate		-0.13	-0.30	-0.517*	-0.554*	-0.444*	-0.21	-0.432*
		(0.25)	(0.28)	(0.30)	(0.31)	(0.25)	(0.25)	(0.26)
Industry five-firm concentration ratio		0.08	0.10	0.22	0.22	0.04	0.06	0.17
		(0.11)	(0.12)	(0.13)	(0.13)	(0.11)	(0.11)	(0.11)
Industry average propensity to be a product innovator	GP1	1.530***						
		(0.20)						
	GP2	1.314***						
		(0.25)						
F statistic		3.19						
prob>F		0.08						
Industry average propensity to be a process innovator	GP1		1.475***					
			(0.29)					
	GP2		0.814**					
			(0.33)					
F statistic			10.27					
prob>F			0.00					
Industry average propensity to view standards as being important to innovation	GP1			1.802**				
				(0.70)				
	GP2			0.05				
				(1.12)				
F statistic				5.98				
prob>F				0.02				

Table 3.11 (continued): The mean or average number of knowledge-protection mechanisms in high-technology/knowledge-intensive industries and low-technology/less knowledge-intensive industries – OLS model

		Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Ind. av. propensity to view publications as being important to innovation	GP1				2.869**			
					(1.13)			
	GP2				-0.92			
					(1.56)			
F statistic					7.36			
prob>F					0.01			
Ind. av. propensity to view formal protection as important	GP1					1.150***		
						(0.15)		
	GP2					0.995***		
						(0.19)		
F statistic						2.61		
prob>F						0.11		
Ind. av. propensity to view informal protection as important	GP1						1.208***	
							(0.16)	
	GP2						1.050***	
							(0.19)	
F statistic							2.88	
prob>F							0.09	
Ind. av. propensity to adopt new formal protection	GP1							1.694***
								(0.24)
	GP2							0.927***
								(0.27)
F statistic								11.08
prob>F								0.00
Constant		-0.06	0.14	0.260***	0.296***	0.03	-0.04	0.169**
		(0.08)	(0.08)	(0.09)	(0.08)	(0.07)	(0.08)	(0.07)
N		99.00	99.00	99.00	99.00	99.00	99.00	99.00
p		0.00	0.00	0.00	0.00	0.00	0.00	0.00
bic		-41.64	-15.05	-1.61	3.39	-38.07	-40.95	-30.05

Notes: See Table 3.2
Coefficients are reported with standard errors in parentheses. * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
GP1=High-technology/knowledge-intensive firms
GP2=Low-technology/less knowledge-intensive firms
Source: UK CIS 2002 to 2010 and BSD 1997 to 2008.

Table 3.12: The variance or variability of knowledge-protection mechanisms in high-technology/knowledge-intensive industries and low-technology/less knowledge-intensive industries – OLS model

		Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Ind. cooperation on any innovation activity		0.639**	0.594*	0.869**	0.819*	0.798**	0.827***	0.40
		(0.31)	(0.34)	(0.34)	(0.43)	(0.31)	(0.30)	(0.34)
Ind. extent of internationalisation		0.490***	0.777***	0.906***	0.952***	0.476***	0.375**	0.695***
		(0.16)	(0.15)	(0.15)	(0.14)	(0.17)	(0.17)	(0.14)
Av. firm employment within industry		-0.000*	0.00	0.00	0.00	0.00	0.00	0.00
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Industry birth rate		-0.64	-1.02	-1.535*	-1.499*	-1.354*	-0.81	-1.28
		(0.79)	(0.84)	(0.86)	(0.89)	(0.79)	(0.78)	(0.80)
Industry five-firm concentration ratio		0.17	0.20	0.47	0.53	0.09	0.10	0.38
		(0.34)	(0.37)	(0.38)	(0.39)	(0.35)	(0.34)	(0.35)
Industry average propensity to be a product innovator	GP1	3.359***						
		(0.63)						
	GP2	3.038***						
		(0.79)						
F statistic		0.69						
prob>F		0.41						
Industry average propensity to be a process innovator	GP1		3.266***					
			(0.87)					
	GP2		1.921*					
			(0.98)					
F statistic			4.78					
prob>F			0.03					
Industry average propensity to view standards as being important to innovation	GP1			3.24				
				(2.03)				
	GP2			-1.29				
				(3.22)				
F statistic				4.78				
prob>F				0.03				

Table 3.12 (continued): The variance or variability of knowledge-protection mechanisms in high-technology/knowledge-intensive industries and low-technology/less knowledge-intensive industries – OLS model

		Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Ind. av. propensity to view publications as being important to innovation	GP1				3.41			
					(3.26)			
	GP2				-4.11			
					(4.52)			
F statistic					3.45			
prob>F					0.07			
Ind. av. propensity to view formal protection as important	GP1					2.428***		
						(0.49)		
	GP2					2.144***		
						(0.61)		
F statistic						0.85		
prob>F						0.36		
Ind. av. propensity to view informal protection as important	GP1						2.700***	
							(0.49)	
	GP2						2.439***	
							(0.61)	
F statistic							0.78	
prob>F							0.38	
Ind. av. propensity to adopt new formal protection	GP1							3.642***
								(0.74)
	GP2							2.444***
								(0.85)
F statistic								2.79
prob>F								0.10
Constant		-0.07	0.38	0.734***	0.784***	0.17	-0.03	0.436**
		(0.26)	(0.25)	(0.25)	(0.23)	(0.24)	(0.25)	(0.21)
N		99.00	99.00	99.00	99.00	99.00	99.00	99.00
p		0.00	0.00	0.00	0.00	0.00	0.00	0.00
bic		188.95	201.32	208.43	214.17	192.08	187.59	194.81

Notes: See Table 3.2
Coefficients are reported with standard errors in parentheses. * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
GP1=High-technology/knowledge-intensive firms
GP2=Low-technology/less knowledge-intensive firms
Source: UK CIS 2002 to 2010 and BSD 1997 to 2008.

Chapter 4

Formal versus informal knowledge protection: which matters most for innovation returns?

4.1 Introduction

The success of organisations and businesses, in the form of growth or performance, often derives from innovation. Successful firm innovation, or the completeness of the development and exploitation of new knowledge (Roper et al., 2008), yields considerable benefits for the innovating firm: higher profits, increased market value, improved credit ratings and a higher chance of survival (Geroski et al., 1993; Hall, 2000; Czarnitzki and Kraft, 2004; Cefis and Marsili, 2005). Previous empirical work finds a positive relationship between innovation and firm performance; some studies find a positive relationship between innovation and productivity (for example, Hall et al., 2009), while others find a positive relationship between innovation and growth (for example, Freel and Robson, 2004).

In practice, however, not all innovating firms are able to successfully exploit their knowledge, increasing profits and improving performance. Outcomes depend upon the extent to which a firm is able to capture profits generated by its innovation (Teece, 1986; Levin et al., 1987). When an innovating firm is unable to limit other firms from imitating its innovations, the appropriability problem (Arrow, 1962) arises.[12] Consequently, a firm may fail to appropriate returns from its own innovations (Ceccagnoli and Rothaermel, 2008) and be unable to gain and sustain a competitive advantage (Laursen et al., 2013).

Before a firm invests in innovation, it has an expectation of post-innovation returns (Du et al., 2007); the incentive to innovate itself comes from this expectation

[12] The innovating firm may earn only a portion of the overall social benefits of the innovation. The social benefits of an innovation include the private benefits received by the firm that developed the innovation and the value of all positive externalities resulting from the innovation i.e. beneficial spillovers to a third party, or parties of the new idea or product; new innovations often lead to other creative endeavours that society also values.

(Laursen and Salter, 2005). To overcome the appropriability problem, firms use knowledge-protection mechanisms – both formal and informal – to capture returns to innovation (Laursen and Salter, 2005; Greenhalgh and Rogers, 2007). Formal knowledge-protection mechanisms are implemented through regulation and are effective by legally excluding imitators, examples include patents and trademarks (Hall, 1992). Informal protection mechanisms are not based upon structures and statutory enforcement possibilities, examples include secrecy and lead-time (Hurmelinna-Laukkanen, 2014). The knowledge-protection mechanisms allow innovators to appropriate returns by making their innovative knowledge (a non-rival good) excludable. Therefore the knowledge-protection mechanisms that are effective and available to the firm provide it with an incentive to invest in innovation activities (Granstrand, 1999).

The present study acknowledges that a firm is able to formulate a knowledge-protection strategy in order to help capture returns from its innovations and that strategies for protecting knowledge have become a central part of the development of a firm's innovative strategy (Rivette and Kline, 2000). The study examines both formal and informal knowledge-protection strategies and seeks to ascertain which knowledge-protection strategy – formal or informal – allows firms to most successfully derive economic benefit from an innovation; the study is concerned with a firm's *returns to innovation* rather than its decision to innovate or not.

By combining features of previous research in this area (Laursen and Salter, 2005; Laursen et al., 2013; Hall and Sena, 2017), this firm-level study examines how both formal and informal knowledge-protection strategies affect firms' innovation returns and seeks to explore how these effects differ across sectors, firm size and innovator type. This study builds upon the existing knowledge-protection literature by using the United Kingdom's Community Innovation Survey data on the *actual use* of formal and informal knowledge-protection mechanisms to investigate the effects of knowledge protection use on a firm's returns to innovation. Previous studies (Laursen and Salter, 2005; Laursen et al., 2013; Hall and Sena, 2017) use data on how firms rate the *importance* of various knowledge-protection mechanisms – data more prone to subjectivity bias (Veulegers and Schneider, 2018). Laursen et al. (2013) focus on manufacturing firms and their orientation towards formal knowledge-protection mechanisms. Hall and Sena (2017) place emphasis on both formal and informal knowledge-protection mechanisms and examine the extent to which this emphasis is correlated with the type of innovation being carried out. Following this, they investigate the relationship between firm productivity and innovation type, conditional on the firm's chosen knowledge-protection mechanisms. The present study builds upon this literature by examining both formal and informal knowledge-protection strategies and their impact upon a firm's returns to innovation in terms of the proportion of firm sales coming from innovation. The analysis is extended by exploring the effects of formal and informal knowledge-protection strategies on the returns to innovation in firms of different sizes, firms with different technologies, firms in different sectors and firms innovating with different degrees of novelty. Following this, those firms undertaking innovation which is new to the marketplace are further explored. The effects of formal and informal knowledge-protection strategies on the returns to innovation in firms of different sizes, firms with different technologies and firms in different sectors within this sub-group of innovators are examined.

The remainder of this chapter is structured as follows. Section 4.2 introduces the concepts of innovation, appropriability and knowledge protection, Section 4.3 discusses firms' knowledge-protection choices and innovation returns, Section 4.4 profiles the data and empirical methodology used in the study, Section 4.5 contains the empirical results and Section 4.6 includes discussion and conclusions.

4.2 Innovation, appropriability and knowledge protection

4.2.1 Innovation

Innovation is essential to the competitive performance of firms and the growth of economies (Granstrand, 1999). It represents the beginning of a process of value creation (Roper et al., 2008) from which a competitive advantage emerges (Porter, 1985). Implementing a value-creating innovation strategy, not being simultaneously implemented by any current or potential competitor (Barney, 1991), helps a firm to gain a competitive advantage and achieve a superior performance relative to other competitors within the same industry group or relative to the industry average.

Those firms more able to mobilise knowledge and technological skills and use their experience to create new products, services and processes gain a competitive advantage over others.

Innovation can be radical or incremental; it can be in products, processes, or services and it can happen in any organisation and at all organisation levels. A radical innovation has a significant impact upon a market and upon the economic activity of firms within that market. The innovation may lead to a change in the structure of the market, create new markets or displace existing products. Incremental innovation is the improvement of an existing product, process or service i.e. it is 'doing better what is already being done' (Tidd et al., 1997). Radical innovations create major, disruptive changes, whereas incremental innovations continuously advance the process of change (Schumpeter, 1942).

Innovative firms are those that create new or improved products or processes, those that develop new methods of commercialisation and those that formulate new models of organisation (Diamond, 1997). An innovating firm's introduction of a new product, process or service represents the end of a process of knowledge sourcing (for example, research and development – R&D – activities) and transformation (i.e. turning knowledge into an innovation) and the beginning of a process of exploitation by the firm in an attempt to improve performance and generate value added (Roper et al., 2008). Combined, this recursive process of knowledge sourcing, transformation and exploitation by the innovating firm is what has become known as the *innovation value chain* (Roper et al., 2008).

4.2.1.1 Innovation value chain

The first stage of the innovation value chain is a firm's knowledge-sourcing activities. From previous research, Roper et al. (2008) identify five different types of knowledge-sourcing activity that firms engage in: intramural R&D (Shelanski and Klein, 1995), customer linkages (Joshi and Sharma, 2004), supplier and external-consultant linkages (Horn, 2005), competitor and joint-venture linkages (Link et al., 2005) and university/public-research-centre linkages (Roper et al., 2004). In practice, knowledge-sourcing activities do not occur in isolation – some complement each other, others are substitutes for one another. In accordance with the resource-based view, a firm's choice of knowledge-sourcing activity may depend upon firm-specific factors, for example, existing knowledge resources and knowledge utilisation capabilities.

The second stage of the innovation value chain – the stage with which the present study is concerned – involves the transformation of knowledge sourced during stage one into innovation outputs (Roper et al., 2008). This transformation depends upon firm characteristics as well as firm resources and capabilities (Griliches, 1992; Love and Roper, 1999). The type of knowledge sourced during stage one of the innovation value chain may have different transformation effects in terms of product-innovation and process-innovation outputs. The transmission process through which sourced knowledge impacts a firm's innovation activity – and in turn the returns to innovation – depends upon the type of knowledge sourced, and different knowledge types may affect different features of a firm's innovation activity (Roper et al., 2008).

The third stage of the innovation value chain is knowledge exploitation. Knowledge is exploited when a firm's innovation output positively influences its performance (Geroski et al., 1993). After a firm sources knowledge and transforms it into innovation outputs, the new products and processes are presented to the market with the ultimate aim of increasing firm performance (in terms of growth or productivity, for example). However, whether or not a firm is able to successfully exploit its knowledge and improve performance depends upon its ability to appropriate innovation returns.

4.2.2 Appropriability

The third stage of the innovation value chain, knowledge exploitation, is when new products and processes in the marketplace lead to an increase in firm growth and performance. Although evidence exists supporting the link between innovation and performance (Freel and Robson, 2004; Hall et al., 2009), the successful exploitation of knowledge, in terms of higher profits or performance is not guaranteed – it depends upon firm attributes and market conditions (Roper et al., 2008) and the extent to which a firm can capture profits generated by an innovation (Teece, 1986; Levin et al., 1987) i.e. appropriability.

4.2.2.1 The appropriability problem

The appropriability problem (Arrow, 1962) – the feature of innovative activity which distinguishes it from other strategic investments made by firms (Geroski, 1995) – arises when firms are unable to limit other firms from imitating their innovations. Consequently, firms may fail to appropriate returns from their own innovations (Ceccagnoli and Rothaermel, 2008).

Innovating firms are faced with a risk of imitation by both existing competitors and new competitors attracted into the market by the existence of high returns (Hurmelinna-Laukkanen, 2009). It is possible that a fast second entrant into the market or even a slow third can outperform the innovator (Teece, 2012). A firm therefore faces a key strategic challenge: it somehow needs to protect returns from its innovations. A firm’s ability to do so determines its performance and continued survival (Ceccagnoli and Rothaermel, 2008).

When an innovating firm is faced with imitation, its competitive advantage may be eroded. Without an expectation of profiting from an innovation and a monopolistic power over an innovation, firms will be discouraged from investing in innovative activities – there will be no incentive to innovate (Schumpeter, 1942). It is the expectation of success which encourages firms to allocate time and money towards innovation. In the extreme case of perfect competition, the rate of innovation amongst firms is low; no firm has market power, there is no product differentiation and all firms have immediate and perfect access to the same technologies (Lopez, 2009).

The semi-public good characteristics of knowledge (exclusion is rarely perfect) leads to the appropriability problem (Arrow, 1962). The appropriability of the returns from new knowledge is always incomplete, and the resulting externalities create a difference between the private and the social marginal return from new knowledge. Unless innovators are able to address this problem by protecting the knowledge which they create, competitors will be able to imitate their innovations at a much lower cost than the innovator themselves – imitators will not incur the high fixed costs associated with the first stage of the innovation value chain when knowledge is sourced (Section 4.2.1.1 above).

In order to address the problem of imitation risk, innovators require an understanding of appropriability. Teece (1986) identifies two essential components of appropriability – the appropriability regime and specialised complimentary assets. The appropriability regime determines the barriers to imitation which exist within an industry and the ease with which competitors are able to imitate an innovation (Ceccagnoli and Rothaermel, 2008); it encompasses the means of protecting both the innovation itself and the increased rents which flow from it (Cohen et al., 2000). The most important dimensions of the appropriability regime are the nature of the technology involved (whether it is a product or process technology or whether technological knowledge is tacit or codified, for example), and the means of intellectual property (IP) protection which are effective and available to the firm for use (for example, patents and trademarks) (Teece, 1986). An appropriability regime is 'weak' when innovations are difficult to protect i.e. when they can be easily codified and legal protection of IP is ineffective, or 'strong' when innovations are easy to protect because knowledge about them is tacit and/or they are well protected legally.

Specialised complementary assets – the second component of appropriability – may be acquired by firms in order to strengthen appropriability conditions (Gans and Stern, 2003). When faced with a weak appropriability regime, firms are unable to use legal protection mechanisms to protect their innovations and any returns which flow from them. Acquiring complimentary assets (for example, competitive manufacturing, distribution channels and complementary technologies), may allow a firm to profit from an innovation, whether it be the innovating firm itself capturing returns or an imitating firm profiting from an innovation at the expense of the innovator.

In order to appropriate returns, it is important for the innovating firm to understand the strength of the industry appropriability regime it faces and the nature of any specialised complementary assets that are required to take the innovation to the marketplace. In reality, some innovating firms fail to appropriate returns, for example, Electrical Musical Instruments (EMI), innovator of the Computerised Axial Tomography (CAT) scanner, lost to the imitator, GE Medical systems (Ceccagnoli and Rothaermel, 2008). Through reverse engineering, the codified nature of the

CAT scanner was identified and imitated. Patents were not enforced and the resulting weak appropriability regime, combined with EMI's lack of specialised complementary assets, meant that EMI lost out to GE Medical systems.

4.2.3 Knowledge protection

A firm's decision to invest in innovation depends upon the expected post-innovation returns (Du et al., 2007), and without the possibility of capturing the benefits of their innovative efforts, there would be little incentive for firms to innovate (Laursen and Salter, 2005). The ability to appropriate or capture the benefits of an innovation is a central element in gaining and sustaining competitive advantage (Laursen and Salter, 2005). Knowledge-protection mechanisms – one component of the appropriability regime – are used by firms as a strategic tool to capture the private benefits or returns to innovation (Laursen and Salter, 2005; Greenhalgh and Rogers, 2007). Such mechanisms encourage innovation (Guellec, 2007) by providing an incentive for firms to invest in innovation activities – they increase appropriability, reduce competition and act as an incentive for future innovations (Granstrand, 1999).

Knowledge-protection mechanisms allow innovators to appropriate returns by making their innovative knowledge – a non-rival good – excludable. Unfortunately, introducing an element of excludability also introduces an inefficiency as the innovator, now a monopolist as a result of the knowledge protection, drives the price of the innovative good above the marginal cost of its production (Greenhalgh and Rogers, 2007). Output becomes restricted in order to increase price, and the customer loses. By encouraging innovation, the knowledge-protection mechanisms may benefit society but they also introduce the consequences of a temporary monopoly – a trade-off formally analysed by Nordhaus (1969).

Product and process innovators benefit from knowledge protection in different ways (Greenhalgh and Rogers, 2007). After protecting its knowledge, the process innovator is able to reduce its costs of production. If prices are kept constant, the firm enjoys higher returns. If the firm chooses to reduce prices, it displaces competitors and increases its market share. After implementing knowledge protection, product innovators are able to earn higher returns due to an increase in market share and by charging relatively higher prices. Both process and product innovators benefit from knowledge protection because they are able to steal returns from competitors – something known as 'a business stealing effect' (Greenhalgh and Rogers, 2007).

Firms may use a variety of knowledge-protection mechanisms – ranging from patents to trade secrets – to protect any returns from innovation from being eroded by imitation. The particular combination of knowledge-protection mechanisms chosen by a firm becomes part of its appropriability strategy (Cohen et al., 2000). The chosen knowledge-protection mechanisms are therefore also a central component of a firm's innovation strategy (Rivette and Kline, 2000); they represent investment into a firm's innovation.

Firms choose between formal (statutory) and informal (non-statutory) knowledge-protection mechanisms to protect their innovations and aid the appropriation of returns. Formal protection mechanisms are legally enforceable protection mechanisms and typically include registered rights such as patents, design rights and trademarks and unregistered rights such as copyright, whereas informal protection mechanisms are not based directly on regulated structures and statutory enforcement possibilities (Hurmelinna-Laukkanen, 2014); they include secrecy, complexity of design and lead-time on competitors. Formal protection mechanisms are an official means of protection provided by society to innovators (Hurmelinna-Laukkanen and Puumalainen, 2007a), whereas informal mechanisms, although not based directly upon statutory enforcement possibilities, may have associated legal contracts alongside them; a firm using secrecy may require employees to sign non-disclosure agreements, for example.

Formal protection mechanisms address the appropriability problem by allowing an innovator to legally exclude imitators. Acquiring such mechanisms is often viewed by firms as a costly exercise – some mechanisms being more costly to obtain than others. Obtaining formal protection can be a slow, time-consuming and costly process, deterring firms from its use. In addition, formal protection often requires firms to disclose technologies; it forces firms to codify the knowledge they source and use in the creation of their innovations. This codification may itself lead to imitation and result in competitors inventing around innovations.

The disclosure of knowledge when formally protecting innovations may lead to positive as well as negative effects. Disclosure allows other firms to avoid duplicating research (Hall et al., 2014), and any knowledge spillovers among firms and sectors – as illustrated by endogenous growth theories – will be important for sustained long-run growth (Romer, 1990). Technology spillovers may generate social benefits for the industry as a whole (Greenhalgh and Rogers, 2007) – over time, many firms may contribute, through the disclosure of knowledge in a patent, towards a new technology. In addition, the disclosure of knowledge in the form of licensing and 'patent pools' – where firms share technologies – may help raise revenues and reduce costs. Such activity helps reduce reverse engineering by imitators and rivals' efforts to 'invent around' an existing patent (Baumol, 2002).

In the same vein, informal knowledge protection is invisible or only partially visible to competing firms. Such protection, in the form of secrecy for example, reduces knowledge spillovers and may in turn restrict economic growth (Hall et. al., 2014).

The use of formal protection mechanisms by firms may also act as a signal of quality – it can signal a firm's expertise. Firms formally protecting knowledge may appear more attractive, thus leading to added benefits, for example, firms may be able to more easily raise finance or attract talented employees. In some cases, the sole aim of firms obtaining formal protection is to experience such effects, rather than to aid the appropriation of innovation returns (Greenhalgh and Rogers, 2007). In their study, Cohen et al. (2000) find evidence that United States (US) firms use protection mechanisms for such strategic reasons – for example, to block competitors and to improve reputation – as well as to appropriate returns. Blind et al. (2006) also find evidence of German firms using patents to block competitors and improve firm image.

4.2.3.1 The choice between informal and formal knowledge protection

The theoretical literature surrounding a firm's knowledge-protection strategy typically regards the use of formal and informal mechanisms as mutually exclusive choices (Friedman et al., 1991). The effects of two mechanisms – one formal (patents) and one informal (secrecy) – are often compared and contrasted. The trade-off between using patents as a protection mechanism, in terms of the associated benefits and costs, are compared with those associated with the use of secrecy. Patents and secrecy are considered to be substitutes for one another with one mechanism ruling out the use of the other – the former requires the disclosure of firm knowledge whereas the latter relies upon non-disclosure. It is for this reason that the two mechanisms become the focus of much theoretical literature. The benefits and costs associated with each mechanism are a function of the innovation to be protected and the innovating firm's defensive strategy in relation to competitors' behaviour; the value of the knowledge-protection mechanism lies in its ability to affect the behaviour of competitors (Hall et al., 2014).

In practice, patents are an unsuitable protection mechanism for some innovations (for example, computer software is not patentable according to the European Patent Office) (Hall et al., 2014). The strength of protection offered by patents differs across industries (Veulegers and Schneider, 2018): patent use is particularly high in industries with discrete technologies, for example pharmaceuticals, where knowledge is well codified (Hall et al., 2014) – the extent to which a firm codifies its knowledge helps determine the effective protection mechanisms available to a firm (Hurmelinna-Laukkanen and Puumalainen, 2007a). The use of secrecy as a protection mechanism is far less restricted. It can be used to protect knowledge at different stages of the innovation value chain rather than at a particular stage of development as is the case with patents. Patents and secrecy also differ with respect to the length of time that knowledge is protected for when each mechanism is used; secrecy provides (potentially) indefinite protection, whereas the protection provided by patents is limited to twenty years (Hall et al., 2014).

The overall strength of protection implemented by a firm is determined by its business strategy and its resources and capabilities. Firms are able to establish relatively strong appropriability conditions by utilising the knowledge-protection mechanisms available to them – whether or not their environment supports enforceable, formal protection mechanisms (Hurmelinna-Laukkanen and Puumalainen, 2007a).

Empirical evidence shows informal mechanisms to be more widely used than formal mechanisms (Hall et. al., 2014; Freel and Robson, 2017). Much of the survey-based evidence suggests that firms rely heavily on informal mechanisms such as lead time and secrecy. Arundel (2001) examines Community Innovation Survey (CIS) data from seven different countries. Results indicate that more than 50 per cent of firms view lead time as the most important protection mechanism and 17 per cent regard secrecy as the most important. The proportion of firms regarding patents and registered designs as most important is much lower – 10 per cent and 7 per cent respectively.

4.3 Knowledge-protection choices and returns to innovation

The discussion in Section 4.2 above suggests that firms which implement knowledge-protection strategies, i.e. use formal and informal knowledge-protection mechanisms, are more likely to capture the returns from their innovations (appropriate the returns). Firms' knowledge-protection strategies are therefore an important source of heterogeneity in firm performance (Teece, 2000b).

Using survey analysis, Levin et al. (1987) and Cohen et al. (2000) were amongst the first to report that firms generally prefer informal knowledge-protection mechanisms to formal mechanisms to aid appropriability of their innovations. Other studies, for example, Arundel (2001) and Laursen and Salter (2005), also find that informal mechanisms are preferred to formal mechanisms. Existing literature on the *performance effects* of a firm's choice of knowledge-protection mechanisms is limited. Some studies focus on the relationship between firms' preferences for different knowledge-protection mechanisms and financial or innovation performance. Hanel (2008) uses a two-stage model to examine the relationship between profits in Canadian manufacturing firms and their knowledge-protection choices. Initially, the propensity to use knowledge-protection mechanisms within innovative firms is calculated. The impact of this propensity on firm profits is then determined. Results indicate that firms that use formal knowledge-protection mechanisms experience either unchanged or higher profit levels. Hussinger (2006) finds a strong positive correlation between patents and sales of new products in German manufacturing firms, although no such correlation is found for secrecy. Hall et al. (2013) find that patent use is positively linked with turnover from innovation but unrelated to other performance measures. The authors suggest that this is because patents are more likely to be used to protect product innovations which directly affect sales, whereas informal protection mechanisms, such as secrecy for example, are more likely to be used to protect process and early-stage innovations.

Three further studies which examine the performance effects of firms' knowledge-protection choices are Hall and Sena (2017), Laursen and Salter (2005) and Laursen et al. (2013). Using data from the Business Structure Database and the United Kingdom (UK) CIS, Hall and Sena (2017) examine the relationship between firm performance and innovation conditional on the firm's chosen knowledge-protection mechanisms. They find that formal knowledge protection has a positive effect on productivity (10 to 20 per cent higher); informal mechanisms do not have the same impact. It is suggested that the firms that experience increased productivity when using formal protection mechanisms are firms that develop high-quality innovations. The increase in productivity may therefore be due to the higher quality innovations rather than the use of formal mechanisms themselves.

Laursen and Salter (2005) use UK CIS data to investigate the relationship between the strength of formal and informal knowledge-protection strategies and innovative performance in manufacturing firms. They find that formal and informal protection mechanisms help innovative performance, but an overemphasis on strength eventually becomes detrimental for innovative performance. In addition, they find that strategies which focus on both formal and informal protection mechanisms are incompatible; formal mechanisms tend to require firms to disclose knowledge whereas informal mechanisms require secrecy. Their results suggest that firms are required to make a choice between different paths of knowledge protection. In a later version of this study (Laursen et al., 2013), the authors define some of their independent variables differently and use a different estimation method. The focus is on formal knowledge-protection mechanisms only, although they do include a variable reflecting the relative weight a firm attaches to informal protection. Results indicate that a stronger formal knowledge-protection strategy leads to an increase in innovative performance up to a maximum point, following which innovative performance declines. However, Laursen et al. (2013) find that this maximum occurs when the strength of formal knowledge protection is outside its range of values.

The discussion in Section 4.2 above suggests that a firm's use of formal and informal knowledge-protection mechanisms is beneficial to innovation returns. The empirical studies discussed here highlight the importance of formal knowledge-protection mechanisms to firm performance; informal knowledge-protection mechanisms are found to be less important – although many of the studies discussed above examine product innovation for which formal protection mechanisms have proved to be more effective (Levin et al., 1987; Harabi, 1995). Taking all of this evidence into account, the importance of a firm's formal and informal knowledge-protection strategy to its innovation returns is clear, and this leads to the first hypothesis that:

Hypothesis 1: A firm's formal and informal knowledge-protection strategies are positively related to its innovation returns.

However, questions remain around the factors which govern firms' choices of informal or formal knowledge-protection strategies and around which strategy is most effective in boosting innovation returns.

4.3.1 Factors affecting firms' knowledge-protection choices

Previous research suggests that a firm's use of formal and informal knowledge-protection mechanisms differs across **sectors and industries** (due to the presence of tacit or codified knowledge, product and process technologies and the industry appropriability regime, for example) (Levin et al., 1987; Cohen et al., 2000), **firms** (due to resources and capabilities, for example) (Lopez, 2009; Hall et al., 2014) and **the novelty of the innovation** (Hanel, 2005).

iv. Industry/technology characteristics

Industry characteristics play an important part in determining whether firms use formal or informal protection methods to protect innovations. Levin et al. (1987) – the Yale I survey – and Cohen et al. (2000) – the Carnegie Mellon survey – examine the extent to which firms in different industries choose formal and informal knowledge-protection methods to appropriate returns. Both studies report broadly consistent findings. For both product and process innovations, secrecy and lead time are viewed as important knowledge-protection mechanisms; a high percentage of firms are found to rely on informal mechanisms in their knowledge-protection strategies. With the exception of the pharmaceutical and chemical industries, patents are found to be much less important. However, patents are identified as being more important for product innovations than for process innovations. One reason for this is that a patented process could easily be invented around once knowledge is disclosed. This is supported by Harabi (1995), who in a study of Swiss firms finds the same result. In this study, firms express concern regarding the disclosure of knowledge because it allows competitors an opportunity to invent around their innovations. Again, patents are identified as being most important to firms in the pharmaceutical, chemical and machinery industries. As in Levin et al. (1987), lead time is found to be the protection mechanism most important for firms' appropriation. Results show that secrecy is also important, more so for process innovations; processes can be effectively retained within the firm and protected with trade secrets. In a survey of one hundred manufacturing firms, Mansfield (1986) finds that in both the pharmaceutical and chemical industries, patent protection is necessary for at least 30 per cent of innovations. Several other industries (petroleum, machinery, and fabricated metals) report patents to be necessary for 10 to 20 per cent of innovations. The remaining industries do not rely on patent use.

Cohen et al. (2000) find that R&D intensive industries, for example pharmaceuticals, report a high effectiveness of almost every protection mechanism. The majority of other industries report a high effectiveness for two or more mechanisms and only a small number of industries report a high effectiveness of only one. Cohen et al. (2000) find that patents are used more often than secrecy in discrete product industries, whereas in complex-product industries it is easier to invent around technologies, and therefore firms rely less on patents and more on informal methods of protection such as lead-time. In their study of small Finnish manufacturing and service firms, Leiponen and Byma (2009) find that R&D intensive firms and science-based firms are more likely to protect knowledge formally. Other firms use speed to market or secrecy as protection methods.

Brouwer and Kleinknecht (1999) examine Dutch manufacturing firms and find that those in high-technology industries are more likely to patent than those in other industries. Their results are consistent with those of Levin et al. (1987) and Harabi (1995) who find patents to be most important within the chemical and pharmaceutical industries. Across all innovating firms, Levin et al. (1987) and Harabi (1995) find around half of firms report patents to be insignificant when protecting their knowledge – lead time and secrecy are reported to be more important.

Some technologies are easier to protect formally than others. For example, in the chemicals and pharmaceuticals sector, a patent is able to protect a specific compound (or a specific chemical formula); it is clear what the patent protects and few disputes arise (Bessen and Meurer, 2008). In other sectors, for example information technology, the range of patents is less precise. The probability of dispute is higher, and patent use is less popular (Hall et al., 2014).

Despite many of the studies discussed here finding that high-technology firms are more inclined to patent, Laursen et al. (2013) find little evidence that formal knowledge-protection mechanisms increase the innovative performance of high-technology industries. Instead, they find a strong inverted U-shaped relationship between formal knowledge-protection mechanisms and the innovative performance of low-technology industries. This suggests that low-technology environments provide firms with the scope to strategically use formal knowledge-protection mechanisms in order to gain from their innovative efforts.

Across industries, different knowledge-protection choices may be made due to evolving regulatory and legal regimes. Hurmelinna-Laukkanen and Puumalainen (2007a) find that some protection methods are difficult to implement in certain knowledge-intensive industries due to legal restrictions that are in place. Regulatory and legal distortions may also lead to the use of knowledge-protection mechanisms varying across industries. In their study, Grindley and Teece (1997) examine the use of licensing in the semiconductor and electronics industries. By forcing firms to license their technologies below market value, courts discourage firms in these industries from using formal knowledge-protection mechanisms. Once the distortions in formal protection regimes across industries are removed, firms recognise the value of formal knowledge protection and its importance to innovation returns.

The use of formal knowledge protection may be low in rapidly growing industries, for example information technology. Within such environments, formal protection mechanisms may inhibit the development of the market for ideas (Andrews and de Serres, 2012). Liebeskind and Oliver (1998) find that the use of formal protection mechanisms is low in technology-intensive industries with a high rate of new inventions. Firms in these industries view formal protection as being a slow and costly process and are thus deterred from using it to protect their knowledge.

Many of the studies discussed above identify R&D intensive and high-technology firms as being those which use formal methods of knowledge protection to protect their knowledge. Form this it follows that these firms perceive formal knowledge-protection mechanisms as those which are most effective at helping them to appropriate the returns from their innovations. Studies examining the performance effects of formal protection mechanisms in R&D intensive and high-technology firms are rather limited, but Laursen et al. (2013) find little evidence that formal knowledge-protection mechanisms increase their innovative performance. Given this conflicting evidence, it is hypothesised that:

Hypothesis 2a: *Formal/informal knowledge-protection strategies have a stronger positive effect upon the innovation returns of high-technology/knowledge-intensive firms than low-technology/less knowledge-intensive firms*

Hypothesis 2b: *Formal/informal knowledge-protection strategies have a weaker positive effect upon the innovation returns of high-technology/knowledge-intensive firms than low-technology/less knowledge-intensive firms*

Innovation in services is quite different from innovation in manufacturing, relying less on R&D and more on new information technology-based processes (Hall and Sena, 2017). Contrary to the view that service sector firms may gain no benefit from using formal knowledge-protection mechanisms, Hall and Sena (2017) find formal protection mechanisms to be more important than informal protection mechanisms for service sector productivity. Their results are ambiguous for the manufacturing sector as informal and formal knowledge protection has an equal effect on productivity, although the effect is negative. This negative effect is attributed to there being longer lags between innovative activity and productivity within the manufacturing sector.

Other studies which focus on services (Mairesse and Mohnen, 2004; Hipp and Herstatt, 2006) suggest that most service firms do not use any type of knowledge protection. Those service firms that do protect their knowledge tend to use formal trademarks and copyrights and informal mechanisms such as customer, supplier and employee lock-ins. Mairesse and Mohnen (2004) examine French firms' use of knowledge-protection mechanisms in the manufacturing and service industries. Innovative service firms are found to use protection mechanisms less often than high-tech manufacturing firms but more often than low-tech manufacturing firms. Hipp and Herstatt (2006) find that service-intensive German firms use long-term labour contracts to protect their knowledge. Secrecy, lead time and complexity are also identified as being important protection mechanisms, whereas only 6 per cent of service firms examined use formal protection mechanisms.

Blind et al. (2003) find that the propensity to patent and the number of patent applications is significantly lower in services compared with manufacturing; 7 per cent of service firms applied for patents compared with 25 per cent of firms in the manufacturing industry. Applying formal methods of protection to services is not straightforward (Blind et al., 2003; Maskus, 2008), for example, the tacit knowledge included in services is not eligible for patenting. It is the intangible nature of service innovations that determines the type of protection mechanisms which can be used successfully (Miles and Boden, 2000).

Baldwin et al. (1998) examine the use of knowledge-protection mechanisms in Canadian service industries (for example, communications and financial services) using innovation survey data from 1996. Less than half of innovators report using any of the knowledge-protection mechanisms available to them. Of those used, copyright and trademarks are the most popular – particularly in the financial services industry. Patents are used only by the technical business service industry. Lead time is identified as the most effective knowledge-protection mechanism by all service industries. Of the formal protection mechanisms available, trademarks are identified as being most effective.

Päällysaho and Kuusisto (2006) examine a sample of Finnish and UK firms in three knowledge-intensive service industries (advertising, business and management consultancy, and software consultancy and supply). Trademarks and copyright are the most popular formal knowledge-protection mechanisms whereas patents are rarely used. The most popular protection mechanism used by firms in these service industries is restrictive contracts (for example, non-disclosure agreements). Secrecy is also identified as being important in these industries.

In terms of the performance effects of formal and informal knowledge-protection mechanisms within the service sector, again, the evidence is limited. One study (Morikawa, 2014) examines Japanese service firms and suggests that service sector productivity is related to firms' use of informal knowledge-protection mechanisms.

Overall, there seems to be no consensus among the empirical studies examining the use of formal and informal knowledge-protection mechanisms within the services and manufacturing sectors. In addition to this, studies investigating the performance effects of formal and informal mechanisms within the services and manufacturing sectors are limited. The hypotheses here reflect this position:

Hypothesis 3a: *Formal/informal knowledge-protection strategies have a stronger positive effect upon the innovation returns of manufacturing-sector firms than service-sector firms*

Hypothesis 3b: *Formal/informal knowledge-protection strategies have a weaker positive effect upon the innovation returns of manufacturing-sector firms than service-sector firms*

v. Firm resources and capabilities

Although all knowledge protection represents a cost to the firm, formal protection mechanisms are often viewed by firms as a more expensive option than informal knowledge-protection mechanisms. Applying for a patent, for example, can be a costly process, and a firm will continue to incur costs whilst keeping a patent in force (Hall et al., 2014). Patent enforcement requires firms to actively monitor markets for potential infringement. If an infringement is detected, patent holders require financial resources to enable them to engage in litigation. Informal protection mechanisms, often viewed as the least expensive method of innovation protection, are not without their costs. For example, the use of secrecy by firms is often accompanied by confidentiality agreements (Hall et al., 2014).

As well as incurring costs when protecting innovations, firms face uncertainty when using both formal and informal protection mechanisms. In the case of patents for example, this uncertainty relates to whether a patent will be granted, whether it will be invalidated at a point thereafter, whether any infringements will occur and if so, whether they will be proven. A firm also faces uncertainty when using informal mechanisms, for example when a firm uses secrecy, it is uncertain as to whether the secret will be maintained and whether any breach of confidentiality will be proven, in court or otherwise.

The strength of a firm's formal knowledge protection often depends upon the resources it has available to threaten court action, and if necessary to take court action. Small firms are likely to lack the necessary resources and capabilities to do this (West, 2006; Olander et al., 2009). They are therefore more likely to choose informal mechanisms to protect their knowledge (Kitching and Blackburn, 1998; Leiponen and Byma, 2009).

The costs and complexity associated with formal methods of protection make it more likely that small firms rely upon informal protection methods such as secrecy and speed to market (Arundel, 2001; Thomä and Bizer, 2013). Arundel (2001) examines firms from seven European countries and analyses whether firm size influences the relative importance of particular knowledge-protection mechanisms. The study finds that for firms of all sizes, secrecy is considered more relevant than patents, although in the case of product innovations, the relative importance of secrecy declines with firm size. Regarding R&D intensive firms, all firms believe secrecy to be more effective than patents, but R&D intensive small and medium-sized enterprises (SMEs) attach more importance to patents than other SMEs.

In their study, Coles et al. (2003) examine small firms in the textile-design sector of the UK, Italy and the United States. Following an increase in computer-aided design and communication technologies, an increase in the speed and quality of design copying occurred. This impacted upon some sectors more than others. Coles et al. (2003) find that small firms are unable to increase their use of formal knowledge protection to address the imitation problem because they lack the resources to do so. It is suggested that the small firms that lack resources may have to adapt their protection strategies in an alternative way, for example by frequently changing designs, implementing competitive pricing policies and increasing technical complexity so that designs are difficult to copy.

In a qualitative study, Kitching and Blackburn (2003) examine how 389 small firms from four different sectors (computer software, design, electronics and mechanical engineering) exploit and protect their innovations. They find that many small firms choose not to protect their innovations in any way and that many are unaware that protection mechanisms are available to them. Small firms that do use formal protection methods to protect knowledge are identified as being the more innovative firms.

Larger firms perceive patents to be effective (Combe and Pfister, 2000; Sattler, 2003) and they attach more importance to them than smaller firms (Blind et al., 2006). Leiponen and Byma (2009) conduct an empirical study of small Finnish manufacturing and service firms. They find that patents become more relevant as firm size increases. R&D-intensive small firms and science-based small firms are identified as those firms more likely to use formal methods of knowledge protection. Other small firms use speed to market or secrecy as protection methods. In a study of Canadian firms, Hanel (2005) finds that the use of all formal protection mechanisms increases with firm size.

With regards to performance, Hall and Sena (2017) find both informal and formal knowledge-protection mechanisms have a significant positive effect on the productivity of SMEs, but informal knowledge protection alone impacts upon larger firms' productivity. In addition, informal protection is more important for larger firms' productivity than for SMEs. Despite formal protection being more popular among larger firms (Hall et al., 2013), informal protection is more useful for increasing productivity in larger firms (Hall and Sena, 2017) – a result which can be explained by large firms being inclined to protect very valuable innovations with secrecy rather than patents to avoid disclosing knowledge (Anton and Yao, 2004). The finding that formal protection mechanisms have a significant positive effect on SME productivity can be explained by SMEs having a greater need to access inputs external to the firm – in this case, formal knowledge-protection mechanisms become more useful to them than informal ones.

The empirical evidence here is inconsistent – some studies find that formal protection mechanisms become more important as firm size increases whereas others find formal mechanisms are more important to SMEs – albeit R&D intensive SMEs – than larger firms. In terms of performance, evidence is yet again limited. The study discussed above finds informal protection mechanisms to be important for firms' productivity – more so for larger firms'. Taking into account this mixed evidence on the importance and use of formal and informal knowledge-protection mechanisms across firms of varying size, the following hypotheses are tested:

Hypothesis 4a: The positive relationship between a firm's use of formal knowledge-protection strategies and its innovation returns becomes stronger as firm size increases.

Hypothesis 4b: The positive relationship between a firm's use of formal knowledge-protection strategies and its innovation returns becomes weaker as firm size increases.

Hypothesis 4c: The positive relationship between a firm's use of informal knowledge-protection strategies and its innovation returns becomes stronger as firm size increases.

Hypothesis 4d: The positive relationship between a firm's use of informal knowledge-protection strategies and its innovation returns becomes weaker as firm size increases.

vi. Innovation novelty

Both the Yale I survey (Levin et al., 1987) and the Carnegie Mellon survey (Cohen et al., 2000) asked firms for the reasons why they did not use patents. One of the most common firm responses was the lack of novelty of innovations (Lopez, 2009).

The degree of novelty associated with an innovation reflects the degree to which new skills, knowledge and capabilities need to be developed in order to capture the commercial value of the innovation (Laursen et al., 2013). An extremely novel (radical) innovation is likely to require significant R&D investment (Hewitt-Dundas et al., 2017) and has a significant impact upon a market and upon the economic activity of firms within that market. Such a radical or *new-to-the-market* innovation exhibits possible technological spillovers (Veugelers and Schneider, 2018), more so than less novel, *new-to-the-firm* innovation. It is therefore reasonable to expect knowledge-protection mechanisms to be more extensively used in conjunction with new-to-the-market innovation than new-to-the-firm innovation. It is also reasonable to expect formal knowledge-protection mechanisms to be used for novel, new-to-the-market innovation. The lack of novelty associated with new-to-the-firm innovation suggests that formal protection mechanisms are less likely.

Empirical studies tend to support these expectations. Thomas (2003) interviews 120 small firms in the biotechnology industry about their knowledge-protection practices. Strategies differ according to the firm's stage of innovation. Firms that took a product or service to the marketplace used patents as a protection method, whereas firms that supplied materials or services to other firms typically relied upon trade secrets. Products developed by suppliers are characterised by rapid innovation, and the use of secrecy is deemed to be sufficient in such an environment where rapid changes in knowledge occur.

In a study of Canadian manufacturing firms, Hanel (2005) finds that new-to-the-market innovators rely more on formal protection than informal protection, although firms developing new markets are more likely to use trademarks than patents. The stage of development of an innovation may determine which knowledge-protection mechanisms a firm uses. When developing a new technology, firms are likely to use secrecy – they tend to apply for patents when taking a product to market (Hussinger, 2006).

Regarding performance, Laursen et al. (2013) find that a firm's use of formal knowledge-protection mechanisms impacts upon sales of new-to-the-market innovation more strongly than sales of significantly improved products.

Significantly improved products represent incremental innovations. These are largely imitative and therefore firms are less able to capture returns using formal mechanisms (Laursen et al., 2013). Given the empirical evidence discussed above, it is expected that:

Hypothesis 5: *Formal knowledge-protection strategies promote new-to-the-market innovation returns*

4.4 Data and methods

4.4.1 Empirical model

The present study is concerned with the innovation output that results during the second stage of the innovation value chain (Section 4.2.1.1 above) and the effect that both formal and informal knowledge-protection strategies have upon this innovation output. During the second stage of the innovation value chain, knowledge sourced during the first stage, through R&D or external knowledge sourcing for example, is combined into a form which can be commercially exploited through innovations (Roper et al., 2008; Roper et al., 2017). This transformation process is modelled here using an innovation production function (Geroski, 1990; Roper et al., 2008; Roper et al., 2017) where innovation outputs (or *innovation returns*) measured by sales of innovative products and processes is related to the firm's *formal and informal knowledge-protection strategies* – themselves a reflection of the internally and externally generated knowledge that is sourced during the first stage of the innovation value chain (firms use formal and informal knowledge-protection strategies to aid the appropriation of returns to their innovations). In accordance with the innovation production function literature, there is an underlying assumption that firms expect to receive a positive return on any investment they make into knowledge sourcing activities, and that the size of this investment is positively related to the expected return (Griliches, 1995). The innovation production function is given by equation 1:

$$I_i = \beta_0 + \beta_1 FC_i + \beta_2 FKP_i + \beta_3 IKP_i + \mu_i \qquad (1)$$

where I_i is innovation outputs (or returns) for firm i, FC_i is a set of firm-level control variables (firm resources and capabilities, R&D, skills and externally sourced knowledge, for example), FKP_i is an indicator of formal knowledge-protection strategies, IKP_i is an indicator of informal knowledge-protection strategies and μ_i is the error term.

4.4.2 Data

The empirical analysis in the present study uses the seventh wave of the UK Community Innovation Survey (CIS) which covers the three-year period 2008 to 2010. The UK CIS is based upon a core questionnaire developed by the European Commission (Eurostat) and Member States, and it forms part of a wider CIS covering European countries – the European Union Community Innovation Survey.

Background and motivation for the UK's innovation survey can be found in the Organisation for Economic Co-operation and Development's (OECD) Oslo manual (OECD, 2005), along with a description of the type of questions and definitions used. In the UK, the Office for National Statistics (ONS) – the UK official government statistical office – manages the administration of and data collection for the UK CIS.

The UK CIS is conducted every two years and represents the main source of innovation data in the UK providing detailed information on firms' innovation activity. The survey provides an insight into the objectives of this innovation activity and firms' external innovation connections. Questions relating to firm size and structure, customer base, firm product and process innovation activity, the sources of innovation, perceived barriers to innovation, the levels of public support and basic economic information about the firm are included.

The UK CIS sampling frame is taken from the Inter-departmental Business Register (IDBR), a UK-Government compiled register of all UK businesses based on tax and payroll records. The survey is statistically representative of the 12 regions of the UK, most industrial sectors and all sizes of firms with more than 10 employees.

Although essentially a postal questionnaire sent to 28 thousand UK enterprises with 10 or more employees across manufacturing and services sectors, an unexpected poor survey return for the seventh wave of the UK CIS meant that almost half of all responses – around seven thousand – were collected by telephone interview. When combined with the postal returns, this resulted in 14,342 valid enterprise responses – a 50 per cent response rate.[13]

The UK innovation surveys ask firms about their intellectual property and knowledge protection, although both the wording and detail level of the question varies across the different waves of data. The seventh wave – covering the three-year period 2008 to 2010 – asks firms about both formal and informal knowledge protection that took place within their business during the three-year period. Of the waves available, this seventh wave of data provides the most detailed insight into firms' new knowledge protection. For this reason, the seventh wave of UK CIS is used here to examine the effect formal and informal knowledge-protection strategies have upon a firm's innovation returns.

Of the 14,342 responses in the seventh wave of the UK CIS, 3,520 are from firms that innovated during the 2008 to 2010 period – these firms introduced new or significantly improved products and processes. The empirical analysis in this study uses the survey data obtained from these 3,520 innovating firms.

4.4.2.1 Dependent variable

The dependent variable – *innovation returns* – uses UK CIS data indicating the proportion of firms' sales – at the time of the survey – coming from products and services newly introduced during the previous three-year period. Firms in the seventh wave of the survey are asked to estimate the percentage of their business's total turnover in 2010 from goods and services that were (a) new to the market in 2008 to 2010 and (b) only new to the business in 2008-2010. The dependent variable is equal to the sum of the firm's two responses and thus indicates the proportion of firm sales coming from new-to-the-market and new-to-the-firm innovation. Previous studies (Laursen and Salter, 2006; Becker et al., 2016; Roper et al., 2016b; Roper et al., 2017, for example) use this measure as an indicator of innovation output. It illustrates a firm's ability to introduce new products and

[13]See:https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/200078/12-P106A-UKIS_2011First_findings_Apr13.pdf

services to the market as well as their commercial success (Roper et al., 2017). The proportion of sales turnover coming from new-to-the-market and new-to-the-firm innovation is estimated by the firm, and therefore, the dependent variable is not measured relative to the sector characteristics – turnover relative to the average sector turnover, for example.

4.4.2.2 Independent variables

There are two independent variables in the analysis – one variable represents a firm's *formal knowledge-protection strategy* and the other represents a firm's *informal knowledge-protection strategy*.

In the seventh wave of UK CIS, firms are asked if they protected innovation and intellectual property during the 2008 to 2010 period. Firms are asked whether they used the following seven knowledge-protection mechanisms: patents, registration of design, trademarks, copyright, secrecy (including non-disclosure agreements), complexity of design and lead-time on competitors. Firms' responses to each question are recorded as a 0 or a 1, with a 1 denoting that the method of protection took place.

The seven knowledge-protection mechanisms in the survey data have a high degree of internal consistency (Cronbach Alpha Coefficient = 0.75), suggesting a high degree of correlation among the individual knowledge-protection survey questions. Groups of questions may therefore measure some underlying latent attribute; consequently, there may be groups of variables that are closely related. With a prior expectation that formal knowledge-protection mechanisms may be closely related to one another and that informal knowledge-protection mechanisms may also be closely related to one another, an exploratory factor analysis of the knowledge-protection data is performed. Factor analysis has previously been used to examine firms' use of knowledge protection mechanisms (Miles et al., 2000). In their study, Miles et al. (2000) find that 65 service firms from a variety of sectors rely on four combinations of protection mechanisms. By conducting an exploratory factor analysis of the data in the present study, the seven dimensions of knowledge protection are reduced and any attributes that exist are condensed into factors.

As the response data is binary, the tetrachoric correlation matrix is computed, and a factor analysis (with principal component factors[14]) of the resulting correlation matrix is performed. The two groups of variables – or factors – with an eigenvalue greater than 1 are retained (Guttman-Kaiser rule) – together they explain approximately 75 per cent of the variation in the knowledge-protection data.

The original knowledge-protection variables are assigned as efficiently as possible to the two extracted factors by undertaking an oblique[15], oblimin rotation. This procedure allows the different knowledge-protection mechanisms to group and cluster together.

The correlations (or factor loadings) between the original seven knowledge-protection mechanisms and the two extracted factors are examined. The knowledge-protection mechanisms with factor loadings less than 0.3[16] (in absolute terms) are hidden in order to identify those knowledge-protection mechanisms most correlated with the two extracted factors. The formal knowledge-protection mechanisms (patents, registration of design and trademarks) are highly correlated with one factor (factor loading for patents: 0.82; registration of design: 0.86; trademarks:0.95), and the informal knowledge-protection mechanisms (secrecy – including non-disclosure agreements, complexity of design and lead-time on competitors) are highly correlated with the other factor (factor loading for secrecy – including non-disclosure agreements: 0.69; complexity of design: 0.85; lead-time on competitors: 0.90). Copyright is found to be correlated with both factors, although it loads more strongly onto the first factor along with patents, registration of design and trademarks (a factor loading of 0.59 compared with 0.36 for the second factor).

The first factor is loaded most highly with formal protection mechanisms and is therefore representative of a *formal knowledge-protection strategy*. The second

[14] The Kaiser-Meyer-Olkin measure of sampling adequacy is 0.8. As this value is greater than 0.5, the use of principal component factor extraction is supported.

[15] Oblique rotation is preferred to orthogonal rotation when the goal is to obtain theoretically meaningful factors or constructs rather than to achieve data reduction. Oblique rotation assumes that factors are correlated. Here, the correlation between factors is 0.48, greater than the suggested 0.32 threshold.

[16] Knowledge-protection mechanisms with factor loadings less than 0.3 (in absolute terms) are considered to be uncorrelated with the extracted factor.

factor is loaded most highly with informal knowledge-protection mechanisms and is representative of an *informal knowledge-protection strategy*. Although copyright is a formal knowledge-protection mechanism, it loads onto both factors. As an easily accessible formal protection mechanism, firms are most likely to use copyright before any other formal method, thus explaining its correlation with both factors.

The aim of the present study is to examine how a firm's formal and informal knowledge-protection strategies impact upon its returns to innovation rather than to investigate the effect of individual knowledge-protection mechanisms. The exploratory factor analysis conducted here extracts two factors – one factor with high factor loadings from formal knowledge-protection mechanisms and the other with high factor loadings from informal knowledge-protection mechanisms (with the exception of copyright). The two extracted factors are used in the empirical analysis to represent firms' formal and informal knowledge-protection strategies.

4.4.2.3 Control variables

A set of control variables are also included in the model. These variables represent factors, other than a firm's formal and informal knowledge-protection strategies, which previous studies have shown to impact upon a firm's innovation outputs or returns; they are variables – in addition to the independent variables – which influence the effectiveness of a firm's knowledge transformation activities (Roper et al., 2008). The control variables used here reflect a firm's characteristics, its resource base and its capabilities (Griliches, 1992; Love and Roper, 1999). Many of the variables, for example skills, firm size and whether or not a firm exported, are an indication of the quality of a firm's knowledge base. The control variables include:

i. Firm size

Firm size – commonly used in studies of innovative performance (Cohen, 1995) – is thought to influence a firm's propensity to innovate (Laursen et al., 2013). The number of employees (expressed as a logarithm) is included here to reflect the scale of a firm's resources.

ii. Skill levels

Skill levels – or the strength of firms' human resources – impact upon innovation (Leiponen, 2005; Freel, 2005; Hewitt-Dundas, 2006) and are measured using the proportion of a firm's employees that hold a degree or higher qualification in (a) science or engineering subjects and (b) other subjects.

iii. Firm's export status

Exporting and innovative activity has been linked through both competition and learning effects (Love and Roper, 2013). A binary (0/1) variable is included indicating whether or not the firm exported during the three-year period.

iv. R&D

Innovation outputs are positively related to internally generated knowledge coming from in-house R&D (Love and Roper, 2001; Love and Roper, 2005) and knowledge sourced from external partners. Two binary (0/1) variables are included in the model to indicate whether or not the firm reported (a) internal R&D expenditure and (b) external R&D expenditure during the three-year period.

v. Other Innovation-related investments

Following Becker et al. (2016), several variables reflecting firms' innovation-related investments are included in the model. Binary (0/1) variables indicating whether or not acquisition of advanced machinery and equipment took place, whether or not acquisition of computer hardware took place, whether or not acquisition of computer software took place, whether or not training for innovative activities took place and whether or not engagement in design activities took place are all included. Investment into design has been shown to impact upon innovation outputs (Love et al., 2011), and it is expected that the additional innovation investment variables included here will also have a positive impact upon a firm's innovation outputs or returns.

vi. The acquisition of external knowledge

The acquisition of knowledge from other businesses or organisations, such as the purchase or licensing of patents and non-patented inventions and know-how, strengthens a firm's knowledge resources and helps promote innovation outputs. A binary (0/1) variable indicating whether or not the firm acquired such external knowledge is included in the model.

vii. Government assistance

Any government assistance a firm receives enhances its resource base, and the additional internal resources are expected to impact positively upon the firm's innovation outputs (Roper and Hewitt-Dundas, 2005; Link et al., 2005). A binary (0/1) variable indicating whether or not the firm received public support for innovation is included in the model.

viii. Breadth of innovation co-operation

The extent of a firm's interactive knowledge search has been used extensively in studies of the determinants of innovation (for example, Laursen and Salter, 2006; Becker et al., 2016) and is measured by a variable indicating the extent or breadth of the firm's innovation co-operation. The UK CIS asks firms if they co-operated on any innovation activity. Firms are asked specifically about co-operation which may have taken place with seven particular co-operation partners (for example, competitors or other businesses within the industry, universities or other higher education institutions and government or public research institutes). Following Laursen and Salter (2006) and Becker et al. (2016), firms' binary (0/1) responses for each of the seven co-operation partners are summed to create a count indicator having a minimum value of 0 and a maximum value of 7. This count indicator is included in the model to represent firms' breadth of innovation co-operation.

ix. Sectoral dummies

To allow for sectoral heterogeneity – different levels of innovation intensities across industries (Levin et al. 1987; Cohen et al. 2000) – sector dummies at the two-digit level are included in the model.

4.4.3 Estimation method

The appropriate estimation method for the innovation production function depends primarily on the nature of the dependent variable. The dependent variable here –

innovation returns – is the *proportion* of firm sales coming from innovation: by definition, its value is bounded between 0 and 100 (or 0 and 1). In this case, the explanatory variables have non-linear effects on the dependent variable (the variance falls as the mean approaches either of the dependent variable boundaries), and therefore linear regression methods are inappropriate.[17] Previously, some studies have used censored normal regression techniques such as Tobit to model proportions data (for example, Laursen and Salter, 2005; Roper and Hewitt-Dundas, 2016; Roper et al., 2016c). But, it is important to note that in this case, the Tobit analysis truncates values at the boundaries implying that they are not true zeros or ones. However, in the case where the dependent variable represents a proportion (bounded between 0 and 1), any observed zeros or ones in the dependent variable data here are not strictly censored data as values outside the [0, 1] range are not feasible (Baum, 2008).

A method for handling proportion or fractional response data of this kind (i.e. bounded between 0 and 1) was first proposed by Papke and Wooldridge in their 1996 seminal paper. Their fractional response model takes into account both the upper and lower bounds of the dependent variable, predicts response values that lie within the dependent variable range and captures the nonlinearity of the data (Gallani et al., 2015).

The fractional response model uses a logit link function (i.e. a logit transformation of the dependent variable that does not treat the fractional dependent variable as a binary response) and the binomial distribution – an appropriate distribution choice given that the variance of the binomial distribution tends to 0 as the mean tends to either 0 or 1 – the boundary values of the dependent variable. At each boundary value, the variable approaches a constant; the variance is therefore maximised when the mean is equal to 0.5. In addition, the fractional response model does not allow for an alternative model of behaviour, or require special data transformations, at dependent variable boundary values. It permits a direct estimation of the conditional expectation of the dependent variable given the predictors (Gallani et al., 2015).

[17] The drawbacks of using linear models for proportion data are analogous to the drawbacks of using them for binary data.

This feature of the model is desirable because while it may be the case that zeros in the dependent variable are structural, for example process innovators will never report product innovation sales, they may also represent product innovators that do not make innovation-related sales.

Following Laursen et al. (2013) who use the Papke and Wooldridge (1996) method to estimate a fractional response model of innovative performance, the innovation production function here (or the fractional response model) is implemented by estimating a generalised linear model (GLM)[18] with a binomial distributional family and logit link function.[19] The estimation of the model's parameters is based on a quasi-maximum likelihood method (QMLE) which generates fully robust and relatively efficient estimates under general linear model conditions (Papke and Wooldridge, 1996).

4.5 Results

4.5.1 Descriptive results

Descriptive statistics and correlation coefficients are given in Tables 4.1 to 4.3. Table 4.1 shows the use of formal knowledge-protection mechanisms (patents, registered industrial designs, registered trademarks and copyright) and informal knowledge-protection mechanisms (secrecy – including non-disclosure agreements, complexity of design and lead-time advantage) within different groups of innovating firms. Levin et al. (1987) and Cohen et al. (2000) identify secrecy as being an important knowledge-protection mechanism across all innovators, and the data here supports this finding as secrecy (including non-disclosure agreements) is the most used knowledge-protection mechanism within each innovator group (Table 4.1). The highest values are experienced in the new-to-the-market, high-technology/knowledge-intensive and manufacturing groups with 36.3 per cent, 35.4 per cent and 34.0 per cent of firms respectively using secrecy (including non-

[18] Generalised linear models model how the mean of the distribution of the dependent variable changes as the explanatory variables change.

[19] Note that the fractional response model requires that the dependent variable – the proportion of firm sales coming from innovation – be in the [0-1] range.

disclosure agreements) to protect innovations during the 2008 to 2010 period. The lowest values are in the low-technology/less knowledge-intensive and the new-to-the-firm group: 20.2 per cent and 22.0 per cent of firms respectively use secrecy to protect innovations during the three-year period.

Registered trademarks are the second most popular knowledge-protection mechanism used by all innovators in the UK CIS 2008 to 2010 (14.7 per cent of firms). Trademarks are also the second most popular knowledge-protection mechanism for five of the individual innovator groups (new-to-the-firm, medium-sized, large-sized, low-technology/less knowledge-intensive and service-sector innovators). For three of the remaining four innovator groups (new-to-the-market, high-technology/knowledge-intensive and manufacturing-sector innovators), patents are the second most popular knowledge-protection mechanism: 22.8 per cent, 15.8 per cent and 20.2 percent of firms respectively use patents to protect innovations. Previous studies (for example, Levin et al., 1987; Harabi, 1995; Cohen et al., 2000) find patents to be an important protection mechanism for firms in the pharmaceutical and chemical industries. The data here is consistent with these studies as patents are more widely used by R&D-intensive innovators. In the final innovator group – small-sized firms – copyright and lead-advantage time are the second most popular knowledge-protection mechanisms. Around 12 per cent of firms in this small-sized-firm group use these knowledge-protection mechanisms. This is supported by Leiponen and Byma (2009) who find that small firms use secrecy and speed-to-market to protect their knowledge. Informal mechanisms such as secrecy, copyright and lead-advantage time are accessed more easily by small firms than the other knowledge-protection mechanisms as their use requires fewer firm resources and capabilities. Given that small firms often lack resources and capabilities, the popularity of secrecy, copyright and lead-advantage time amongst small firms is unsurprising.

There is a relatively high use of all seven knowledge-protection mechanisms in the new-to-the-market and manufacturing sector innovator groups. In each of these groups, the proportion of firms using each protection mechanism is similar.

The least popular protection mechanism within all innovator groups is the registration of industrial designs. The proportion of firms using the mechanism is highest in the manufacturing sector innovator group (7.9 per cent) and lowest in the new-to-the-firm innovator group (2.2 per cent). The new-to-the-market and large-sized innovator groups have values towards the top of this range; 6.5 per cent and 7.1 per cent of firms respectively use the registration of design as a knowledge-protection mechanism.

The use of complexity of design as a protection mechanism is the sixth most popular knowledge-protection mechanism in all innovator groups. The largest proportion of firms using this mechanism is found in both the new-to-the-market and manufacturing-sector innovator groups (13.6 per cent and 13.2 percent respectively), although 10.1 per cent of firms in the large-sized innovator group and 11.9 per cent of firms in the high-technology/knowledge-intensive innovator group use this protection mechanism.

The proportion of firms using patents, registered industrial designs and registered trademarks – all formal knowledge-protection mechanisms – increases with firm size as does the proportion of firms using complexity of design – an informal protection method.

Table 4.2 shows the mean and standard deviation value for each of the variables described in Section 4.4.2 above and used in the empirical analysis. Minimum and maximum values are not given in compliance with ONS's rule on disclosure. Across all 3,520 innovating firms, on average, 13.4 per cent of a firm's sales (at the time of the survey) came from products and services newly introduced by the firm during the 2008 to 2010 period. On average, 10.6 per cent of an innovating firm's workforce has a science/engineering degree, and 11.7 per cent has a degree from other disciplines. The mean of each binary (0/1) independent variable indicates the proportion of innovating firms that gave a positive 'yes' response to the particular question being asked. For example, 18 per cent of innovating firms indicated that they received public support for innovation during the 2008 to 2010 period; 47 per cent of innovating firms indicated that they exported during the 2008 to 2010 period; and 33 per cent of innovating firms indicated that they acquired advanced machinery and equipment during the 2008 to 2010 period. The breadth of innovation co-operation data indicates that, on average, an innovating firm had 2 innovation cooperation partners during the 2008 to 2010 period.

Table 4.3 shows the correlation coefficients for all variables included in the analysis. The reported values do not indicate collinearity problems: The highest value in the table is 0.63, and this represents the correlation between the innovating firm's acquisition of computer hardware and its acquisition of computer software. Although it is reasonable to expect that these two variables may be correlated, the value of the correlation coefficient is not high enough to warrant that further action be taken.

4.5.2 Econometric results

The estimation results are given in Tables 4.4 to 4.9. All estimations include two-digit industry dummy variables, results of which are not shown in the tables.

4.5.2.1 Baseline model

A baseline model – including all 3,520 innovating firms – is first estimated. The baseline-model results in Table 4.4 show that a formal knowledge-protection (FKP) strategy and an informal knowledge-protection (IKP) strategy have, on average, significant, positive effects (at the 1 per cent level) on a firm's innovation returns. The parameter for the FKP strategy variable and the IKP variable is identical (0.441) suggesting that formal and informal protection strategies have similar positive effects upon a firm's returns to innovation. These results indicate that a stronger protection strategy – be it a FKP strategy or an IKP strategy – leads to higher innovation returns. These findings are evidence in support of Hypothesis 1 which states that a firm's formal and informal knowledge-protection strategies are positively related to its innovation returns.

The results show that a firm's knowledge-protection strategy is an important determinant of the proportion of its sales coming from innovation (i.e. innovation returns), and that, on average, implementing a stronger protection strategy leads to an increase in this proportion or an increase in innovation returns. By strengthening its knowledge-protection strategy, a firm can capture the benefits of its innovative efforts – shown here by an increase in the proportion of its sales coming from innovation. If a firm is unable to capture the benefits of its innovative efforts, there is little incentive for the firm to innovate (Laursen and Salter, 2005), and these results provide evidence in support of the view that knowledge-protection mechanisms can be used by firms as a strategic tool to capture the private returns to innovation (Laursen and Salter, 2005; Greenhalgh and Rogers, 2007). By allowing firms to capture returns to innovation, knowledge-protection mechanisms provide firms with an incentive to innovate and, in addition, offer them an incentive for future innovation (Granstrand, 1999).

4.5.2.2 Sub-sample models

Section 4.3.1 above identifies reasons – suggested by previous studies – why the use of formal and informal knowledge-protection mechanisms may differ across firms. In accordance with this thinking, sub-sample estimates for specific groups of firms are also obtained. The model is estimated for firms within different industry groups, firms with different resources and capabilities and firms carrying out innovations with different degrees of novelty.

i. Different industries/different technologies

To examine whether the effects of the two different types of knowledge-protection strategy vary across industries/technologies, the 3,520 innovating firms are classified into two separate groups using two different methods of separation. Firstly, all innovating firms are separated into high-technology/knowledge-intensive firms and low-technology/less knowledge-intensive firms, and secondly, all innovating firms are separated into service-sector firms and manufacturing-sector firms.

a. High-technology/knowledge-intensive firms and low-technology/less knowledge-intensive firms

Following the OECD (2011), manufacturing firms are sorted into four groups based upon their level of technology – a firm is identified as belonging to one of four categories: high-technology industries, medium-high-technology industries, medium-low-technology industries or low-technology industries. In its classification, the OECD uses expenditure on R&D to determine the technological input of each manufacturing industry. Both direct and indirect expenditure on R&D

are considered, including the purchase of machinery, equipment and intermediary inputs (Hatzichronoglou, 1997). For the purpose of this study, each firm's economic activity is classified according to the level of technology and knowledge given by its three-digit Standard Industrial Classification (SIC) code.

Firms in the service sectors are sorted into six categories based upon the OECD's proposal for knowledge-intensive services (Eurostat, 2007) – they are identified as belonging to one of six groups: knowledge-intensive high-technology services, knowledge-intensive market services, knowledge-intensive financial services, other knowledge-intensive services, less knowledge-intensive market services or other less knowledge-intensive services. The most knowledge-intensive services generally show higher investment in R&D, a greater use of information technology and a tendency to hire highly qualified personnel. As for the manufacturing sector, each service-sector firm's economic activity is classified according to the level of technology and knowledge given by its three-digit SIC code.

In order to obtain two groups of firms with contrasting technology/knowledge levels, firms belonging to the high-technology and medium high-technology manufacturing groups are merged with those belonging to the four knowledge-intensive service-sector groups – forming a group of high-technology/knowledge-intensive firms (1,758 firms), and firms belonging to the medium low-technology and low-technology manufacturing groups are merged with those belonging to the two less knowledge-intensive service groups – forming a group of low-technology/less knowledge-intensive firms (1,762 firms).

The estimation results for the high-technology/knowledge-intensive firms and the low-technology/less knowledge-intensive firms are shown in Table 4.5. The results show that a FKP strategy and an IKP strategy have a significant, positive effect (at the 1 per cent level) on the returns to innovation of high-technology/knowledge-intensive firms: a stronger FKP strategy leads to higher returns to innovation as does a stronger IKP strategy. The parameter for the IKP strategy variable (0.555) is larger than that for the FKP strategy variable (0.461) suggesting that an informal strategy has a larger, positive effect upon a firm's returns to innovation.

Both a FKP strategy and an IKP strategy have a significant, positive effect upon the returns to innovation of low-technology/less knowledge-intensive firms, although the degree of significance for each strategy variable is less than in the high-technology/knowledge-intensive firm case (the protection variables are significant at the 5 per cent and 10 per cent level respectively). As with high-technology/knowledge-intensive firms, a stronger FKP strategy leads to higher returns to innovation as does a stronger IKP strategy. In contrast to the high-technology/knowledge-intensive firms, the parameter for the FKP strategy is larger than that for the IKP strategy (0.415 compared with 0.276) suggesting that a formal strategy has a larger, positive effect upon a firm's returns to innovation than an informal strategy. These findings provide evidence which suggests that Hypothesis 2b should be rejected in favour of Hypothesis 2a which states that formal/informal knowledge-protection strategies have a stronger positive effect upon the innovation returns of high-technology/knowledge-intensive firms than low-technology/less knowledge-intensive firms.

Although the analysis shows FKP strategies and IKP strategies to have a significant, positive impact upon the innovation returns of high-technology/knowledge-intensive and low-technology/less knowledge-intensive firms, the two different protection strategies illustrate a greater level of statistical significance for high-technology/knowledge-intensive firms' innovation returns. This is consistent with Cohen et al. (2000) who find that R&D intensive industries report a high effectiveness of almost every knowledge-protection mechanism – the results here show that a predominantly formal protection strategy and a predominantly informal protection strategy have a highly significant, positive effect upon a firm's innovation returns. Levin et al. (1987) and Cohen et al. (2000) find that a high percentage of all firms rely on informal protection mechanisms, and it is the R&D intensive firms, such as those in the chemical and pharmaceutical industries, that also use formal protection methods. Other studies (for example, Mansfield, 1986; Harabi, 1995; Leiponen and Byma, 2009) find similar results. The results here support previous studies that highlight the importance of informal knowledge-protection mechanisms for the innovation returns of all firms, regardless of their industry. They also illustrate the importance of formal protection mechanisms for the innovation returns of low-technology/less knowledge-intensive firms. Results here show that informal protection strategies have a less significant effect upon the innovation returns of firms in low-technology/less knowledge-intensive firms than those in high-technology/knowledge-intensive firms.

b. Service-sector firms and manufacturing-sector firms

The 3,520 innovating firms are separated into service sector firms (2,310 firms) and manufacturing sector firms (1,210 firms) according to their three-digit SIC codes. The estimation results for each group are shown in Table 4.6. The results show that a FKP strategy and an IKP strategy have a significant, positive effect (at the 10 per cent level) on a firm's innovation returns in manufacturing-sector firms, indicating that a stronger FKP strategy leads to higher returns to innovation as does a stronger IKP strategy. The parameter for the FKP strategy variable (0.295) is slightly larger than that for the IKP strategy variable (0.272) suggesting that a formal protection strategy has a slightly larger, positive effect on manufacturing firms' innovation returns than an informal protection strategy.

As for service-sector firms, the results in Table 4.6 show that a FKP strategy and an IKP strategy have a significant, positive effect (at the 1 per cent level) on firms' innovation returns, so that a stronger FKP strategy leads to higher innovation returns as does a stronger IKP strategy. The parameter for the IKP strategy variable is slightly larger than that for the FKP strategy variable (0.559 compared with 0.504) suggesting that an informal protection strategy has a slightly larger positive effect on service firms' innovation returns than a formal protection strategy. These findings provide evidence which suggests that Hypothesis 3a should be rejected in favour of Hypothesis 3b which states that formal/informal knowledge-protection strategies have a weaker positive effect upon the innovation returns of manufacturing-sector firms than service-sector firms.

Although FKP strategies and IKP strategies are found to be statistically significant for manufacturing and service firms' innovation returns, both knowledge-protection strategies illustrate a greater level of statistical importance for service-sector firms' innovation returns. These results are evidence against the view that service-sector firms gain no benefit from using formal knowledge-protection mechanisms. Indeed, some studies (for example, Mairesse and Mohnen, 2004) suggest that most service-sector firms do not use any protection mechanisms. In accordance with Hall and Sena (2017) who find that formal protection mechanisms are important for service-sector productivity, the results here show that formal protection mechanisms have a significant, positive effect on service-sector firms' innovation returns. In contrast to Hall and Sena (2017), results here show that an informal protection strategy has a slightly larger effect upon service-sector firms' innovation returns than a formal protection strategy; Hall and Sena (2017) find that formal protection mechanisms are more important for service-sector productivity. In this study, both protection strategies have a significant, positive effect on the returns to innovation of firms in the manufacturing sector although the effects are not as strong as in the service sector. In contrast, Hall and Sena (2017) find that formal and informal protection has a negative effect on the productivity of manufacturing firms.

Previous studies highlight the limited use of formal and informal protection methods in service-sector firms: Hipp and Herstatt (2006) find that those that use protection tend to use informal methods with only 6 per cent of service-sector firms using formal protection methods, Blind et al. (2003) find that applications made for formal protection mechanisms in the service sector are far fewer than those in the manufacturing sector and Baldwin et al. (1998) find that less than half of all innovating service-sector firms report using any knowledge protection. The analysis here shows the importance of formal and informal protection mechanisms for returns to innovation in service-sector firms and highlights the need to promote the use of protection mechanisms in these firms.

ii. Different resources and capabilities

Section 4.3.1 above discusses previous studies that find small firms lack the necessary resources and capabilities needed to use formal knowledge-protection mechanisms to protect their knowledge (for example, Olander et al., 2009; West, 2006). In line with this viewpoint, firm size is used here to indicate the level of firm resources and capabilities that are available in order to protect knowledge.

To examine whether the effects of the two knowledge-protection strategies vary across firms with different resources and capabilities, the 3,520 innovating firms are classified into three separate groups according to firm size. The first group includes firms with 10 to 49 employees (1,491 firms), the second group includes medium firms with 50 to 249 employees (1,143 firms) and the third group includes large firms with 250 or more employees (789 firms).[20]

Table 4.7 shows the model estimation results for all three sizebands. In small firms, both the FKP strategy and the IKP strategy have significant, positive effects (at the 1 per cent and 5 per cent levels respectively) on a firm's innovation returns. This indicates that a stronger protection strategy leads to higher innovation returns. However, a FKP strategy has a higher level of statistical significance than an IKP strategy.

In medium-sized firms, a FKP strategy and an IKP strategy have significant, positive effects (at the 10 per cent level) on a firm's innovation returns. As with small firms, the results imply that a stronger protection strategy leads to higher innovation returns. The parameter for the FKP strategy variable (0.375) is slightly larger than that for the IKP strategy variable (0.359) suggesting that a FKP strategy has a slightly larger, positive effect on the innovation returns of medium-sized firms than an IKP strategy.

The results for large firms show that an IKP strategy has a significant, positive effect (at the 1per cent level) on a firm's innovation returns, and therefore a stronger IKP strategy leads to higher innovation returns. In contrast, a FKP strategy has an insignificant effect on the innovation returns of large firms.

Previous studies find that patents – a formal protection mechanism – become more relevant to firms as firm size increases (for example, Leiponen and Byma, 2009) and that the use of all formal protection mechanisms increases with firm size (for example, Hanel, 2005). Larger firms also perceive patents to be effective (Combe and Pfister, 2000), but results here show that large-firm innovation returns are positively related to informal protection strategies – formal protection strategies have an insignificant effect upon innovation returns in large firms. This introduces an

[20] There are 97 firms with fewer than 10 employees.

inconsistency between the mechanisms large firms believe to be important for innovation returns and those which have a significant impact upon them.

Many studies identify that formal knowledge-protection mechanisms may be too costly and complex for small firms to use (for example, Olander et al., 2009) and that because of this, they are more likely to use informal protection methods (for example, Kitching and Blackburn, 1998). The results here show that the benefits to small firms from using formal protection mechanisms – in terms of returns to innovation – are greater than those from using informal knowledge protection.

Although the significance of formal knowledge-protection strategies for firm innovation returns falls here as firm size increases and formal knowledge-protection strategies are insignificant in the large-firm model results, it is important to note that the results for each sizeband relate to all sectors – formal protection mechanisms are more relevant in some sectors than others. In contrast, informal knowledge-protection strategies have a significant, positive effect on a firm's innovation returns in all sizebands emphasising the importance of informal protection strategies more generally. In terms of performance effects, the results here are consistent with those of Hall and Sena (2017) who find that both formal and informal knowledge-protection mechanisms have a significant positive effect on SME productivity but only informal knowledge-protection mechanisms impact upon large-firm productivity.

Overall, the estimation results in Table 4.7 lead to the rejection of Hypothesis 4a in favour of Hypothesis 4b which states that the positive relationship between a firm's use of formal knowledge-protection strategies and its innovation returns becomes weaker as firm size increases and the rejection of Hypothesis 4d in favour of Hypothesis 4c which states that the positive relationship between a firm's use of informal knowledge-protection strategies and its innovation returns becomes stronger as firm size increases.

iii. Different levels of innovation novelty

To examine whether the effects of the two protection strategies vary with the novelty of the firm's innovation, three different groups of innovators are identified. Firstly, firms that introduce a new good or service to the market before competitors represent a new-to-the-market group, secondly, firms that introduce a new good or service that was essentially the same as a good or service already available from competitors represent a new-to-the-firm group and thirdly, firms that introduce both a good or service before competitors and a good or service essentially the same as competitors represent form a new-to-the-market-and-firm group.

The estimation results for the three different innovator types – new-to-the-market, new-to-the-firm and new-to-the-market-and-firm – are shown in Table 4.8. The results for the new-to-the-market group of firms show that a FKP strategy has a significant, positive effect (at the 5 per cent level) on a firm's innovation returns – a stronger FKP strategy will lead to higher returns to innovation. An IKP strategy has an insignificant effect on the innovation returns of new-to-the-market innovators.

The two protection strategy variables have an insignificant effect on the innovation returns of new-to-the-firm innovators, whereas both protection-strategy variables have a significant, positive effect on the innovation returns of firms carrying out both new-to-the-market and new-to-the-firm innovations. Results for firms carrying out both types of innovation show the FKP strategy variable to be significant at the 10 per cent level – less significant than in the new-to-the-market case, and the IKP strategy variable to be significant at the 1 per cent level – the IKP strategy is insignificant in the new-to-the-market case.

Results here are consistent with Levin et al. (1987) and Cohen et al. (2000) who find that firms do not use patents when an innovation lacks novelty and Thomas (2003) and Hanel (2005) who find firms that take a product or service to the marketplace are those that use formal knowledge-protection mechanisms. The estimation results in Table 4.8 show that formal and informal knowledge-protection strategies have no significant impact upon the innovation returns of a new-to-the-firm innovator. A new-to-the-firm innovation lacks novelty, and because of this, the use of formal knowledge-protection mechanisms is less likely. In contrast, new-to-the-market innovation is novel, and the results here are consistent with those of Laursen et al. (2013) who find firms that carry out new-to-the-market innovation are able to use formal protection mechanisms to increase their innovative sales.

In summary, the estimation results support Hypothesis 5 which states that formal knowledge-protection strategies promote new-to-the-market innovation returns.

4.5.2.3 New-to-the-market innovators: an extended analysis

Those firms introducing a new good or service to the marketplace are described here as new-to-the-market innovators. Section 4.5.2.2 above examines the effects a formal knowledge-protection strategy and an informal knowledge-protection strategy have upon the innovation returns of new-to-the-market innovators. This section explores whether the effects of the two different knowledge-protection strategies vary across different firms within this new-to-the-market group. In line with the sub-sample estimations discussed above, the new-to-the-market innovators are separated into different groups for comparative purposes: small firms, medium firms and large firms; high-technology/knowledge-intensive firms and low-technology/less knowledge-intensive firms; and manufacturing-sector firms and service-sector firms.

Table 4.9 shows the estimation results for small, medium and large new-to-the-market innovators. In small, new-to-the-market innovating firms, a FKP strategy has a significant, positive effect (at the 5 per cent level) on firms' innovation returns, while an IKP strategy has an insignificant effect. Both protection strategies have an insignificant effect on the innovation returns of medium-sized, new-to-the-market innovators, and an IKP strategy alone has a significant, positive effect on the innovation returns of large, new-to-the-market innovators. While IKP strategies have a significant, positive effect on the innovation returns of firms across sizebands when all innovators are aggregated, it is only in large firms that they have a significant, positive effect on innovation returns when the new-to-the-market innovators are examined as a separate group.

Table 4.10 shows the estimation results for high-technology/knowledge-intensive and low-technology/less knowledge-intensive new-to-the-market innovators. In the high-technology/knowledge-intensive, new-to-the-market innovator group, a FKP strategy has a significant, positive effect (at the 1 per cent level) on a firm's innovation returns, whereas an IKP strategy has an insignificant effect. In contrast, when all innovators are aggregated (Table 4.5), both protection strategies are highly significant. In low-technology/less knowledge-intensive, new-to-the-market firms, both protection strategies have an insignificant effect on firms' innovation returns. This contrasts with the results for the aggregated group of innovators (Table 4.5) which show that both a FKP strategy and an IKP strategy have significant, positive effects on firms' innovation returns (at the 5 per cent level and 10 per cent level respectively).

Table 4.11 shows the estimation results for manufacturing and service-sector new-to-the-market innovators. Both a FKP strategy and an IKP strategy have a significant, positive effect (at the 5 per cent level) on innovation returns in new-to-the-market manufacturing-sector firms. When all innovators are aggregated (Table 4.6), the two protection-strategy variables are less significant for the innovation returns of manufacturing-sector firms than when new-to-the-market innovators are considered in isolation (Table 4.11). The two protection strategies have an insignificant effect on the innovation returns of new-to-the-market service-sector firms, but when all innovators are aggregated (Table 4.6), both protection strategies have a highly significant effect on the innovation returns of service-sector firms.

4.6 Discussion and conclusions

A firm's incentive to innovate comes from the expectation of post-innovation returns (Laursen and Salter, 2005). But unless a firm is able to limit others from imitating its innovations, it may fail to appropriate returns from its own innovations (Cecccagnoli and Rothaermel, 2008). Firms overcome this appropriability problem (Arrow, 1962) by using knowledge-protection mechanisms as a strategic tool to capture the returns to innovation (Laursen and Salter, 2005; Greenhalgh and Rogers, 2007). A firm's strategy for protecting its knowledge is an integral part of its innovation strategy, and the firm is faced with a choice about how best to protect this knowledge: it can choose to rely upon formal, legally-enforceable protection mechanisms or it can choose to protect knowledge using more informal protection mechanisms that are based upon secrecy and non-disclosure.

This firm-level study examines formal and informal knowledge-protection strategies and asks how a firm's choice of protection strategy – be it formal or informal – affects returns to innovation. Using UK CIS data for the 2008 to 2010 period, an innovation production function is estimated to investigate the relationship between the proportion of firm sales coming from innovation and the firm's orientation towards formal and informal knowledge-protection mechanisms. Initially, the analysis examines all innovating firms and then moves on to examine and compare firms within different industries, firms in different sizebands and firms innovating with different degrees of novelty. Firms that carry out novel, new-to-the-market innovations are analysed further: different sub-groups – industries and sizebands – are compared both with each other and with the sub-group estimates obtained using the wider sample of innovating firms.

This study adds to the existing knowledge-protection literature by asking if a firm's knowledge-protection strategy – formal or informal – matters for innovation returns. It adds to the existing body of knowledge by combining features of previous research in this area (Laursen and Salter, 2005; Laursen et al., 2013; Hall and Sena, 2017) and using data on firms' use of knowledge-protection mechanisms rather than data on the importance of knowledge-protection mechanisms to firms – data prone to subjectivity bias (Veulegers and Schneider, 2018). Unlike previous studies, the present study examines both formal and informal knowledge-protection strategies in innovating firms, analyses how each strategy-type affects innovation returns and asks how the effects on innovation returns are influenced by the sector/technology of the firm, the size of the firm and the novelty of the innovation being carried out.

This study deepens our understanding of how firms are able to use formal and informal knowledge-protection strategies to capture the returns to innovation. The empirical analysis leads to a number of key findings.

i. First, the results suggest that a stronger knowledge-protection strategy – either formal or informal – increases a firm's returns to innovation. A firm is able to capture the benefits of its innovative efforts by strengthening its knowledge-protection strategy. Interestingly, the results here suggest that an informal knowledge-protection strategy has a similar impact upon a firm's innovation returns to a formal knowledge-protection strategy. This finding illustrates the benefits to the innovating firm of allocating resources to knowledge protection – formal or informal – when formulating an innovation strategy.

ii. Second, the analysis suggests that the industrial context plays a part in determining the effect formal and informal knowledge-protection strategies have on a firm's innovation returns. Both a stronger formal and informal knowledge-protection strategy increases innovation returns across high-technology/knowledge-intensive and low-technology/less knowledge-intensive innovating firms, although both protection strategies are more significant for the former. This finding is supported by those firms in industries with more technological opportunities placing a greater emphasis on knowledge-protection mechanisms (Laursen and Salter, 2005). With regards to the manufacturing and service sectors, both a stronger formal and informal knowledge-protection strategy increases a firm's innovation returns, although both strategies are more significant in service-sector innovating firms.

iii. Third, a stronger formal and informal knowledge-protection strategy increases the innovation returns of small firms, but formal strategies are more significant. Hall and Sena (2017) suggest that smaller firms have a greater need than larger firms to access inputs external to the firm and therefore derive a greater benefit from formal protection mechanisms. In large firms, only a stronger informal knowledge-protection strategy increases innovation returns. Hall and Sena (2017) find informal protection to be more important for large-firm productivity than for smaller-firm productivity. They suggest that large firms protect valuable innovations with informal mechanisms rather than formal mechanisms to avoid the disclosure of their knowledge.

iv. Fourth, a stronger formal knowledge-protection strategy increases the innovation returns of a radical, new-to-the-market innovator, whereas an informal protection strategy has an insignificant effect. As expected, new-to-the-market innovators are able to successfully appropriate the returns to innovation by protecting their knowledge with formal, legally enforceable, mechanisms. Formal knowledge-protection mechanisms are insignificant for new-to-the-firm innovation returns, as are informal mechanisms. As new-to-the-firm innovations are largely imitative, it is not surprising that firms are unlikely to increase their returns to innovation by using formal protection mechanisms (Laursen et al., 2013), whereas it is surprising that informal protection strategies have no significant impact on a new-to-the-firm innovator's returns. For example, a new-to-the-firm innovator taking a product to market behind a new-to-the-market innovator would be expected to benefit from using speed-to-market and secrecy, for example.

v. Fifth, a stronger formal knowledge-protection strategy increases the innovation returns of small new-to-the-market innovators, whereas a stronger informal knowledge-protection strategy increases the innovation returns of large new-to-the-market innovators. The extended analysis on radical, new-to-the-market innovators confirms the findings that were found in the wider-innovator data; formal knowledge-protection mechanisms are important for small-firm innovation returns and informal knowledge-protection mechanisms are important for large-firm innovation returns. In the high-technology/knowledge-intensive, new-to-the-market innovator group, a stronger formal knowledge-protection strategy increases innovation returns – an informal knowledge-protection strategy is insignificant. This supports the viewpoint that formal knowledge protection is more likely to be used by new-to-the-market innovators. A stronger formal and informal knowledge-protection strategy in manufacturing firms carrying out new-to-the-market innovations leads to increased innovation returns, although both protection strategies are insignificant for the innovation returns of radical, new-to-the-market innovators in the services sector.

Much of the policy debate surrounding the use of knowledge protection in the UK focuses on formal knowledge-protection mechanisms. In 2011, for example, an independent review of the UK's IP system was carried out to assess how the existing IP framework supported economic growth and innovation (Hargreaves, 2011). A series of recommendations were made in order to "ensure that the UK has an IP framework best suited to supporting innovation and promoting economic growth in the digital age".[21] Interestingly, the analysis undertaken in the present study not only

[21] IPO - Independent Review of IP and Growth Homepage
https://web.archive.org/web/20130112213030/http://www.ipo.gov.uk/ipreview.htm

highlights the importance of formal knowledge-protection mechanisms for innovation returns but also highlights the importance of informal knowledge-protection mechanisms. Informal protection mechanisms have a significant, positive effect upon the innovation returns of all sub-sample groups of innovators, suggesting that government policy should also be directed towards the promotion of informal protection mechanisms.

The significance of informal mechanisms for large-firm innovation returns – both in the wider-innovator group and in the new-to-the-market innovator group is particularly interesting given that a higher proportion of large firms relative to most other innovator groups use formal protection mechanisms (Table 4.1). Given the widespread use of formal protection mechanisms across large firms, this study shows that large firms that position themselves differently by using informal protection mechanisms achieve higher innovation returns.

The Intellectual Property Office (IPO) – the official UK government body responsible for intellectual property rights – organises events, provides guidance and internet tool-kits which are designed to help firms identify and protect their intellectual property. The focus is on formal protection mechanisms (patents, designs, trademarks and copyright). This service should be expanded to help firms develop strategies to protect their knowledge in an informal way. Some of the strategies firms should be encouraged to use include:

i. Designating an individual within the firm to identify intellectual property and implement and enforce secrecy compliance, for example. The individual should keep records, distribute and collect operations manuals, conduct exit interviews and respond to questions relating to the protection of the firm's IP.

ii. Making IP protection part of the employees' orientation and training program, and informing those employees who have access to firm-specific knowledge and confidential information of their continuing duty to prevent disclosure.

iii. Prohibiting individuals from making copies of confidential information unless it is necessary for them to perform their duties.

iv. Establishing physical safeguards to prevent third parties from gaining access to confidential information. For example, restricting access to proprietary documents and information and implementing log-in procedures prior to gaining access to locked desks and files.

v. Restricting access to software or records to those who have a need to use them in their job function. For example, only those involved in performing accounting services should be permitted to access the proprietary accounting software.

vi. Prohibiting employees from downloading proprietary software onto portable computers without prior authorisation and maintain detailed records of employees permitted to download proprietary software.

The government should direct the IPO to provide events and guidance to help firms use these and other informal strategies as a way of protecting their knowledge in an informal way.

The significance of formal knowledge-protection mechanisms for the innovation returns of small firms, both in the wider-innovator group and in the new-to-the-market innovator group, is evidence in support of policies aimed at improving the accessibility of IP for small firms. The Hargreaves Review in 2011 (Hargreaves, 2011) recommended that the accessibility of the IP system to small firms should be improved, and that small firms should have access to lower-cost providers of integrated IP legal and commercial advice. But in 2015, a study by the Federation of Small Businesses (FSB) found that small firms were still struggling to protect their innovations (FSB, 2015). The FSB surveyed more than 1,000 of its members and found that 25 per cent of these firms experienced a violation of their IP within the previous five years. Half of these firms reported that a product had been imitated by a competitor; a third reported a copyright infringement; a third said that they had experienced trademark infringements; and 44 per cent of firms that spent money on IP did not think that it was a worthwhile investment. The study concluded that there is a need for small firms to be better supported in utilising IP in the UK and overseas. The analysis conducted in the present study highlights that small, innovating firms may benefit – in terms of returns to innovation – by implementing a formal knowledge-protection strategy. It provides further evidence in support of IP-policy initiatives directed towards small firms. Given the significance of smaller firms in the UK economy – over 99 per cent of UK businesses were SMEs at the beginning of 2016 (NESTA, 2017) – policy designed to help small firms gain access to formal protection mechanisms, as well as policy aimed at promoting the use of formal knowledge-protection mechanisms in small firms, would support small-firm innovation and promote both firm and national-economy growth.

Expensive enforcement action presents major difficulties for SMEs. The UK government should look to other countries for examples of best practice. Start-ups and SMEs in the UK would benefit from an IP-voucher scheme similar to that which operates in Austria. The Austrian Ministry for Transport, Innovation and Technology absorbs 80 per cent of firms' patent-application costs, encouraging start-ups and SMEs to protect their IP using patents. In addition to receiving financial help, a team of experts advises firms throughout the process and provides the answers to any questions that they may have.

In addition, the IP problems of SMEs are often overlooked or underestimated by the police and customs authorities and by the courts and legal profession. SMEs should be helped to work more effectively with these agencies. Accordingly, staff at these agencies should be trained to take SMEs' IP problems more seriously.

Globally, the IP system is fragmented and would benefit from IP co-ordination offices at national levels. These offices should promote, co-ordinate and monitor the enforcement of formal IP rights. They should work with the courts and customs authorities to exchange information and experiences between countries. The promotion of an effective, co-ordinated enforcement system will encourage SMEs – and indeed firms of all sizes – to use formal IP protection; they will view it as a worthwhile investment.

4.6.1 Limitations and future work

There are several limitations to this study. First, this is a cross-sectional study, and due to the associated reverse-causality limitations, causal statements cannot be made. Pooling UK CIS data and creating a balanced-panel dataset would allow a causal analysis to be undertaken. Unfortunately, due to the nature of the UK CIS survey questions on knowledge protection varying across the different waves of data, a pooled UK CIS panel could not be used in the analysis. Second, it is expected that firms' knowledge-protection strategies have a delayed impact upon innovation returns. Given the cross-sectional nature of this study, it is not possible to allow for this delay in the estimations. In an attempt to overcome this problem, the proportion of firm sales coming from innovation *at the end of the 2008 to 2010 period* is related to formal and informal knowledge-protection strategies which take place *during the three-year period*. Future research will attempt to link firms' IP application and acquisition data with a pooled UK CIS panel dataset in order to address this limitation and enable a more in-depth analysis to be carried out. Third, the analysis here is limited to the UK. IP systems vary from country to country, and the effectiveness of formal knowledge-protection mechanisms may differ in different countries: the findings from the analysis carried out here may be specific to the UK. Fourth, there is no guarantee that the firm sales coming from innovation at the end of the survey period represent sales of innovations that were protected by formal and informal protection strategies during the previous three-year period – there is no link between the firm's innovative sales at the end of the period and the knowledge-protection mechanisms used during the period.

Using a pooled UK CIS panel dataset and matched IP data, future research will conduct a more detailed exploration of the performance effects of individual formal IP mechanisms within different industries – exploring sectoral contexts in more detail – and different sizebands. Analysis within specific industries and different sizebands within those industries is not undertaken in this study due to small sample sizes. The availability of a pooled UK CIS panel dataset with matched IP data will enable this detailed analysis to be undertaken.

Table 4.1: Innovators' use of knowledge-protection mechanisms during the 2008 to 2010 period

	Proportion of firms using each knowledge-protection mechanism (%)									
Knowledge-protection mechanism	**All innovators N=3,520**	**New-to-the-market innovators N=557**	**New-to-the-firm innovators N=1,344**	**Small-sized innovators N=1,491**	**Medium-sized innovators N=1,143**	**Large-sized innovators N=789**	**High-technology, knowledge-intensive innovators N=1,758**	**Low-technology, less knowledge-intensive innovators N=1,762**	**Service sector innovators N=2,310**	**Manufacturing sector innovators N=1,210**
Patent	12.8	22.8	7.2	9.6	14.7	17.0	15.8	9.8	8.9	20.2
Registered industrial design	4.5	6.5	2.2	3.0	5.0	7.1	4.5	4.5	2.7	7.9
Registered trademark	14.7	18.9	10.8	10.9	15.3	21.5	15.0	14.4	13.0	17.9
Copyright	12.6	16.7	8.6	12.2	11.2	15.7	15.4	9.7	11.5	14.6
Secrecy (including non-disclosure agreements)	27.8	36.3	22.0	26.9	29.0	28.8	35.4	20.2	24.5	34.0
Complexity of design	9.0	13.6	6.7	8.3	9.5	10.1	11.9	6.0	6.8	13.2
Lead-advantage time	11.8	16.5	8.3	12.3	11.1	12.0	13.1	10.5	9.1	16.9

Source: UK CIS, 2008 to 2010

Table 4.2: Descriptive statistics

Variable	Number of firms	Mean	Standard Deviation
Proportion of sales coming from products and services newly introduced (%)	3,520	13.38	21.16
Log of employment	3,369	4.05	1.74
Proportion of workforce that has a science/engineering degree (%)	3,249	10.64	19.93
Proportion of workforce that has a degree from other disciplines (%)	3,284	11.71	19.01
Export indicator (0/1)	3,520	0.47	0.50
Public support for innovation indicator (0/1)	3,520	0.18	0.38
Internal R&D indicator (0/1)	3,520	0.56	0.50
External R&D indicator (0/1)	3,520	0.24	0.43
Acquisition of advanced machinery and equipment indicator (0/1)	3,520	0.33	0.47
Acquisition of computer hardware indicator (0/1)	3,520	0.47	0.50
Acquisition of computer software indicator (0/1)	3,520	0.58	0.49
Acquisition of external knowledge indicator (0/1)	3,520	0.19	0.39
Training for innovative activities indicator (0/1)	3,520	0.43	0.50
Engagement in design activities indicator (0/1)	3,520	0.40	0.49
Extent or breadth of innovation co-operation (0 to 7)	3,520	2.03	2.00
Factor 1 – Formal knowledge-protection strategy	3,520	0.13	0.26
Factor 2 – Informal knowledge-protection strategy	3,520	0.17	0.30

Source: UK CIS, 2008 to 2010

Table 4.3: Correlation matrix (N=3,520)

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
(1) Proportion of sales coming from products and services newly introduced (%)	1.00																
(2) Log of employment	-0.19	1.00															
(3) Proportion of workforce that has a science/engineering degree (%)	0.20	-0.02	1.00														
(4) Proportion of workforce that has a degree from other disciplines (%)	0.03	-0.03	0.09	1.00													
(5) Export indicator (0/1)	0.06	0.15	0.24	0.04	1.00												
(6) Public support for innovation indicator (0/1)	0.11	0.04	0.23	-0.02	0.16	1.00											
(7) Internal R&D indicator (0/1)	0.15	0.11	0.21	0.04	0.25	0.21	1.00										
(8) External R&D indicator (0/1)	0.10	0.09	0.15	0.03	0.14	0.19	0.37	1.00									
(9) Acquisition of advanced machinery and equipment indicator (0/1)	0.04	0.11	0.04	-0.11	0.16	0.14	0.17	0.15	1.00								
(10) Acquisition of computer hardware indicator (0/1)	0.09	0.02	0.09	0.03	0.03	0.08	0.13	0.14	0.25	1.00							
(11) Acquisition of computer software indicator (0/1)	0.06	0.04	0.06	0.05	0.01	0.07	0.14	0.16	0.17	0.63	1.00						
(12) Acquisition of external knowledge indicator (0/1)	0.09	0.05	0.09	0.05	0.09	0.12	0.22	0.38	0.17	0.17	0.18	1.00					
(13) Training for innovative activities indicator (0/1)	0.09	0.08	0.14	0.05	0.04	0.11	0.26	0.23	0.17	0.24	0.25	0.28	1.00				
(14) Engagement in design activities indicator (0/1)	0.14	0.06	0.16	0.01	0.24	0.14	0.40	0.27	0.14	0.17	0.16	0.25	0.21	1.00			
(15) Extent or breadth of innovation co-operation (0 to 7)	0.13	0.15	0.19	0.05	0.16	0.25	0.26	0.28	0.16	0.15	0.16	0.23	0.25	0.23	1.00		
(16) Factor 1 – Formal knowledge protection strategy	0.15	0.14	0.21	0.07	0.30	0.20	0.29	0.26	0.15	0.06	0.08	0.22	0.14	0.28	0.27	1.00	
(17) Factor 2 – Informal knowledge protection strategy	0.19	0.04	0.27	0.05	0.27	0.25	0.31	0.25	0.15	0.11	0.13	0.20	0.17	0.32	0.34	0.32	1.00

Source: UK CIS, 2008 to 2010

Table 4.4: The effect of formal and informal knowledge-protection strategies on firm innovation returns – GLM regression (all innovators)

	All innovators
Log of employment	-0.228***
	(0.02)
Proportion of workforce that has a science/engineering degree (%)	0.006***
	(0.00)
Proportion of workforce that has a degree from other disciplines (%)	0.001
	(0.00)
Export indicator (0/1)	-0.048
	(0.08)
Public support for innovation indicator (0/1)	0.01
	(0.08)
Internal R&D indicator (0/1)	0.266***
	(0.08)
External R&D indicator (0/1)	-0.009
	(0.08)
Acquisition of advanced machinery and equipment indicator (0/1)	-0.061
	(0.07)
Acquisition of computer hardware indicator (0/1)	0.224***
	(0.09)
Acquisition of computer software indicator (0/1)	-0.092
	(0.09)
Acquisition of external knowledge indicator (0/1)	0.014
	(0.08)
Training for innovative activities indicator (0/1)	0.087
	(0.07)
Engagement in design activities indicator (0/1)	0.153**
	(0.07)
Extent or breadth of innovation co-operation (0 to 7)	0.051***
	(0.02)
Factor 1 – Formal knowledge-protection strategy	0.441***
	(0.12)
Factor 2 – Informal knowledge-protection strategy	0.441***
	(0.11)
Constant	-0.865
	(0.56)
N	3178
Log pseudo-likelihood	-960.97

Notes: Coefficients are reported with standard errors in parentheses. Models contain sectoral dummies, * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2008 to 2010.

Table 4.5: The effect of formal and informal knowledge-protection strategies on the innovation returns of high-tech/knowledge intensive and low-tech/less knowledge-intensive firms – GLM regression

	High-tech/knowledge-intensive innovators	Low-tech/ less knowledge-intensive innovators
Log of employment	-0.277***	-0.175***
	(0.03)	(0.03)
Proportion of workforce that has a science/engineering degree (%)	0.006***	0.005
	(0.00)	(0.00)
Proportion of workforce that has a degree from other disciplines (%)	-0.002	0.009***
	(0.00)	(0.00)
Export indicator (0/1)	-0.159	0.064
	(0.12)	(0.10)
Public support for innovation indicator (0/1)	-0.026	0.051
	(0.11)	(0.12)
Internal R&D indicator (0/1)	0.280**	0.274***
	(0.12)	(0.10)
External R&D indicator (0/1)	0.125	-0.214*
	(0.11)	(0.12)
Acquisition of advanced machinery and equipment indicator (0/1)	-0.078	-0.049
	(0.11)	(0.09)
Acquisition of computer hardware indicator (0/1)	0.192	0.270**
	(0.12)	(0.12)
Acquisition of computer software indicator (0/1)	-0.081	-0.116
	(0.13)	(0.12)
Acquisition of external knowledge indicator (0/1)	-0.066	0.122
	(0.12)	(0.12)
Training for innovative activities indicator (0/1)	0.053	0.135
	(0.10)	(0.10)
Engagement in design activities indicator (0/1)	0.066	0.220**
	(0.11)	(0.10)
Extent or breadth of innovation co-operation (0 to 7)	0.075***	0.028
	(0.03)	(0.02)
Factor 1 – Formal knowledge-protection strategy	0.461***	0.415**
	(0.16)	(0.16)
Factor 2 – Informal knowledge-protection strategy	0.555***	0.276*
	(0.14)	(0.15)
Constant	-1.295**	-1.016*
	(0.53)	(0.55)
N	1567	1611
Log pseudo-likelihood	-496.02	-459.86

Notes: Coefficients are reported with standard errors in parentheses. Models contain sectoral dummies, * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2008 to 2010.

Table 4.6: The effect of formal and informal knowledge-protection strategies on the innovation returns of manufacturing sector and service sector firms – GLM regression

	Manufacturing sector innovators	Service sector innovators
Log of employment	-0.164***	-0.251***
	(0.03)	(0.03)
Proportion of workforce that has a science/engineering degree (%)	0.011***	0.004**
	(0.00)	(0.00)
Proportion of workforce that has a degree from other disciplines (%)	0.005	0
	(0.00)	(0.00)
Export indicator (0/1)	-0.026	-0.052
	(0.12)	(0.10)
Public support for innovation indicator (0/1)	0.051	-0.015
	(0.11)	(0.11)
Internal R&D indicator (0/1)	0.201	0.287***
	(0.13)	(0.10)
External R&D indicator (0/1)	-0.202*	0.111
	(0.12)	(0.11)
Acquisition of advanced machinery and equipment indicator (0/1)	-0.052	-0.093
	(0.10)	(0.10)
Acquisition of computer hardware indicator (0/1)	0.117	0.282***
	(0.13)	(0.11)
Acquisition of computer software indicator (0/1)	0.028	-0.169
	(0.13)	(0.12)
Acquisition of external knowledge indicator (0/1)	0.034	-0.018
	(0.14)	(0.10)
Training for innovative activities indicator (0/1)	0.245**	0.003
	(0.11)	(0.09)
Engagement in design activities indicator (0/1)	0.167	0.15
	(0.11)	(0.09)
Extent or breadth of innovation co-operation (0 to 7)	0.049*	0.052**
	(0.03)	(0.02)
Factor 1 – Formal knowledge-protection strategy	0.295*	0.504***
	(0.15)	(0.17)
Factor 2 – Informal knowledge-protection strategy	0.272*	0.559***
	(0.14)	(0.15)
Constant	-1.115**	-4.692***
	(0.55)	(0.53)
N	1106	2072
Log pseudo-likelihood	-327.97	-629.77

Notes: Coefficients are reported with standard errors in parentheses. Models contain sectoral dummies, * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2008 to 2010.

Table 4.7: The effect of formal and informal knowledge-protection strategies on the innovation returns of small, medium and large firms – GLM regression

	Small-firm innovators (10 to 49 employees)	**Medium-firm innovators (50 to 249 employees)**	**Large-firm innovators (250 or more employees)**
Log of employment	-0.322***	-0.164***	-0.144***
	(0.06)	(0.06)	(0.06)
Proportion of workforce that has a science/engineering degree (%)	0.005**	0.005	0.009**
	(0.00)	(0.00)	(0.00)
Proportion of workforce that has a degree from other disciplines (%)	-0.001	0.001	-0.003
	(0.00)	(0.01)	(0.00)
Export indicator (0/1)	-0.129	0.099	-0.109
	(0.11)	(0.15)	(0.19)
Public support for innovation indicator (0/1)	-0.002	0.18	-0.167
	(0.12)	(0.14)	(0.16)
Internal R&D indicator (0/1)	0.380***	0.037	0.276
	(0.12)	(0.14)	(0.19)
External R&D indicator (0/1)	-0.04	0.161	-0.098
	(0.13)	(0.14)	(0.16)
Acquisition of advanced machinery and equipment indicator (0/1)	-0.084	-0.038	0.037
	(0.11)	(0.12)	(0.15)
Acquisition of computer hardware indicator (0/1)	0.213*	0.299*	0.316*
	(0.13)	(0.15)	(0.18)
Acquisition of computer software indicator (0/1)	-0.054	-0.196	-0.23
	(0.13)	(0.16)	(0.17)
Acquisition of external knowledge indicator (0/1)	0.033	-0.102	-0.068
	(0.12)	(0.18)	(0.18)
Training for innovative activities indicator (0/1)	0.189*	-0.251**	0.162
	(0.11)	(0.12)	(0.16)
Engagement in design activities indicator (0/1)	0.128	0.199	0.201
	(0.11)	(0.13)	(0.16)
Extent or breadth of innovation co-operation (0 to 7)	0.044	0.107***	0.055
	(0.03)	(0.03)	(0.04)
Factor 1 – Formal knowledge-protection strategy	0.556***	0.375*	0.142
	(0.21)	(0.20)	(0.19)
Factor 2 – Informal knowledge-protection strategy	0.396**	0.359*	0.784***
	(0.17)	(0.19)	(0.21)
Constant	-0.674	-2.644***	-2.490**
	(0.71)	(0.52)	(1.04)
N	1344	1056	697
Log pseudo-likelihood	-454.88	-280.74	-168.71

Notes: Coefficients are reported with standard errors in parentheses. Models contain sectoral dummies, * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2008 to 2010.

Table 4.8: The effect of formal and informal knowledge-protection strategies on the innovation returns of new-to-the-market, new-to-the-firm and new-to-the-market-and-firm innovators – GLM regression

	New-to-the-market innovators	New-to-the-firm innovators	New-to-the-market-and-firm innovators
Log of employment	-0.262***	-0.257***	-0.158***
	(0.05)	(0.04)	(0.03)
Proportion of workforce that has a science/engineering degree (%)	0.002	0.006*	0.005*
	(0.00)	(0.00)	(0.00)
Proportion of workforce that has a degree from other disciplines (%)	0.001	0.004	-0.004
	(0.00)	(0.00)	(0.00)
Export indicator (0/1)	0.194	-0.031	-0.238**
	(0.20)	(0.12)	(0.10)
Public support for innovation indicator (0/1)	0.099	0.104	-0.062
	(0.22)	(0.16)	(0.10)
Internal R&D indicator (0/1)	0.112	-0.014	0.036
	(0.23)	(0.13)	(0.12)
External R&D indicator (0/1)	0.089	-0.083	-0.111
	(0.21)	(0.15)	(0.11)
Acquisition of advanced machinery and equipment indicator (0/1)	-0.114	0.022	-0.111
	(0.20)	(0.11)	(0.09)
Acquisition of computer hardware indicator (0/1)	0.563***	0.227	0.131
	(0.19)	(0.15)	(0.11)
Acquisition of computer software indicator (0/1)	-0.088	-0.156	-0.045
	(0.20)	(0.16)	(0.12)
Acquisition of external knowledge indicator (0/1)	-0.393*	0.029	0.069
	(0.22)	(0.15)	(0.10)
Training for innovative activities indicator (0/1)	-0.069	0.021	0.056
	(0.19)	(0.12)	(0.10)
Engagement in design activities indicator (0/1)	-0.038	0.069	0.122
	(0.20)	(0.12)	(0.10)
Extent or breadth of innovation co-operation (0 to 7)	-0.015	0.057	0.025
	(0.04)	(0.04)	(0.02)
Factor 1 – Formal knowledge-protection strategy	0.745**	-0.02	0.238*
	(0.31)	(0.24)	(0.13)
Factor 2 – Informal knowledge-protection strategy	0.292	0.151	0.352***
	(0.26)	(0.21)	(0.13)
Constant	-2.249***	-0.267	-0.179
	(0.40)	(0.71)	(0.91)
N	502	1225	802
Log pseudo-likelihood	-162.27	-356.72	-320.76

Notes: Coefficients are reported with standard errors in parentheses. Models contain sectoral dummies, * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2008 to 2010.

Table 4.9: The effect of formal and informal knowledge-protection strategies on the innovation returns of small, medium and large new-to-the-market innovators – GLM regression

	Small new-to-the-market innovators	Medium new-to-the-market innovators	Large new-to-the-market innovators
Log of employment	-0.508***	-0.002	-0.403***
	(0.17)	(0.12)	(0.12)
Proportion of workforce that has a science/engineering degree (%)	-0.002	0.006	0.001
	(0.01)	(0.01)	(0.01)
Proportion of workforce that has a degree from other disciplines (%)	-0.004	0.002	-0.001
	(0.01)	(0.01)	(0.01)
Export indicator (0/1)	0.017	0.659**	0.519
	(0.30)	(0.33)	(0.46)
Public support for innovation indicator (0/1)	0.007	0.256	0.216
	(0.34)	(0.38)	(0.44)
Internal R&D indicator (0/1)	-0.067	0.039	0.655
	(0.36)	(0.31)	(0.51)
External R&D indicator (0/1)	0.333	0.204	-0.236
	(0.34)	(0.27)	(0.43)
Acquisition of advanced machinery and equipment indicator (0/1)	0.171	-0.276	0.874*
	(0.33)	(0.27)	(0.51)
Acquisition of computer hardware indicator (0/1)	0.800**	0.591**	0.838**
	(0.32)	(0.30)	(0.41)
Acquisition of computer software indicator (0/1)	0.357	-0.424	0.207
	(0.33)	(0.29)	(0.38)
Acquisition of external knowledge indicator (0/1)	-0.624*	-0.209	-1.403***
	(0.36)	(0.39)	(0.43)
Training for innovative activities indicator (0/1)	0.084	-0.487*	-0.564
	(0.28)	(0.29)	(0.43)
Engagement in design activities indicator (0/1)	-0.27	0.181	-0.104
	(0.30)	(0.34)	(0.45)
Extent or breadth of innovation co-operation (0 to 7)	0.009	-0.044	-0.072
	(0.07)	(0.09)	(0.10)
Factor 1 – Formal knowledge-protection strategy	1.109**	0.513	0.296
	(0.47)	(0.52)	(0.62)
Factor 2 – Informal knowledge-protection strategy	0.398	0.077	1.188**
	(0.49)	(0.33)	(0.51)
Constant	-1.664**	-2.192***	-1.726
	(0.78)	(0.58)	(1.08)
N	215.00	162.00	113.00
Log pseudo-likelihood	-74.94	-45.02	-24.38

Notes: Coefficients are reported with standard errors in parentheses. Models contain sectoral dummies, * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2008 to 2010.

Table 4.10: The effect of formal and informal knowledge-protection strategies on the innovation returns of high-tech/knowledge-intensive and low-tech/less knowledge-intensive new-to-the-market innovators – GLM regression

	High-tech/knowledge-intensive new-to-the-market innovators	Low-tech/ less knowledge-intensive new-to-the-market innovators
Log of employment	-0.300***	-0.228***
	(0.07)	(0.08)
Proportion of workforce that has a science/engineering degree (%)	0.003	0.007
	(0.01)	(0.01)
Proportion of workforce that has a degree from other disciplines (%)	0.001	-0.006
	(0.01)	(0.01)
Export indicator (0/1)	-0.184	0.805***
	(0.26)	(0.30)
Public support for innovation indicator (0/1)	-0.334	0.749**
	(0.28)	(0.31)
Internal R&D indicator (0/1)	0.022	0.287
	(0.38)	(0.29)
External R&D indicator (0/1)	0.313	-0.188
	(0.26)	(0.31)
Acquisition of advanced machinery and equipment indicator (0/1)	0.192	-0.472*
	(0.26)	(0.26)
Acquisition of computer hardware indicator (0/1)	0.678**	0.01
	(0.30)	(0.25)
Acquisition of computer software indicator (0/1)	-0.363	0.482**
	(0.29)	(0.24)
Acquisition of external knowledge indicator (0/1)	-0.667**	0.019
	(0.29)	(0.40)
Training for innovative activities indicator (0/1)	-0.078	-0.103
	(0.24)	(0.29)
Engagement in design activities indicator (0/1)	0.007	-0.087
	(0.30)	(0.24)
Extent or breadth of innovation co-operation (0 to 7)	0.048	-0.077
	(0.07)	(0.06)
Factor 1 – Formal knowledge-protection strategy	1.104***	0.135
	(0.43)	(0.56)
Factor 2 – Informal knowledge-protection strategy	0.343	0.325
	(0.32)	(0.42)
Constant	0.353	-2.433***
	(0.65)	(0.59)
N	273.00	229.00
Log pseudo-likelihood	-91.97	-65.77

Notes: Coefficients are reported with standard errors in parentheses. Models contain sectoral dummies, * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2008 to 2010.

Table 4.11: The effect of formal and informal knowledge-protection strategies on the innovation returns of manufacturing sector and service sector new-to-the-market innovators – GLM regression

	Manufacturing sector new-to-the-market innovators	Service sector new-to-the-market innovators
Log of employment	-0.116	-0.338***
	(0.07)	(0.07)
Proportion of workforce that has a science/engineering degree (%)	0.017**	-0.004
	(0.01)	(0.01)
Proportion of workforce that has a degree from other disciplines (%)	-0.002	-0.001
	(0.01)	(0.01)
Export indicator (0/1)	0.404	0.219
	(0.30)	(0.25)
Public support for innovation indicator (0/1)	0.131	0.123
	(0.32)	(0.28)
Internal R&D indicator (0/1)	-0.382	0.214
	(0.34)	(0.29)
External R&D indicator (0/1)	-0.267	0.282
	(0.33)	(0.26)
Acquisition of advanced machinery and equipment indicator (0/1)	-0.612**	0.205
	(0.27)	(0.27)
Acquisition of computer hardware indicator (0/1)	0.654**	0.596**
	(0.28)	(0.24)
Acquisition of computer software indicator (0/1)	-0.159	-0.071
	(0.30)	(0.25)
Acquisition of external knowledge indicator (0/1)	-0.36	-0.48
	(0.31)	(0.30)
Training for innovative activities indicator (0/1)	0.048	-0.128
	(0.25)	(0.25)
Engagement in design activities indicator (0/1)	-0.113	0.001
	(0.31)	(0.24)
Extent or breadth of innovation co-operation (0 to 7)	0.011	-0.013
	(0.07)	(0.05)
Factor 1 – Formal knowledge-protection strategy	0.919**	0.673
	(0.38)	(0.42)
Factor 2 – Informal knowledge-protection strategy	0.638**	-0.022
	(0.28)	(0.39)
Constant	-1.221*	-4.252***
	(0.65)	(0.89)
N	186.00	316.00
Log pseudo-likelihood	-51.89	-107.29

Notes: Coefficients are reported with standard errors in parentheses. Models contain sectoral dummies, * denotes significance at the 10 per cent level, ** at the 5 per cent level and *** at the 1 per cent level.
Source: UK CIS 2008 to 2010.

Chapter 5

Conclusion

5.1 Summary of findings and policy implications

Since the recent emergence of the knowledge-based economy, intangible assets have overtaken tangible assets as the dominant driver of value creation. The recognition that growth and innovation stem from intangible assets (Montresor et al., 2014; Roper et al., 2016a) has led firms to become increasingly concerned with strategies relating to such assets, focusing particularly on the creation of intangible assets through investment and their management thereafter.

This thesis contributes towards the understanding of firms' intangibles strategies and the link between firms' intangibles strategies and innovation returns. More specifically, it explores how the investment and protection components of firms' intangibles strategies are influenced by the industry environment (in particular the industry appropriability regime and elements of industry structure), how the industry appropriability regime influences the complexity and variability of firms' knowledge-protection strategies within an industry and how firms' intangibles protection strategies influence innovation returns.

As an important part of overall industrial policy, knowledge protection mechanisms support firms' investment into knowledge. Knowledge protection mechanisms boost innovation and productivity and allow for faster growing, more resilient businesses. This thesis supports policy teams by providing economic analysis on key issues. The development of well-informed policy relies upon robust data and evidence, and this thesis can inform knowledge-protection policy by providing an economic, evidence-based approach to research into intangibles strategy.

The research findings in this thesis are of interest to both the academic and policy audience. The policy audience – including the Intellectual Property Office (IPO) and Innovate UK – can use the results from the three empirical studies in this thesis to inform and justify focused policy initiatives. The IPO – the official United Kingdom (UK) government body responsible for intellectual property (IP) rights – supports firms in obtaining the correct protection for creations or inventions and helps firms to better understand how to manage and exploit IP. The IPO encourages and supports innovation, helping the economy and society to benefit from knowledge and ideas. Innovate UK – the UK's innovation agency – supports business-led innovation and helps to drive growth by working with firms to enable and support innovation. This thesis provides both the IPO and Innovate UK (amongst other policy bodies) with information on the determinants of firms' intangibles strategies (including IP). In addition, it provides information on how these strategies impact upon firm innovation performance. The research helps inform policymakers on how best to direct firm strategy, through policy interventions, in order to promote firm innovation and growth.

5.1.1 Chapter 2: Conclusions and policy implications

Chapter 2 investigates the proposition that firms' strategy decisions depend strongly on the market environment in which they operate (Scott, 1982). The empirical analysis examines how the industry appropriability regime and industry structure – both part of the industry environment – affect firms' intangibles investment and protection strategies. The empirical results suggest that both an industry's structure and the industry appropriability regime help drive firms' intangibles strategies. Both elements of the industry environment are found to affect the individual components of a firm's intangibles strategy in different ways. Consequently, it is not possible to single out one part of the industry environment as having the greatest impact upon a firm's intangibles strategy.

Theory suggests that a change in industry structure – given by a change in the competitive forces within the industry (Porter, 1980) – may affect firm strategy. In this firm-level study, an increase in competition within an industry reduces the probability that a firm will invest in research and development (R&D) and Training – two forms of intangible investment. In addition, the analysis suggests that the source of any new competition within an industry – be it from new entrants or existing firms – may be important; as well as reducing the probability that a firm will invest in R&D and Training, an increase in competition from new entrants also reduces the probability that a firm will invest in Design, whereas an increase in competition from incumbent firms also reduces the probability that a firm will invest in Computer Software.

In summary, the analysis presented in Chapter 2 suggests that an increase in competition within an industry reduces the probability that a firm will invest in intangible assets. Firms are discouraged from investing in innovative activities because the expected return to investment falls. As there is little incentive to innovate (Schumpeter, 1942), the probability that a firm will invest in intangible assets falls.

In addition to industry structure, the industry appropriability regime – also part of the industry environment – has implications for a firm's intangibles strategy; it governs a firm's ability to capture profits from an innovation (Teece, 1986). In Chapter 2, several variables are included to represent the industry appropriability regime. The empirical analysis suggests that there is a consistent, positive effect on the investment component of a firm's intangibles strategy when the 'nature of technology' dimension of the industry appropriability regime weakens. As part of this study, it is hypothesised that those variables which reflect the importance of standards and publications to firms' innovation activities will be negatively related to firms' intangibles investment; it is assumed that they reflect the extent to which knowledge is codified. In contrast to the expected findings, the results show that an increase in the importance of standards and publications to firms' innovation activities represents a source of benefit for a firm. Indeed, Spencer (2003) suggests that firms that share technological knowledge may achieve higher innovative performance than firms that do not share knowledge because they are able to shape the institutional environment in favour of their own technological design.

In addition, the analysis in Chapter 2 finds that there is a clear, consistent, positive effect on the investment component of a firm's intangibles strategy when the 'knowledge-protection dimension' of the industry appropriability regime strengthens. An increase in the effective knowledge protection within an industry provides firms with the tools necessary to appropriate the returns to investment. It is these stronger appropriability conditions which provide firms with an incentive to invest in innovative activities (Levin et al., 1987).

In Chapter 2, the protection component of a firm's intangibles strategy is analysed by examining how the industry appropriability regime and elements of industry structure affect the *importance* firms attach to different knowledge-protection mechanisms as well as examining how the industry appropriability regime and elements of industry structure affect firms' *actual* protection decisions. The empirical results suggest that when industry competition increases, the importance firms attach to various knowledge-protection mechanisms depends upon the source of the competition. It seems that firms attach more importance to formal protection when the increase in competition comes from existing firms, whereas when the increase in competition is from new, young firms, less emphasis is placed upon the importance of all knowledge-protection mechanisms. This may be explained by new, young firms posing less of a threat than existing firms due to their limited resources and capabilities, for example.

When the 'nature of technology' dimension of the industry appropriability regime weakens (knowledge becomes more codified), the empirical analysis finds that firms are more likely to view informal and formal knowledge-protection mechanisms as being important. Firms realise that knowledge-protection mechanisms allow them to appropriate the returns from their investments by helping guard against the increased risk of imitation (as knowledge is more codified). Firms are also more likely to view informal and formal knowledge-protection mechanisms as being important when the 'knowledge-protection dimension' of the industry appropriability regime strengthens. As the effective protection mechanisms within an industry increases, firms have available tools to protect their knowledge and help appropriate the returns from their investment; they are therefore more likely to view protection mechanisms as being important.

Upon examination of firms' *actual* protection decisions, the analysis suggests that new competition from new entrants increases the probability that firms will use some forms of informal knowledge protection (Secrecy and Complexity of Design). The probability that firms will use formal knowledge protection is reduced. When knowledge within an industry becomes more codified, and when effective knowledge protection within an industry increases, there is also an increase in the probability that a firm will use informal knowledge-protection mechanisms (Secrecy, Lead-time Advantage and Copyright).

The results in Chapter 2 suggest that firms' actual knowledge-protection decisions differ from what they say is important. As the industry environment changes, firms indicate that the importance of both informal and formal knowledge-protection mechanisms changes. In reality, the results suggest that firms are more likely to use protection mechanisms which are easy to implement, rather than opt for more formal, costly options.

The analysis in Chapter 2 suggests that both industry structure and the industry appropriability regime have a role in driving a firm's intangibles strategy. The results indicate that the industry appropriability regime has a consistent effect – in terms of direction – on all of the intangible investments examined. The effects of a change in industry structure or competition vary across the intangible investments being examined and also depend upon the source of the change in competition.

Firms attach more importance to both informal and formal knowledge-protection mechanisms when the industry appropriability regime increases in strength. When there are changes in industry structure, firms attach more importance to formal mechanisms. Regarding firms' actual protection decisions, the results suggest that industry structure is less important than the industry appropriability regime in determining firms' knowledge-protection strategies – increased competition from incumbents has an insignificant effect on the probability that a firm will use most knowledge-protection mechanisms, whereas there is a significant, positive effect on a firm's use of the easier-to-implement protection mechanisms when the industry appropriability regime strengthens.

5.1.1.1 Policy implications

The analysis in Chapter 2 provides policymakers with an understanding of how different elements of the industry environment – industry structure and the industry appropriability regime – impact upon firms' innovation strategies. By ensuring that the correct policy levers are in place, the government can help firms foster the accumulation of intangibles and, in turn, unleash potential growth.

Policy designed to strengthen industry appropriability regimes (for example, policy designed to increase the available, effective protection mechanisms or policy designed to help firms strengthen their natural protection) will encourage firms to invest in innovative activities. Particular industries have strong appropriability regimes – the pharmaceuticals industry, for example. Some firms in these industries may face barriers to formal protection (for example, smaller firms), and government policy should target these firms; innovation vouchers could be issued to help those firms facing financial constraints; firms could be helped identify IP that they own; firms could be guided through the formal-IP application process; and firms could be given specialist advice if an IP-infringement occurs. Other industries, for example the soft-drinks industry, have weak appropriability regimes. Typically, formal protection such as patents is ineffective in these industries, and firms rely on trademarks, copyright and easier-to-implement protection such as secrecy. In the case of the soft-drinks industry, secret recipes help deter imitation, for example. Government policy should help firms in these industries develop a protection strategy using formal protection mechanisms such as trademarks and copyright and informal protection mechanisms such as secrecy. Government policy initiatives can support firms to increase their informal protection by helping them: designate an individual within the firm to identify intellectual property and implement and enforce secrecy compliance; make IP protection part of their employees' orientation and training program; inform those employees who have access to firm-specific knowledge and confidential information of their continuing duty to prevent disclosure; prohibit individuals from making copies of confidential information unless it is necessary for them to perform their duties; and prohibit employees from downloading proprietary software onto portable computers without prior authorisation and maintain detailed records of employees permitted to download proprietary software. The Intellectual Property Office (IPO) (the official UK government body responsible for intellectual property rights) should, in the same way as they do for formal protection, provide events, tool-kits, case studies and guidance to help firms use these and other informal strategies as a way of protecting their knowledge in an informal way. In summary, government policy aimed at increasing appropriability strength across all industries – by promoting both informal and formal knowledge protection – will encourage innovative investment in all firms.

An increase in industry competition sees firms increase their use of informal protection mechanisms and identify formal mechanisms as having an increased level of importance in the innovation process. Firms should be encouraged to know their market – they should actively monitor the market in which they are engaged as firms can only react to changes in their competitive environment if they know that they have happened. Monitoring competitors' behaviour can be costly – both financially and in terms of time. Large firms may employ market analysts to keep abreast of the industry climate, whereas small firms may be resource constrained. Policy initiatives should be put in place to help firms monitor their market and set up appropriate strategies in order to protect themselves.

5.1.2 Chapter 3: Conclusions and policy implications

In Chapter 3, the heterogeneous nature of firm-specific resources and capabilities gives rise to a variation in firms' knowledge-protection strategies within an industry, despite all firms within an industry being faced with identical knowledge-protection opportunities as defined by the industry appropriability regime. Firms choose protection mechanisms in line with their own resources and capabilities and the appropriability regime of the industry to which they belong. They assess the potential of and the restrictions related to the use of each available protection mechanism – in terms of its availability, efficacy and efficiency (Hurmelinna-Laukkanen and Puumalainen, 2007b) – before deciding which protection mechanisms to implement. Firms reach optimising decisions by considering the constraint which they face i.e. the appropriability regime, and this results in a range of knowledge-protection choices – or profiles (Hurmelinna- Laukkanen et al., 2017).

In this industry-level study, the empirical analysis examines how an increase in the strength of the industry appropriability regime – given by an increase in the availability of effective knowledge-protection mechanisms within the industry – affects the average complexity and variability of firms' knowledge-protection strategies within an industry.

The industry appropriability regime – part of the industry environment – governs a firm's ability to capture profits from an innovation (Teece, 1986). As a consequence, the two dimensions of the industry appropriability regime – the nature of the industry technology and the methods of knowledge protection available to protect both innovations themselves and any increased rents which flow from them (Teece, 1986, 1998, 2000a; Levin et al., 1987; Teece and Pisano, 1998), have implications for a firm's knowledge-protection strategy. The empirical results in Chapter 3 suggest that the average complexity of firms' knowledge-protection strategies within an industry increases when the knowledge-protection dimension of the industry appropriability regime strengthens. The stronger appropriability regime allows those firms equipped with the required resources and capabilities to strengthen their own knowledge-protection strategy by increasing the number of knowledge-protection mechanisms they use to help appropriate returns to their innovations. The stronger protection regime increases firms' strategy space and allows more firms within the industry to optimise their knowledge-protection decisions. More firms capture the benefits from innovation and are incentivised to make further innovative investments (Granstrand, 1999).

The empirical analysis further suggests that the diversity or variability of firms' knowledge-protection strategies within an industry increases when the knowledge-protection dimension of the industry appropriability regime strengthens. Within an industry, a firm that conforms to the strategies of others has many similar competitors; this limits performance and increases failure rates (Henderson, 1981; Hannan et al., 1990; Baum and Singh, 1994). As the industry protection regime strengthens, the knowledge-protection strategy space increases. Firms with the necessary resources and capabilities to do so are able to position themselves differently to other firms within the industry because they are no longer forced to conform to the knowledge-protection strategies of others. Consequently, within an industry, the variability of firms' knowledge-protection strategies increases. By positioning themselves differently, firms face less competition and improve their chances of success. Subsequently, successful firms will be incentivised to make further innovative investments.

These empirical results i.e. that, within an industry, the average complexity and variability of firms' knowledge-protection strategies increases when the knowledge-protection dimension of the industry appropriability regime strengthens, emerge from UK Community Innovation Survey (CIS) data which covers all industries. Following this initial analysis, the empirical analysis is further extended to include a comparison of different industries – high-technology/knowledge-intensive industries and low-technology/less knowledge-intensive industries. The results from this comparison suggest that there is a stronger relationship between strategic complexity and the strength of the industry appropriability regime in knowledge-intensive industries. High-technology/knowledge intensive firms undertake knowledge-intensive innovations, and are therefore more likely to use any additional protection options available to them.

The increase in the diversity or variability of firms' knowledge-protection strategies within an industry following an increase in the strength of the industry formal-protection regime is also greater for high-technology/knowledge-intensive industries than for low-technology/less knowledge-intensive industries, although the difference between the two industry groups is less significant than in the complexity-of-strategy case. Given that firms in high-technology/knowledge-intensive industries have more complex strategies when the knowledge-protection dimension of the industry appropriability regime strengthens, their 'strategy sets' will be larger than those of firms in low-technology/less knowledge-intensive industries, and therefore they have more opportunities to act differently to other firms within the industry. By positioning themselves differently, firms face less competition and improve their chances of success.

5.1.2.1 Policy implications

Government policy relating to firms' use of knowledge-protection mechanisms focuses on formal protection methods. The empirical results in Chapter 3 suggests that the availability and effectiveness of both informal and formal protection mechanisms have implications for the average complexity and variability of firms' knowledge-protection strategies within an industry.

It is important, therefore, that in addition to the current policy which surrounds formal knowledge protection, new policy initiatives are directed towards the promotion and use of informal protection mechanisms across all firms. This will enable firms to seize valuable, strategic opportunities by engaging in informal protection practices. The likelihood of a firm finding a strategic opportunity is increased if it is able to use its resources and capabilities in a unique way – differentiating itself from other firms. Therefore, government policy aimed at promoting the use of informal protection will enable those firms that face barriers to the use of formal mechanisms to position themselves differently to other firms when new opportunities arise. In doing so, a firm is more likely to receive the benefits from its positioning (Denrell et al., 2003). Government policy supporting informal protection will increase firms' chances of receiving the returns to its innovation, increase the probability of further innovative investment and, in turn, promote long-run growth. Government policies supporting informal knowledge protection will encourage firms that do have the resources and capabilities to use formal knowledge protection to also invest in informal protection. This may allow both the innovations and the knowledge-protection to be used more widely (Hurmelinna-Laukkanen, 2014). A wide set of knowledge-protection mechanisms will give firms the readiness to change direction and, at the same time, it will increase their chances of performance success in new ventures – given that performance outcomes depend upon a firm's ability to protect assets.

Examples of ways in which government policy initiatives can support firms to increase their informal protection include: designating an individual within the firm to identify intellectual property and implement and enforce secrecy compliance. The individual should keep records, distribute and collect operations manuals, conduct exit interviews and respond to questions relating to the protection of the firm's IP; making IP protection part of the employees' orientation and training program, and informing those employees who have access to firm-specific knowledge and confidential information of their continuing duty to prevent disclosure; prohibiting individuals from making copies of confidential information unless it is necessary for them to perform their duties; and prohibiting employees from downloading proprietary software onto portable computers without prior authorisation and maintain detailed records of employees permitted to download proprietary software.

The Intellectual Property Office (IPO) (the official UK government body responsible for intellectual property rights) should, in the same way as they do for formal protection, provide events, tool-kits, case studies and guidance to help firms use these and other informal strategies as a way of protecting their knowledge in an informal way.

The empirical results also indicate that there is a need for policymakers to be aware of the differences which exist in relation to the individual industry responses to a change in the strength of the industry appropriability regime. The results in Chapter 3 help inform policymakers about the sensitivity of different industries to knowledge-protection policies. Results suggest that government policies supporting formal knowledge-protection will have stronger positive effects upon the average knowledge-protection strategy and the diversity of knowledge-protection strategies in high-technology/knowledge intensive industries than in low-technology/less knowledge-intensive industries. Government policy should provide extra formal-protection support for firms in high-technology/knowledge-intensive industries. The IPO should target high-technology/knowledge-intensive firms – particularly those that may find it difficult to engage in formal knowledge protection (small firms, for example) and help them to identify their intellectual property (through tool-kits, for example) and suggest appropriate formal protection mechanisms. Resource-constrained high-technology/knowledge-intensive firms should also be directed towards any financial help that is available to them (innovation vouchers, for example).

5.1.3 Chapter 4: Conclusions and policy implications

The empirical analysis in Chapter 4 tests the contention that knowledge-protection strategies help firms capture returns from their innovations. The empirical analysis examines both formal and informal knowledge-protection strategies and seeks to ascertain which knowledge-protection strategy – formal or informal – allows firms to most successfully derive economic benefit from an innovation.

The empirical results in Chapter 4 suggest that a stronger formal or informal knowledge-protection strategy increases a firm’s returns to innovation, and the effects are similar in magnitude for both strategy types. In addition, the analysis highlights industrial context as being an important determining factor; both formal and informal knowledge-protection strategies are more significant for firms' innovation returns in high-technology/knowledge-intensive industries than in low-technology/less knowledge-intensive industries, and both formal and informal knowledge-protection strategies are more significant for firms' innovation returns in service-sector firms compared with manufacturing-sector firms.

In addition, Chapter 4 considers whether formal and informal knowledge-protection strategies impact upon firms' innovation returns differently across firms of different sizes. Although empirical results suggest that both formal and informal protection strategies are significant for small-firm innovation returns, the results indicate that formal knowledge-protection strategies are more significant. This result supports that of Hall and Sena (2017) who suggest that smaller firms derive a greater benefit than larger firms from formal mechanisms because small firms have a greater need to access inputs external to the firm. Indeed, the results in Chapter 4 suggest that a stronger informal protection strategy increases large-firm innovation returns, but a stronger formal protection strategy does not. Hall and Sena (2017) suggest that large firms derive more benefit from informal mechanisms because formal mechanisms require the disclosure of knowledge.

In addition to comparing results across different industries and firm sizes, Chapter 4 considers how informal and formal knowledge-protection strategies affect the innovation returns of different innovator types. The empirical results suggest that a stronger formal knowledge-protection strategy increases the innovation returns of a radical, new-to-the-market innovator, whereas an informal protection strategy has an insignificant effect. The innovation returns of new-to-the-firm innovators are not significantly affected by either formal or informal knowledge-protection strategies. The imitative nature of new-to-the-firm innovators makes it unsurprising that such firms are unlikely to benefit from using formal knowledge-protection mechanisms. Informal knowledge-protection mechanisms, on the other hand, may benefit a new-to-the-firm innovator by shielding knowledge from other competitors in the marketplace (for example secrecy, and speed-to-market). The insignificant effect of informal protection strategies on new-to-the-firm innovator returns is therefore somewhat surprising.

An extended analysis further examines the new-to-the-market innovator group. The findings confirm that a more formal knowledge-protection strategy is important for small-firm innovation returns and a more informal knowledge-protection strategy is important for large-firm innovation returns. Upon examination of different industries within the new-to-the-market innovator group, high-technology/knowledge-intensive firms only benefit from stronger formal knowledge-protection strategies; informal knowledge-protection strategies are insignificant. In manufacturing new-to-the-market innovating firms, both a stronger formal and informal knowledge-protection strategy leads to increased innovation returns. In contrast, both formal and informal knowledge-protection strategies are insignificant for the innovation returns of new-to-the-market innovators in the services sector.

5.1.3.1 Policy implications

Formal knowledge-protection mechanisms lie at the centre of much of the policy debate surrounding the use of knowledge protection in the UK. The empirical analysis in Chapter 4 confirms the importance of formal knowledge-protection mechanisms for innovation returns (in some firms), and in addition, highlights the important performance effects associated with the use of informal knowledge-protection mechanisms (in some firms). Consequently, tailored policy directed towards particular innovators and aimed at promoting the use of formal and/or informal knowledge protection may lead to wider economic benefits. It is particularly interesting that informal knowledge-protection strategies appear to be a source of benefit to large firms, given that a higher proportion of large firms, than any other sizeband, use formal knowledge protection. In light of this result, the promotion of informal protection in large firms would free-up resources being used to obtain formal protection and allow for them to be directed elsewhere.

The results in Chapter 4 provide evidence of the importance of formal knowledge protection mechanisms for small firms. In 2011, the Hargreaves Review (Hargreaves, 2011) recommended that the accessibility of IP for small firms needed to be improved, and following this, a study by the Federation of Small Businesses (FSB) in 2015 (FSB, 2015) found that small firms struggle to protect their innovations. The analysis in Chapter 4 provides further evidence in support of IP-policy initiatives directed towards small firms. At the beginning of 2016, over 99 per cent of UK businesses were small and medium-sized enterprises (SMEs) (NESTA, 2017). Given the significance of small firms in the UK economy, it is in the national economy's interest to target IP policy towards small firms. By helping small firms overcome any barriers to formal knowledge protection that they face, and by promoting the use of formal protection mechanisms within small firms, policymakers will play a part in promoting both firm-level and national-economy growth.

5.2 Contributions

5.2.1 Chapter 2: Contributions

This study adds to existing literature by providing a holistic view of a firm's intangibles strategy; it examines factors which influence a firm's investment into intangibles, a firm's attitudes towards knowledge protection mechanisms and a firm's actual knowledge-protection decisions. Previous studies have examined the performance effects of firms' intangibles strategies i.e. how intangibles investment affects performance (for example, Nesta, 2008) and how intangibles protection influences performance (for example, Hu, 2013). In contrast to these studies, the empirical analysis in Chapter 2 is concerned with the determinants of a firm's intangibles strategy rather than the performance effects.

Previously, many studies have examined the determinants of a firm's innovative investment – one dimension of a firm's intangibles strategy. The majority of this literature focuses upon two factors: the effects of firm size and market power (Schumpeter, 1942) and industry-specific determinants such as appropriability (Teece, 1986). Empirical studies investigating the effects of market concentration or industry structure upon innovative behaviour (for example, Acs and Audretsch, 1987; Kraft, 1989; Aghion et al., 2005) do not reach a consensus. Empirically, evidence on the relationship between appropriability and innovative investment is inconclusive. Some studies find no statistically-significant effect of appropriability upon R&D intensity (for example, Levin et al., 1985), while others find a positive effect for some industries (for example, Mansfield, 1986). Market concentration plays a part in determining a firm's knowledge-protection decisions – another dimension of a firm's intangibles strategy. For example, it would be inefficient for firms to use costly protection methods within an industry controlled by a monopolist (Granstrand, 1999). In addition, studies have found that appropriability conditions within an industry's environment help determine a firm's knowledge-protection strategy (for example, Harabi, 1995; Arundel and Kabla, 1998; Leiponen and Byma, 2009). Chapter 2 adds to this existing body of knowledge by considering how two elements of the industry environment – the industry appropriability regime and industry structure – affects firms' intangibles strategies. Unlike previous studies, Chapter 2 focuses on both factors which have previously been identified as helping to determine a firm's intangibles investment and protection strategy. The study contributes to existing knowledge by asking if one particular element of the industry environment matters more than the other in determining a firm's intangibles investment and protection strategies. In addition, the study examines whether the effects of the different elements of the industry environment are consistent across the individual components of a firm's intangibles strategy.

5.2.2 Chapter 3: Contributions

This study adds to the existing literature on knowledge protection by providing a holistic view of firms' knowledge-protection strategies within an industry setting. The empirical analysis examines how the industry appropriability regime affects the average complexity and variability of firms' protection strategies within an industry. Previous studies identify industry characteristics such as the level of technology and R&D intensity as being an important determinant of a firm's protection strategy (Mansfield, 1986; Levin et al., 1987; Harabi, 1995; Cohen et al., 2000), and factors such as the availability of firm resources (Kitching and Blackburn, 1998; Leiponen and Byma, 2009) and the novelty of an innovation (Thomas, 2003; Hanel, 2005; Hussinger, 2006) have been found to be important. Hurmelinna-Laukkanen et al. (2017) identify three different appropriability profiles among firms (patterns of knowledge-protection choice) with industry factors and firm-resource factors jointly determining the profile group to which a firm belongs. Their findings suggest that firms are better to approach the appropriability problem by considering protection mechanisms as a whole rather than by comparing one protection mechanism with another, and they suggest that firms are likely to benefit from having a wide range of protection mechanisms available to them. Chapter 3 adds to this body of knowledge and builds upon the study by Hurmelinna-Laukkanen et al. (2017) by examining how strengthening the protection dimension of the industry appropriability regime impacts upon firms' protection choices within an industry. Rather than examining the nature of firms' knowledge-protection profiles across different industries, this study is concerned with firms' knowledge-protection profiles within an industry. Previous studies acknowledge that industry characteristics have implications for firms' knowledge-protection choices, and the analysis here examines, quantitatively, the relationship between the strength of the protection dimension of the industry appropriability regime and the complexity and variability of knowledge-protection choices (or strategies) made by firms within the industry. In addition, the analysis considers whether the effects on firms' knowledge-protection choices differ across industries by undertaking a comparison of high-technology/knowledge-intensive industries and low-technology/less knowledge-intensive industries.

5.2.3 Chapter 4: Contributions

A firm's ability to formulate a knowledge-protection strategy in order to help capture the returns from its innovations lies at the heart of Chapter 4. Strategies for protecting knowledge have become a central part of the development of a firm's innovative strategy (Rivette and Kline, 2000), and the empirical analysis in Chapter 4 examines both formal and informal knowledge-protection strategies, seeking to discover which knowledge-protection strategy – formal or informal – most successfully drives firms' innovation returns.

Chapter 4 contributes to existing knowledge by deepening our understanding of how firms use formal and informal knowledge-protection strategies to capture the returns to innovation. This firm-level study combines the features of previous research in this area (Laursen and Salter, 2005; Laursen et al., 2013; Hall and Sena, 2017), and seeks to explore how the effects of different knowledge-protection strategies differ across industrial sectors, firm size and innovator type. Previously, studies have identified sectors and industries (for example, Levin et al., 1987; Cohen et al., 2000), firm characteristics (for example, Kitching and Blackburn, 1998; Hall et al., 2014) and the novelty of an innovation (for example, Hanel, 2005) as being important determinants of a firm's knowledge-protection strategy, and the empirical analysis in Chapter 4 adds to this existing knowledge.

In addition, the analysis in Chapter 4 builds upon existing knowledge-protection literature by using data on the *actual use* of firms' formal and informal knowledge-protection mechanisms to investigate the effects of knowledge protection use on a firm's returns to innovation. Previous studies (Laursen and Salter, 2005; Laursen et al., 2013; Hall and Sena, 2017) use data on how firms rate the *importance* of various knowledge-protection mechanisms – data more prone to subjectivity bias (Veulegers and Schneider, 2018).

The empirical analysis in Chapter 4 is further extended to explore the effects of formal and informal knowledge-protection strategies on the returns to innovation in firms of different sizes, firms with different technologies, firms in different sectors and firms innovating with different degrees of novelty. Previous literature focuses on manufacturing firms and their orientation towards formal knowledge-protection mechanisms (Laursen and Salter, 2013) as well as the extent to which formal and informal knowledge-protection mechanism are correlated with the innovation type being carried out and the relationship between firm productivity and innovation type, conditional on the firm's chosen knowledge-protection mechanisms (Hall and Sena, 2017). The analysis in Chapter 4 adds to this literature by considering both manufacturing and service firms, formal and informal knowledge-protection mechanisms and their effect upon the innovation returns of different innovator sub-groups. In addition to this, Chapter 4 further explores those firms undertaking new-to-the-market innovation. The effects of both formal and informal knowledge-protection strategies on the innovation returns in firms of different sizes, firms with different technologies and firms in different sectors within this new-to-the-market innovator group are examined.

5.3 Limitations and future work

5.3.1 Chapter 2

There are several limitations to Chapter 2. First, the variables which are designed to represent the industry appropriability regime in the empirical analysis are highly correlated with one another. For this reason, each variable is included in a separate regression model. Future work will aim to address this issue and seek ways to develop an appropriability-regime measure that can be used in a single model. Second, the empirical analysis in Chapter 2 only considers UK data. Innovation data for a single country may not be sufficient to support an innovation policy. As some countries are more intangible-intensive than others and IP systems vary across countries, further research using other countries' data may be necessary to verify results. Third, the knowledge-protection data obtained from the UK CIS is binary data, indicating whether or not the firm used the particular protection method, and ordered categorical data, indicating the importance of a particular protection method to a firm's innovation. This data does not indicate the extent of a firm's use of particular mechanisms. Future research will make use of firms' IP application and acquisition data (patents, registered designs and trademarks) obtained from the UK IPO. Once linked with innovation survey data, the resulting dataset will allow for a more in-depth analysis of firms' knowledge-protection strategies and how a changing industry environment affects the extent to which firms protect knowledge. Fourth, the analysis is carried out across all industries and all sizes of firm. Future research aims to conduct a more detailed exploration of firms' intangibles strategies across different sizebands and different sectors, for example. Fifth, the study assumes that industry appropriability regime is exogenous, and firms are required to consider the protection mechanisms that are available to them. The assumption that firms only adjust their knowledge-protection strategies in this way may be too narrow. Firms use other endogenous features of the appropriability regime – contracts and labour legislation, and human resource management, for example – to appropriate the returns to innovation. Sixth, the empirical analysis adopts a reductionist perspective (Venkatraman and Prescott, 1990). This approach enables specific theoretical links to be separated out, but the ceteris paribus conditions come with the disadvantage of specification errors.

5.3.2 Chapter 3

There are several limitations to Chapter 3. First, as in Chapter 2, the variables designed to represent the industry appropriability regime exhibit a high degree of correlation between one another. This led to each element of the appropriability regime being examined in a separate regression model. Future work will aim to address this issue by exploring ways of representing the industry appropriability regime as a single measure. Second, the empirical analysis examines firms' cumulative knowledge-protection strategies and provides no indication as to which mechanisms formulate these strategies when the appropriability regime changes in strength. Future work will aim to examine the responses of particular mechanisms to a change in strength of the industry appropriability regime so that complementarities and connections between particular protection mechanisms can be identified. Third, the study examines how the results differ across high-technology/knowledge-intensive industries and low-technology/less knowledge-intensive industries. Providing that data is available, future work will aim to carry out a more in-depth industry analysis so that individual industries can be compared with one another. Fourth, the analysis in Chapter 3 assumes that industry appropriability regime is exogenous, and firms are required to consider the protection mechanisms that are available to them. The assumption that firms only adjust their knowledge-protection strategies in this way may be too narrow. Firms use other endogenous features of the appropriability regime – contracts and labour legislation, and human resource management, for example – to appropriate the returns to innovation. Fifth, the analysis considers UK data only. As knowledge-protection availability and effectiveness varies across countries, future work will aim to undertake a multi-country comparative analysis, providing the data is available.

5.3.3 Chapter 4

There are several limitations to Chapter 4. First, the study is essentially cross-sectional as it uses one wave of UK CIS data. Associated reverse-causality issues limit the ability to make causal statements. Due to the changing nature of CIS questions relating to firms' knowledge protection across the different waves of CIS data, a pooled dataset could not be used in the analysis. Second, it is expected that firms' knowledge-protection strategies have a delayed impact upon innovation returns. Given the cross-sectional nature of this study, it is not possible to allow for this delay in the estimations. To overcome this limitation, the proportion of firm sales coming from innovation at the end of the 2008 to 2010 period is related to formal and informal knowledge-protection strategies which take place during the three-year period. Future work will aim to link firms' formal protection – patent, trademark and registered design – application and acquisition data with a pooled UK CIS panel dataset in order to partially address this limitation. It will enable a more in-depth analysis of how firms' formal knowledge-protection strategies affect firms' innovation returns to be carried out. Third, as with Chapter 2 and Chapter 3, the analysis is confined to UK data. The effectiveness of different knowledge-protection strategies may vary across countries, given that IP systems and the availability of knowledge protection methods varies across different countries. Fourth, the innovations from which firm sales come may not be those innovations being protected by the formal and informal mechanisms. The UK CIS survey provides no link between the firm's innovative sales at the end of the period and the knowledge-protection mechanisms used during the period.

The availability of a pooled UK CIS dataset covering the 2002 to 2016 period matched with formal knowledge protection application and acquisition data will allow for a more detailed exploration of the performance effects of individual formal IP mechanisms. This richer, more detailed data will allow sectoral contexts and firm-size implications to be explored in more depth.

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