Understanding the role of IP protection in UK firms' growth, productivity and innovation 1998-2016: Patents, trade marks and registered designs reconsidered

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ABSTRACT

Based on new intellectual property (IP) protection histories for around 110,000 UK firms from 1995-2018, we examine the contribution of patents, trade marks and registered designs to growth, productivity and innovation outcomes. Our analysis builds on prior research on the appropriability problem which reflects the ease of imitation and the difficulty for firms to maximise the returns to their innovation investments. We develop two new matched databases linking the Business Structure Database (1998-2018) and the IP protection histories, and the UK Innovation Survey (2002-2016) and the IP protection histories. For the first time, we are able to include registered designs in these datasets. Our analysis based on data on 1.1m firms emphasises the strong sectoral differences in the use of IP protection mechanisms, and for the most IP-intensive sectors, suggests a positive association between IP protection use and growth and productivity. This relationship is most consistent for productivity. Using survey data for around 58,000 observations, we find strong causal registered design-to-innovation relationships but weaker, and generally insignificant, patent-to-innovation and trade mark-to-innovation relationships. Our results suggest the value of re-visiting a policy dialogue which is focussed on the patents-to-innovation relationship but plays scant attention to the value of design and specifically registered designs.

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Keywords: Intellectual property, patents, registered designs, innovation.

CONTENTS

1. INTRODUCTION

UK investment in intangible or knowledge assets has been greater than that for tangible assets since the early 2000s (Goodridge et al. 2016). This emphasises the importance of knowledge and intellectual property (IP) as a source of competitive advantage and also the potential importance of IP protection in helping firms to maximise the returns from innovation (Ceccagnoli and Rothaermel 2008). Here, based on newly constructed IP protection histories for UK firms matched with data from the UK innovation survey, we explore the causal links between forms of formal IP protection – patents, trade marks and registered designs – and innovation outcomes. Specifically, we explore two rather different roles which IP protection might play in influencing innovation and the benefits which firms derive from innovating. First, we consider the role of formal IP protection in shaping the probability that UK firms engage in different types of innovation. Firms' ability to protect their IP may, for example, increase the anticipated returns from innovation and firms' willingness to make intangible investments. Both Park and Lippoldt (2008) and Lo (2011), for example, find evidence that stronger patent protection leads to higher R&D investment and more innovation. In a UK context, Arora and Athreye (2012) find that an increase in the perceived effectiveness of patents increases R&D investments. Second, building on previous studies of the appropriability problem, we consider whether IP protection increases firms' ability to capture the returns from innovation (Arrow 1962). This recognises that in many situations knowledge is a semi-public good, permitting imitation behaviour by firms and reducing an innovating firm's ability to fully capture the profits generated by its innovation (Teece 1986; Levin et al. 1987; Laursen et al. 2013). To overcome the appropriability problem, firms may use IP protection to limit imitation and enhance their ability to appropriate economic returns (Laursen and Salter 2005; Greenhalgh and Rogers 2007).

Previous studies of the impacts of patents on innovation and firm performance adopt a range of estimation approaches based on accounting data and company surveys (Athreye 2019). In general terms, and regardless of the approach adopted, studies tend to identify a positive relationship between patents and metrics of firm performance, although this relationship varies strongly between sectors (Griliches 1981; Connolly and Hirschey 1988). Other studies find a weaker relationship between patents and innovation outcomes, particularly where broadly-defined groups of firms are considered (Roper and Hewitt-Dundas 2015). The more limited literature on trade marks also suggests a positive relationship with firm performance (Schmock 2013; Greenhalgh et al. 2011), although again returns differ between sectors (Greenhalgh and Longland 2005). Evidence on the impact of registered designs is limited and largely descriptive. In design-intensive UK firms, the evidence suggests a positive relationship between registered design use and commercial success (Bascavusoglu-Moreu and Tether 2011), a result supported by the limited international evidence (e.g. Brem et al. 2017). We therefore anticipate positive relationships between the use of IP protection and firm and innovation performance, although recognise that these relationships may vary between sectors due to the intensity of IP protection use and its performance benefits.

Our analysis is based on data on all UK patents, trade marks and registered designs provided by the Intellectual Property Office. We use this data to create IP protection histories for around 110,000 UK firms covering the 1995-2016 period. Each IP protection history includes firms' live patent holdings, trade mark profile and registered design holdings in each year. We match these IP protection histories to two other UK datasets – the Business Structure Database (BSD) and the UK Innovation Survey (UKIS). The BSD-IP match allows us to examine the extent of IP protection use across sectors and the association between IP protection use and firm performance. The UKIS-IP match allows us to undertake a causal analysis of the impact of IP protection on a firm's propensity to innovate and its innovation returns. We believe our analysis represents the most comprehensive assessment of the contribution of formal IP use to UK innovation including patents, trade marks and registered designs. The inclusion of registered designs in the analysis, in particular, provides a significant extension to the knowledge base, as of the three IP protection instruments considered, registered designs have the strongest and most consistent influence on innovation outcomes.

The argument proceeds as follows. In Section 2, we provide the conceptual basis for the analysis, with a focus on the appropriability problem and appropriability regime. In addition, we provide a summary of existing evidence. Section 3 describes our data and analytical approach. Section 4 summaries the key results in terms of the relationship between formal IP use and business performance. Section 5 looks at the relationship between formal IP use and innovation outcomes. Section 6 reviews the key results and develops some policy implications.

2. CONCEPTUAL BACKGROUND

2.1 Innovation and the appropriability regime

Innovation is essential to the competitive performance of firms and the growth of economies (Granstrand 1999) and represents the beginning of a process of value creation (Roper et al. 2008) from which a competitive advantage emerges (Porter 1985). Firms more able to mobilise their knowledge and technological skills, and to use their experience to create new goods, services and processes, gain a competitive advantage over others and achieve a superior performance relative to their industry competitors or to the industry average. Innovation can be radical or incremental. Radical innovation may lead to a disruptive change in market structure, create new markets or displace existing products and services (Schumpeter 1942), whereas incremental innovation is the improvement of an existing product, process or service, and although it may be commercially significant, it is unlikely to impact upon market structure (Tidd et al. 1997).

The innovation process is both expensive and time consuming for firms. At the same time, innovation involves risk; the probability of failure is high, and 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). Imitation may erode an innovating firm's competitive advantage and discourage it from investing in innovative activities. A firm's decision to invest in innovation depends on its expected post-innovation returns (Du et al. 2007), so without the possibility of capturing the benefits of its innovative efforts, there is little incentive to innovate (Schumpeter 1942). Consequently, the ability to appropriate the returns from innovation is a central element in gaining and sustaining a competitive advantage (Laursen and Salter 2005).

The semi-public good characteristics of knowledge (exclusion is rarely perfect) lead to the so-called appropriability problem (Arrow 1962)[1]. The appropriability problem arises when firms are unable to limit other firms from imitating their innovations. As a result, firms are

[1] The appropriability problem (Arrow 1962) is a feature of innovative activity which distinguishes it from other strategic investments made by firms (Geroski 1995).

unable to appropriate the full returns from their innovations, resulting in implications for both firm performance and survival (Ceccagnoli and Rothaermel 2008).

Teece (1986) identifies two essential components of appropriability – specialised complimentary assets and the appropriability regime, with a firm's ability to profit from an innovation depending on both components (Pisano 2006). Specialised complementary assets are those assets acquired by firms which enable them to strengthen appropriability conditions (Gans and Stern 2003). Acquiring complimentary assets (e.g. competitive manufacturing 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.

The environmental factors a firm faces (excluding firm and industry structure) which govern its ability to capture profits from an innovation are collectively known as the appropriability regime (Teece 1986). The appropriability regime encompasses the means of protecting innovations and the increased rents which flow from them (Cohen et al. 2000). Important dimensions of the regime include natural protection in the form of the nature of the technology being used (e.g. whether technological knowledge is tacit or codified), and the practical means of knowledge protection which are both effective and available for use by firms (e.g. patents and trade marks) (Teece 1986; 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, which in turn determines the likelihood of imitation (Jones Day 2006). Accessibility varies across both products and processes and tacit and codified knowledge. For example, many process technologies are generally unobservable and are therefore considered to be 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. Furthermore, some technologies are based on difficult-to-understand tacit knowledge, making them particularly inaccessible. Other technologies are accessible to everyone because of their use of codified knowledge. In summary, the less (more) accessible the technology, the less (more) likely it will be subject to imitation and the more (less) likely it is that a firm will appropriate the returns from its innovation.

The effective methods of knowledge protection available to protect innovations and the rents which flow from them represent the knowledge-protection dimension of the appropriability regime. Knowledge protection methods include both formal and informal mechanisms. Formal protection mechanisms are legally enforceable and typically include registered rights such as patents, design rights and trade marks, and unregistered rights such as copyright. Informal protection mechanisms are not based on regulated structures and statutory enforcement possibilities (Hurmelinna-Laukkanen 2014); they include secrecy, complexity of design and lead-time on competitors. The availability and enforceability of both formal and informal knowledge protection mechanisms helps shape the appropriability regime (Hurmelinna-Laukkanen and Jauhiainen 2004).

Barriers to imitation and the ease with which competitors can imitate an innovation are determined by the different dimensions of the appropriability regime (Ceccagnoli and Rothaermel 2008). Appropriability regimes are described as being 'strong' or 'weak' (Teece 1986), with their strength varying across industries. An appropriability regime is described as being strong when innovations are easy to protect – knowledge about them is tacit or is well protected by protection mechanisms. In this instance, innovations are difficult to imitate as 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 have strong appropriability regimes. Competitors find it difficult to imitate innovations because formal protection methods are particularly effective. In addition to the use of formal protection methods, some industries (software, for example) are technically able to limit imitation. An appropriability regime is described as being weak when innovations are difficult to protect, knowledge can be easily codified, and knowledge protection mechanisms are ineffective. In the digital economy, for example, the appropriability regime is relatively weak, and firms rely on 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, others emphasising the nature of technology over protection (Teece 1998, 2000). A strong regime, for example, 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, the aim is to create a first-mover advantage and earn higher than average returns.

2.2 IP protection, innovation and performance

IP protection includes legally enforceable protection methods which are implemented through regulation (Hall 1992). Typically, these are registered rights such as patents, design rights and trade marks and unregistered rights such as copyright. In this study, we focus on registered rights, namely patents, trade marks and registered designs.

2.2.1 Patents

Patents are often viewed as the first-choice innovation protection instrument (Athreye 2019). They 'protect new inventions and cover how products work, what they do, how they do it, what they are made of and how they are made'[2]. Patents solve the problem of appropriability by vesting an ownership right with the inventor and preventing others from profiting from the new knowledge. A patent allows an inventor to take legal action against anyone who makes, uses, sells or imports an invention without the inventor's permission. Rather than keeping an invention secret, a patent shares how to create or replicate an invention with the public, and once the patent has expired, others can make and sell the invention. Patents protect innovations such as machines, industrial processes, pharmaceuticals and their production methods, computer hardware, electrical appliances and biological products and processes; they cannot protect literary, dramatic, musical or artistic works, or anything that is an idea, a way of thinking, or a scientific or mathematical discovery. Applying for a patent can be an expensive and lengthy process. It may take several years, and once granted, renewal fees are payable for twenty years – the full period of protection (IPO 2018). During this period, it is the inventor's responsibility to enforce the patent and ensure that an invention is protected. Any legal action which may take place as a result of a dispute or an infringement must be paid for by the inventor.

The economic value of a patent depends on a firm's ability to appropriate the benefits of the temporary monopoly that the patent creates (Athreye et al. 2020). Previous studies estimate the value of patents for innovating firms using one of three approaches (Athreye 2019). The *market value approach* estimates the value of patents using stock market values i.e. investors' evaluation of firms' tangible and intangible (including patents) capital stock. Some studies report the monetary value of an additional patent, and find that it varies

[2] https://www.gov.uk/government/publications/ip-basics/ip-basics

across technological sectors (e.g. Griliches 1981; Connolly and Hirschey 1988). The *patent renewal approach* examines patent renewal records and the costs of patenting and renewing to assess the distribution of patent earnings from the patent holder's perspective (e.g. Barney 2002). The understanding here is that a firm is likely to renew a valuable patent. As with the market value approach, the returns to patents differ across sectors, with the largest returns occurring in the pharmaceuticals sector. The *inventor survey approach* (e.g. Giuri et al. 2007) uses the inventor's subjective estimate of a patent's value on the date of invention to find its market value. The value of a patent to the innovating firm varies across the three approaches; the inventor survey approach yields the largest value, and the patent renewals method yields the smallest value.

Assigning a financial value to a patent is more straightforward in some industries than in others. In the pharmaceutical sector, for example, there is often a one-to-one relationship between the patent and the product, and therefore assigning value to the patent is straightforward. However, in other sectors (e.g. the motor vehicle manufacturing sector), there may be a number of patents protecting a product. Other types of IP protection may also protect a product (e.g. registered designs and trade marks). In these industries, it is difficult to isolate the value to the innovator of each type of protection.

Over the long term, patents are strongly correlated with increased innovation, knowledge sharing, and economic growth[3]. In one 2015 Forbes article[4], it is stated that, "Investments in the biotech industry are based entirely on patents. Without strong patents, we cannot raise money to find cures for disease." The high value of patents for the innovating firm is a common conclusion of many empirical studies. Arora et al. (2008) construct a structural model of R&D investment and innovation outcomes using the Carnegie Mellon Survey. Model results suggest that the patent premium for patented innovations is substantial; firms can expect to earn almost 50 per cent more (on average) from a patented invention than from the same invention left unpatented. Health-related industries are found to earn a higher 60 per cent premium, whereas the electronics sector is found to earn a lower 40 per cent premium. Using a modified model more suited to the UK Community Innovation Survey (CIS) data structure, Arora and Athreye (2012) find a unit increase in perceived

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[3] https://www.forbes.com/sites/marshallphelps/2015/09/16/do-patents-really-promote-innovation-a-response-to-the-economist/#20c6d4691921
[4] https://www.forbes.com/sites/matthewherper/2015/03/24/new-patent-law-would-trash-disease- cures/#11260dd924d5

patent effectiveness increases revenue from new products by 160 to 200 per cent. The same increase in perceived patent effectiveness leads to an 11 to 27 per cent increase in R&D. Furthermore, results suggest that patents boost larger firms' revenue most; the average patent premium is 66 per cent for larger firms compared with 46 per cent for smaller firms. In addition, results show some sectors (e.g. biotechnology and pharmaceuticals, computer and electronic equipment, instruments, machinery and medical instruments) to have a higher than average patent premium, suggesting that they may benefit more from patenting. In another study, Park and Lippoldt (2008) find that stronger patent protection has a significant, positive effect on R&D expenditure and high-tech product development, and Lo (2011) finds that strengthening the Taiwanese patent system in 1986 led to more inventive activity, especially in R&D-intensive industries and those industries more commonly associated with patent use.

2.2.2 Trade Marks

Registered trade marks protect brands, be it a business name, a product or a service. However, a brand is much more than a company logo – a brand is a 'promise of an experience' and offers consumers assurance about the nature of the product or service they will receive[5]. A trade mark can be a word, a phrase or logo, a shape, a colour, a sound, an aspect of packaging, it can be action based, or it can be any combination of these[6]. The most effective trade marks are those 'distinctive' to the goods and services they protect. Drawing on the economic theories of information and reputation (Economides 1988; Landes and Posner 1987), trade marks are designed to signal to consumers the distinctiveness and quality of a product, addressing the presence of asymmetric information between buyers and sellers. They are designed to differentiate products from those provided by other firms, so that they have a significant role in the marketing of innovations (Turner 2019).

[5] https://www.gov.uk/government/publications/ip-basics/ip-basics#trade-marks

[6] A word mark is represented using words, letters, numbers or any other characters that can be typed; a figurative mark is represented using pictures, graphics or images and may also combine words, letters or numbers; a shape mark is represented using a three-dimensional shape, such as the actual product; a colour mark is used only to register an actual colour to distinguish products or services; a hologram mark is a three-dimensional image; and a sound mark is represented graphically using, for example, musical notation.

By registering a trade mark, it is much easier for a firm to take legal action against another firm that uses the trade mark without permission. In addition, it allows authorities to bring criminal charges against counterfeiters if they use the trade mark. A firm can sell a registered trade mark, franchise it or provide firms with a licence which allows them to use it. A firm pays a fee when registering a trade mark, and registration must be renewed every ten years for an indefinite period (IPO 2018). The application process is less time consuming than for patents, with the applicant receiving a formal report detailing the outcome of the examination within ten days of the application. If the trade mark is accepted, it can be registered in around three months from the original date of filing.

The literature surrounding trade marks and the link to innovation and performance is more sparse than that for patents. Complementary to the more traditional measures of innovative activity (e.g. R&D expenditure and patents), trade marks are also a useful proxy for innovation (Mendonça et al. 2004). Indeed, the evidence suggests that trade marks are more highly correlated with innovation than more traditional proxies (Jensen and Webster 2009). In their study of 1,400 Australian firms, Jensen and Webster (2009) find that correlations between innovation and trade mark applications vary across sectors, with the highest correlations occurring in the manufacturing sector and in those firms undertaking product innovation.

Much of the previous empirical literature supports the existence of a positive relationship between trade marking activity and firm performance. In a study using German survey data, Schmock (2003) examines how firms' trade mark use impacts upon the share of firm turnover attributable to new products and services. Results suggest that trade mark use has a positive effect on a firm's innovation success, with the strongest impact occurring in knowledge-intensive firms. In a study of 2,645 UK firms, Greenhalgh et al. (2011) show how trade mark use and trade mark intensity affect gross value added and turnover growth. Results of the study suggest that trade marking firms have a higher productivity level (as much as 21 per cent higher) and higher turnover growth (some 6 per cent higher) than non-trade marking firms. Krasnikov et al. (2009) examine 108 US manufacturing and service firms and investigate how trade mark stock and trade mark intensity impacts upon firm performance. Findings suggest that a firm's use of trade marks positively affects cash flows, Tobin's q, stock returns, return on assets (ROA) and return on sales (ROS) and reduces the variability of future cash flows.

Several studies identify firm age, size and industrial sector as factors which determine the performance effects of trade marks. Using data for 300 Australian-located public and private companies, trusts, associations, cooperatives and partnerships, Griffiths et al. (2005) find trade mark stocks, both registered and pending, to be strongly associated with annual profits. Furthermore, the positive impact on profits diminishes as the firm ages. Brem et al. (2017) use data for 2,873 Spanish manufacturing and service firms to examine how trade mark use affects firm turnover. Findings suggest that trade mark use has a positive effect on the performance of small firms but not that of medium firms. In addition, the relationship between trade mark use and firm performance is found to be stronger for small and medium-sized enterprises (SMEs) in less knowledge-intensive service industries than for firms in general. In their study, Greenhalgh et al. (2011) find that higher trade mark intensity is associated with higher productivity in younger and smaller firms, although large firms have also been shown to experience a 10 to 30 per cent increase in value added premium following trade mark use (Greenhalgh and Rogers 2012). Munari and Santoni (2010) examine the joint use of patents, registered designs and trade marks in 425 Italian manufacturing SMEs. Their results suggest that trade mark use has a positive effect on firm performance in terms of ROA and ROS.

Greenhalgh and Longland (2005) suggest that returns to trade marks are higher in low-technology sectors, despite trade mark use being higher in high-technology firms (Mendonça et al. 2004). In their study, Greenhalgh and Longland (2005) use data for 740 large British firms, across a wide range of industrial sectors, to examine how the stock of trade marks and trade mark intensity affect firm net output or value added. Their results show a positive relationship between trade marks and value added, with those firms registering both patents and trade marks and undertaking R&D being more productive. However, immediate productivity benefits are shown to be short-lived. Using data for 724 Portuguese firms, Mendonça et al. (2004) examine and how trade mark stock is correlated with firms' patent use by undertaking pairwise comparisons of trade mark use across industries. They find a positive correlation between the use of patents and the use of trade marks, suggesting that registered trade marks are a complementary indicator of innovation. In addition, their analysis shows information-intensive services (e.g. banking) use more trade marks than less information-intensive services.

2.2.3 Registered designs

A design registration "…protects the visual appearance of a product, part of a product, or its ornamentation" (IPO 2018), providing it is new and has individual character[7]. To be registered, the design must have a special shape, configuration, pattern or ornamentation. By registering a design, a firm is able to prevent other firms from using that design without permission. The process of registering a design is relatively short compared with applying for a patent or a trade mark. Once the application has been made and fees have been paid, the process takes around four weeks providing the design meets the required criteria. Design protection lasts for five years and can be renewed every five years, for up to twenty five years (IPO 2018).

The literature surrounding registered designs and the link to innovation and performance is much more limited than that for patents and trade marks. In general, the evidence suggests that effective design protection is important for design innovation, and that attitudes towards registered designs, together with attitudes towards enforcement, have a significant effect on a firm's motivation to create. However, the evidence does not support a positive correlation between registered designs and innovation. In a study of 1,400 Australian firms, Jensen and Webster (2009) find significant negative correlations between registered designs and process and organisational innovation.

Much of the evidence on the benefits to firms of registered designs is descriptive, with relatively few studies adopting an econometric approach. In one study, Bascavusoglu-Moreu and Tether (2011) examine UK design-intensive firms during the late 1990s and early 2000s. Results show that registered designs are positively related to firm performance and commercial success; registered design use is associated with a 17 per cent performance benefit in terms of sales per employee. In another study, Brem et al. (2017) examine how registered design use impacts on firm turnover in Spanish SMEs. Results suggest a positive relationship between registered design use and SME firm performance. Support is stronger for SMEs in medium-high and medium-low technology manufacturing industries than for firms in general. Munari and Santoni (2010) use data for 425 Italian manufacturing SMEs to examine how registered design use affects performance. Results

[7] Confusion sometimes arises between the protection offered by a design registration and that offered by a patent: a design registration protects the visual appearance of a product whereas a patent protects a technical product and how it functions.

show firms that use patents, trade marks and registered designs experience higher performance levels in terms of ROA and ROS than firms that do not.

Moultrie and Livesey (2011) use a cross-sectoral sample of 32 UK firms and 10 design agencies to conduct a questionnaire to explore the role and value of registered designs. Responses indicate a very strong feeling that the design of a product helps to differentiate against competitors, and that design registrations affect commercial success. Using successful innovation information deduced from good product design award-winners data, Yoshioka-Kobayashi et al. (2018) suggest that firms frequently use registered designs for the protection of award-winning design products. They examine industrial designs registered between January 2011 and August 2016 in Japan, Korea and the US, and find 150 products received at least one of the selected design awards in 2015.

3. DATA AND METHODS

3.1 Data

Our analysis is based on three matched data sources: UK Intellectual Property Office (IPO) data detailing patents granted, trade marks registered and designs registered in the UK during the 1995-2018 period; data from the UK Innovation Survey (UKIS) covering the 2002-2016 (CIS4-CIS10) period; and, data from the UK Business Structure Database (BSD) covering the 1998-2018 period. We discuss each in turn before providing an overview of the matching procedure.

UK Intellectual Property Office (IPO) data

IPO provided us with patent data covering UK patents granted during the 1995-2018 period. Each record includes the patent application number, the name and address of the applicant[8], the company reference number (CRN, obtained from FAME data[9]/Companies House records), the date the patent was granted, the date of the most recent renewal payment and the year of protection provided by the most recent renewal payment (renewal

[8] The applicant details linked to a particular patent may change over time due to the applicant changing its name or address, or because there has been a transfer of IP between two parties.
[9] FAME (Financial Analysis Made Easy) is a database published by Bureau van Dijk (BvD) that contains information on over two million active companies in the UK and Ireland as well as historical information on six million companies that are no longer active.

fees are required for the 5th-20th year of protection). The IPO trade mark data details UK trade marks in force between 1995 and 2018. Each record includes the published trade mark number (be it a standard, certification or collective trade mark), the CRN, the year of registration and the next renewal date (renewal is necessary every 10 years), and the trade mark class (goods, service or 'complex' i.e. trade marks that relate to both goods and services). The IPO registered design data covers designs registered in the UK during the 1997 to 2018 period. Each record includes the design number, the applicant's name, the CRN, the date of registration, the number of registration renewals that have been made (the first renewal takes place 5 years after the initial registration, with a maximum of four renewals being permitted, providing 25 years of protection in total), and the date the next renewal is due (dates in the past indicate lapsed registrations).

UK Innovation Survey (UKIS)

The UKIS represents the main source of innovation data in the UK, providing detailed information on firms' innovation activity; it is a data source widely used by innovation researchers (e.g. Laursen and Salter 2005; Love et al. 2010; Hall and Sena 2017). Based upon a core questionnaire developed by the European Commission (Eurostat) and Member States, the UKIS 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 UKIS. The sampling frame is taken from the Inter-departmental Business Register (IDBR), a live UK-Government compiled register of all UK businesses based on Value Added Tax (VAT) and Pay As You Earn (PAYE) records.

The UKIS is conducted every two years by means of a postal questionnaire and follow-up telephone interviews. The surveys are non-compulsory and, for the seven waves analysed here, achieved a response rate ranging between 43 per cent in 2016 (CIS10) and 58 per cent in 2004 (CIS4)[10]. The UK surveys provide detailed information on firms' innovation activity, an indication of the objectives of firms' innovation activity and their external

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

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, each with 10 or more employees. In addition, the data are designed to be statistically representative of the 12 regions of the UK, most industrial sectors and all sizes of firms.

Business Structure Database (BSD)

The BSD is derived primarily from the IDBR. 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 some of 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. A small number of variables are included for almost all UK firms, including employment, turnover, foreign ownership, Standard Industrial Classification (SIC) codes, start-up dates and termination dates.

Data-matching process

From the IPO data, we derived the number of live patents, trade marks and registered designs associated with each CRN for each year during the 1995-2018 period[11]. This exercise identified firms with 102,641 separate CRNs which had held IP protection during this period. These IP protection histories for each CRN were then imported into the ESRC Secure Data Service (SDS) to allow CRNs to be matched to the enterprise reference numbers – entrefs – which provide the link to other administrative datasets, including the UKIS and the BSD. Of the CRNs provided, it proved possible to match 79,327 with entrefs. Pseudo-CRNs were retained in the matching file to assist with the relatively rare situations where either a single entref was matched with multiple CRNs or a single CRN was matched with multiple entrefs. In these more complex situations, we assume that patents, trade marks and registered designs linked to shared entrefs or Pseudo-CRNs are available to all enterprise units (defined by their enterprise reference numbers) within that group. Pseudo-

[11] An IP protection mechanism is assumed to exist for a particular CRN during a given year if it is available to that CRN for more than six months in that given year.

CRNs were then used to aggregate IP protection holdings and create a set of unique IP protection histories for all unique entrefs. The resulting data file contains IP protection histories for 76,033 unique enterprise units.

For our analysis, we created two matched datasets. The first matched dataset (BSD-IP) links the IP protection histories with the BSD (1998-2018), allowing us to explore the propensity to use IP protection and its links to performance across all UK firms. 66,438 entrefs in the IP protection history data file were successfully matched with those in the BSD (1998-2018) file. The resulting data file contains the BSD variables for more than 5.5 million firms and the stock of live IP protection (patents, trade marks and registered designs) for the matched entrefs.

The second matched dataset (UKIS-IP) links the IP protection histories with the UKIS (2002-2016), allowing us to explore the relationship between IP protection holdings and innovation output indicators. Data in each of the UKIS waves covers a three year period (e.g. UKIS 4 covers 2002-2004, UKIS 5 covers 2004-2006, UKIS 6 covers 2006-2008 etc.). The IP protection histories relate to single years, and therefore the matching process is less straightforward than with the BSD. Rather than have a single IP protection stock for a matched entref in one particular wave of the UKIS data, two IP protection stocks are assigned – the IP protection stock at the start of the period and the IP protection stock at the end of the period. For example, an entref in the UKIS 4 data has a starting IP protection stock equal to its IP protection holding in 2002, and an ending IP protection stock equal to its IP protection holding in 2005 – the time of the UKIS survey.

Variable definitions are given in Annex 2 and pairwise correlation coefficients[12] are given in Annex 3. Table 1 provides descriptive statistics (the number of observations, the mean and the standard deviation) for the variables included in the empirical analysis.

[12] Pairwise correlation coefficients are reported rather than standard correlation coefficients because the standard correlation coefficient calculation drops all observations when missing values are present, and this results in missing correlation coefficients amongst our variables.

3.2 Methods

3.2.1 IP protection, growth and productivity

To investigate the correlation between IP protection and growth/productivity, we use the Wilcoxon rank-sum/Mann-Whitney non-parametric test. In each test, the dependent variable is the performance indicator – turnover growth (2012-2016), employment growth (2012-2016) or productivity (2016). The independent variable is the binary (0/1) IP protection indicator. If a firm within the sector has a live patent, trade mark or registered design, the indicator is set equal to 1, and if a firm within a sector does not have any of the forms of IP protection, the indicator is set equal to 0[13]. The null hypothesis for each test is given as,

> *H_0= the values for growth (turnover and employment) and productivity in IP protection users and non-users are two samples from the same population.*

Failing to reject this hypothesis would provide evidence in support of there being no difference between the two groups of firms, and it would suggest that there is no significant difference between the performance of firms that use IP protection and those that do not. The alternative hypothesis for each test is given as,

> *H_1 = the values for IP protection users and non-users are two samples from two different populations.*

Rejecting H_0 in favour of H_1 would suggest that there is a significant difference between the performance of IP protection users and that of non-users.

3.2.2 IP and innovation

Dependent variables

Five dependent variables derived from the UKIS are included in our analysis. Three of these dependent variables are used in three models that examine the effect IP protection

[13] A Wilcoxon rank-sum/Mann-Whitney non-parametric test with a two-level independent variable produces results identical to the Kruskal Wallis non-parametric test.

has on firm innovation, and the remaining two dependent variables are used in two models that examine the effect IP protection has on firm turnover attributable to innovation.

In the models that examine how IP protection influences firm innovation, the three dependent variables relate to product/service innovation. The UKIS asks firms whether they introduced any new or significantly improved goods or services during the survey period. Our first model explores how IP protection influences product/service innovation in firms. Based upon firms' responses, the first dependent variable is a binary variable constructed to represent product/service innovators. The dependent variable takes on the value of 1 if the firm introduced a new or significantly improved good or service and 0 if it did not. The descriptive statistics in Table 1 show that some 28 per cent of firms in the estimation sample engaged in product/service innovation.

The UKIS also asks firms that engaged in product/service innovation whether any of the goods and services they produced were new to the market or only new to the business. Our second and third dependent variables are constructed using this information. Our second model examines how IP protection influences new-to-the-firm (NTF) product/service innovation in firms. In constructing the second binary dependent variable, our reference group of firms i.e. those taking on the value of 0, are non-innovators. The dependent variable takes on the value of 1 if the firm indicated that it undertook goods and service innovation that was new to its business. Data for this dependent variable is replaced with a missing value if the firm also indicated that it undertook goods and service innovation that was new to its market. Consequently, our second model examines how IP protection influences NTF product/service innovation in firms that engage only in NTF product/service innovation. The descriptive statistics in Table 1 show that some 15 per cent of firms in the estimation sample engaged solely in NTF product/service innovation.

Our third model examines how IP protection influences new-to-the-market (NTM) product/service innovation in firms. In constructing the third binary dependent variable, our reference group of firms, i.e. those taking on the value of 0, are non-innovators and firms that engaged solely in NTF product/service innovation. The dependent variable takes on the value of 1 if the firm indicated that it undertook goods and service innovation that was new to its market. These firms may have engaged solely in NTM product/service innovation or they may have engaged in both NTF product/service innovation and NTM product/service innovation. Our third model therefore examines how IP protection influences NTM product/service innovation in firms that engage only in NTM product/service innovation and firms that engage in both NTM and NTF product/service innovation. The descriptive statistics in Table 1 show that some 12 per cent of firms in the estimation sample engaged in NTM product/service innovation.

The UKIS response data also includes firms' estimates of the percentage of business turnover (in the final year of the survey period) from goods and services that were new to the business during the survey period and goods and services that were new to the market during the survey period. Previous studies (e.g. Laursen and Salter 2006; Becker et al. 2016; Roper et al. 2017) use this data as an indicator of innovation output. It illustrates a firm's ability to introduce new goods and services to the market as well as the commercial 'success' of a firm's innovative activities (Roper et al. 2017). We use this information to construct two dependent variables that allow us to investigate whether IP protection is successful in allowing firms to profit from innovation. The first of these dependent variables uses firms' estimates of the percentage of business turnover from goods and services that were new to its business only. The data is replaced with a missing value if a firm simultaneously undertook product/service innovation that was new to its market, so that the dependent variable reflects the proportion of turnover from NTF product/service innovation for firms solely engaged in NTF product/service innovation. The descriptive statistics in Table 1 show that, on average, 2.47 per cent of business turnover in firms that were solely engaged in NTF innovation came from NTF innovation.

The second dependent variable that we use to examine whether IP protection is successful in allowing firms to profit from innovation is the sum of a firm's estimate of the percentage of business turnover from goods and services that were new to its business only and the percentage of business turnover from goods and services that were new to its market. This variable captures NTF innovators, NTM innovators and firms that engaged in both NTF and NTM innovation. Consequently, observed differences between our two innovation 'success' dependent variables originate from those firms that engaged in NTM innovation activities during the survey period, whether in isolation or in conjunction with NTF innovation. The descriptive statistics in Table 1 show that, on average, 4.39 per cent of business turnover in innovating firms came from NTF and NTM innovation.

Independent variables

Our empirical analysis includes three main independent variables. The analysis considers how the three different IP protection mechanisms – patents, trade marks and registered designs – are related to our five dependent variables. Each firm's stock of live patents, live trade marks and live registered designs are determined when the IP histories data file is matched with the UKIS data. The empirical analysis uses the logarithm of each live IP protection stock at the beginning of the UKIS survey period as an independent variable[14].

Control variables

A set of control variables – factors, other than IP protection, which previous studies have shown to impact on firm innovation or innovation returns – are also included in the empirical analysis. The control variables used here reflect a firm's characteristics, capabilities and resource base (Griliches 1992; Love and Roper 1999). Firm size is commonly included in innovation studies (Cohen 1995) as it is thought to influence a firm's propensity to innovate (Laursen et al. 2013). Employment is included here (expressed as a logarithm) to reflect firm size and the scale of a firm's resources. Employee skills allow firms to successfully harness the performance benefits of innovation (Leiponen 2005; Hewitt-Dundas 2006), and are reflected here through the inclusion of two variables – the proportion of a firm's employees that hold a degree or higher qualification in (a) a science or engineering subject, and (b) other subjects. Across our sample, 6.45 per cent of employees are science graduates and 9.61 per cent of employees have a degree from another discipline (Table 1). A firm's exporting behaviour and innovative activity has been linked through both competition and learning effects (Love and Roper 2015). A binary (0/1) variable is included in the analysis to indicate whether or not the firm exported during the survey period. Some 30 per cent of firms in our sample engage in exporting (Table 1).

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 analysis to indicate whether or not the firm reported (a) internal R&D expenditure and (b) external R&D

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[14] The logarithm of each IP protection stock is used, rather than the actual value, to address the non-linear effect an additional unit of each protection mechanism is expected to have on the dependent variable.

expenditure during the survey period. Table 1 shows that 27 per cent of firms in our sample invested in internal R&D, whereas 9 per cent of firms invested in some form of external R&D. The extent of a firm's interactive knowledge search has been used extensively in studies of the determinants of innovation (e.g. Laursen and Salter 2006; Becker et al. 2016), and is measured here by a variable indicating the extent or breadth of the firm's innovation co-operation. The UKIS 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 (e.g. 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. Table 1 shows that on average, firms in our sample have approximately one co-operation partner (0.87). In keeping with Becker et al. (2016), several variables reflecting innovation-related investments are included in the analysis. Binary (0/1) variables indicating whether the acquisition of advanced machinery and equipment took place, whether training for innovative activities took place, whether the acquisition of knowledge from other businesses or organisations took place, whether investment into the market introduction of innovations took place and whether a firm engaged in design activities took place are all included in the analysis. In our sample, some 43 per cent, 27 per cent, 9 per cent, 28 per cent and 17 per cent of firms, respectively, engaged in these innovation-related investments (Table 1).

UKIS wave dummies are also included in the analysis to control for any temporal effects on the dependent variables, and sector dummies (at the 2-digit level) are included to allow for sectoral heterogeneity i.e. different innovation intensities across industries (Levin et al. 1987; Cohen et al. 2000).

Estimation method

The empirical approaches we adopt reflect the nature of the five dependent variables being investigated. Two different types of model are estimated. First, a probit model is used to examine how the three different methods of IP protection influence product/service innovation, NTF product/service innovation and NTM product/service innovation. Each of the three binary (0/1) dependent variables is set equal to 1 if the firm introduced a new product/service (of the type being examined) and 0 if it did not. Using the maximum-likelihood method, the probit estimation procedure models the probability that the dependent variable will be equal to one i.e. it models the probability that the particular type of product/service innovation being examined will take place. Second, a Tobit model is used to examine how the three different methods of IP protection influence the proportion of business turnover from goods and services that were new to the firm and the proportion of business turnover from goods and services that were new to the firm or new to the market. As proportions, the two dependent variables are bounded between the values of 0 and 100. The Tobit regression model (Tobin 1958) – a censored regression application – is an appropriate estimation method for response data of this kind as it uses the maximum-likelihood estimation procedure to model the non-linear relationship between the independent variable and the censored dependent variable.

4. IP PROTECTION – USE AND PERFORMANCE EFFECTS ACROSS SECTORS

Previous studies have emphasised the differences in IP protection use across different sectors and the differential returns to the use of IP protection methods (Griliches 1981; Connolly and Hirschey 1988; Greenhalgh and Longland 2005). Here, using the BSD-IP database, we explore firms' use of IP protection across sectors and any associated performance benefits. Although the BSD data includes over 5.5 million firms, only 1.1-1.2 million firms are considered to be 'live' firms for the purpose of this study[15]. Around 5.5 per cent of these firms had some form of IP protection – be it patents, trade marks or registered designs – at some point during the 1998-2018 period.

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[15] A 'live' firm is defined here as one where the number of employees in a firm is greater than 1 and where the number of employees in a firm is not missing in the dataset.

4.1 Use of IP protection across sectors

Data for two years in the BSD-IP dataset, 2012 and 2016, are examined to investigate firms' use of IP protection across sectors. First, live firms for each year are separated into sectors according to their 2-digit SIC code[16]. Second, the number of live firms within each sector with at least one form of IP protection (of the three examined here) is calculated, followed by the number of live firms within each sector with at least one patent, with at least one trade mark and with at least one registered design. The corresponding proportions are illustrated in Figures 1-4 (see also Tables A1.1 and A1.2).

Figure 1 highlights the relatively small proportion of firms that used at least one of the three IP protection mechanisms (less than 10 per cent in most sectors) during both years. In 2012, only seven sectors had more than 10 per cent of firms using at least one of the three forms of IP protection, this increased to twelve sectors in 2016. In general, the profile of IP protection use across sectors in both years is very similar, with a higher proportion of firms in manufacturing sectors than in service sectors using at least one of the three IP protection mechanisms. Over the four-year period, there was a general increase within sectors in the proportion of firms using the IP protection mechanisms, depicted graphically here by an elongation of the blue bars in Figure 1a to form the orange bars in Figure 1b.

The proportion of firms within sectors that used at least one patent is illustrated in Figure 2. Note, however, that the picture here is incomplete as in the majority of sectors where firms used patents, there were fewer than 10 patent-holding firms. This data cannot be reported due to UK Secure Data Service disclosure rules. Here, we see a more marked distinction between manufacturing sectors and the service sectors in patent use than in IP protection use more generally (Figure 1), with many service sectors having no patent-holding firms. Of those sectors that made use of patent protection, the majority had less than 0.3 per cent of firms using patents. Furthermore, any increase in these proportions during the 2012-2016 period is small.

[16] Sectors 15 and 16 (food, beverages and tobacco products) are amalgamated due to the small number of live firms producing tobacco products, and sector 99 (extra-territorial organisations and bodies) is eliminated due to the very small number of live firms. The analysis examines 1,092,915 live firms in 2012 and 1,136,545 live firms in 2016.

Figure 3 shows the proportion of firms within each sector that used at least one trade mark. The two charts in Figure 3 are remarkably similar to those in Figure 1. They show that trade mark use is widespread, with the proportion of firms that used trade marks being higher in the manufacturing sectors than in the service sectors. The strong similarity between Figure 1 and Figure 3 suggests that the profiles of the charts in Figure 1 are driven by trade mark users. This is confirmed by the data in Tables A1.1 and A1.2 where trade marks are shown to be by far the most popular IP protection mechanism across all sectors in both years.

The proportion of firms used at least one registered design is shown in Figure 4. There is a concentration of registered design use in manufacturing sectors where the proportions (of firms) that used a registered design is higher than in service sectors. Although not obvious from the figures, there was some registered design use in many service sectors, but as is the case with the data on patent use, UK Secure Data Service disclosure rules mean that much of this registered design use cannot be reported here. In Figure 4, the illustrated proportions for registered design use are slightly higher than those for patent use in Figure 2, but despite this, they are smaller than those for trade mark use in Figure 3.

Our exploration of firms' IP protection use across sectors has uncovered similar findings to the IPO (IPO 2020) in their examination of IP protection use across 616 4-digit industries. Trade marks were found to be the most widely used IP right, occurring across over 95 per cent of industries. Registered designs were found to be used more widely than patents, and more industries had above average use of registered designs than had above average use of patents. Furthermore, the manufacturing sector accounted for the majority of high or above average IP protection use industries.

4.2 IP protection – correlations with growth and productivity

Comparing firm performance in the BSD-IP over the 2012-16 period allows us to examine whether firms that used IP grew faster or were able to achieve a higher future productivity level. Previous studies suggest a positive relationship between IP protection use and firm performance, so we anticipate positive relationships (Athreye 2019; Schmock 2013; Greenhalgh et al. 2011; Brem et al. 2017). Reflecting sectoral differences in IP protection use and value, we report both aggregate and sectoral results (Griliches 1981; Connolly and Hirschey 1988; Greenhalgh and Longland 2005). We distinguish IP protection users from non-users and compare growth rates (in employment and turnover) over the four-year period 2012-2016, and their productivity (turnover per employee) levels in 2016. Our analysis focuses on the seven sectors where more than 10 per cent of firms were using at least one form of IP protection in 2012[17]. Table A1.1 details the number of firms in each of these sectors along with the number of IP protection users, allowing the number of non-users to be deduced. Turnover growth and employment growth between 2012 and 2016, for firms in each of the seven sectors, is calculated using data from the BSD data file. Productivity (turnover per employee) in 2016 is also calculated for firms in each of the seven sectors[18] using the 2016 BSD data.

Table 2 shows the results from the Wilcoxon rank-sum/Mann-Whitney non-parametric tests. When comparing the turnover growth of IP protection users and non-users, the results suggest that H_0 can be rejected in favour of H_1 in four of the seven sectors, thus reflecting a significant difference between the two groups of firms in the four sectors. The probability that the turnover growth in IP protection users is greater than the turnover growth in non-users ranges between 53 and 65 per cent across the four sectors. When examining employment growth across IP protection users and non-users, a significant difference between the two groups of firms is found in three of the seven sectors, and H_0 can be rejected in favour of H_1 in these cases. The probability that the employment growth in IP protection users is greater than the employment growth in non-users ranges between 52 and 55 per cent. The difference between the future productivity of IP protection users and non-users is significant in six of the seven sectors. H_0 is rejected in favour of H_1 in the six sectors suggesting that the IP protection users and non-users belong to two different populations. The probability that future productivity of IP protection users is greater than the future productivity of non-users ranges between 62 and 86 per cent across the six sectors. For these IP intensive sectors, these results provide consistent evidence of a strong and positive association between IP protection use and growth, and a particularly strong association between IP protection use and productivity (Table 2).

[17] The seven sectors are: food/beverages/tobacco products; coke/petroleum products/nuclear fuel; chemicals/chemical products; office machinery/equipment; medical/precision/optical/ watches/clocks; collection/purification/ distribution of water; R&D.

[18] Outliers are removed from the analysis: turnover growth > |150| per cent, employment growth > |150| per cent and productivity > £1,000,000 are excluded.

5. IP PROTECTION – INNOVATION AND INNOVATION SUCCESS

Before investing in innovation, a firm has an expectation of post-innovation returns (Du et al. 2007), indeed, a firm's incentive to innovate comes from this expectation (Laursen and Salter 2005). To help realise its expectation and profit from innovation, a firm can use IP protection mechanisms. In this section, using the UKIS-IP dataset, we examine whether IP protection is effective in helping firms to undertake and profit from innovation. In each case, our IP protection data pre-dates our innovation output measures, so a causal interpretation is appropriate.

The estimation results are shown in Tables 3 and 4, with the key results summarised in Table 5. Results for the probit models, which examine how patents, trade marks and registered designs influence product/service innovation in firms, are shown in Table 3. Across all firms, an increase in a firm's stock of patents or trade marks at the beginning of the UKIS period (ceteris paribus) has an insignificant effect on the probability that the firm will engage in product/service innovation (NTF or NTM) during the survey period (Table 5). This result is consistent across the four sub-groups of firms, with the exception of the effect of trade marks in manufacturing firms. An increase in a firm's stock of trade marks in manufacturing firms at the beginning of the survey period leads to a statistically significant increase in the probability that the firm will engage in product/service innovation during the period. As with the other sub-groups, the trade mark effect is insignificant when NTF and NTM innovation is considered separately. The results are somewhat different for registered designs, however. Across all firms, an increase in a firm's stock of registered designs at the beginning of the UKIS period (ceteris paribus) leads to a statistically significant increase in the probability that the firm will engage in product/service innovation during the survey period (significant at the 5 per cent level). We see a similar result in manufacturing and low-tech/less knowledge-intensive firms, although the significance level in manufacturing firms is lower. The registered design effect is insignificant in service firms and high-tech/knowledge-intensive firms (Table 5). When we consider NTF and NTM innovation separately, the stock of registered designs has an insignificant effect on the probability of NTF innovation in the whole-sample model and all sub-group models. In contrast, the stock of registered designs has a positive, significant effect on the probability of NTM innovation in all models. In the whole-sample model, an increase in a firm's stock of registered designs at the beginning of the UKIS period (ceteris paribus) leads to a statistically significant increase in the probability that the firm will engage in NTM product/service innovation during the survey period. In the sub-group models, the effect is largest in high-tech/knowledge-intensive firms and smallest in low-tech/less knowledge-intensive firms.

The control variables used in the probit models largely take the expected signs, but they also suggest some significant differences between the determinants of NTF and NTM innovation (Table 3). For example, the proportion of graduates that a firm employees has a positive effect on the probability of product/service innovation, but it seems that the proportion of science graduates is what matters for NTM innovation in manufacturing and high-tech/knowledge-intensive firms. Firm training to encourage innovative activities and the number of innovation co-operation partners a firm has are both important for NTF and NTM innovation, but they have a larger impact on NTF innovation. The results also show that external R&D is important for NTM innovation in manufacturing and high-tech/knowledge-intensive firms, but is insignificant elsewhere. The acquisition of advanced machinery is important for both types of innovation, but will have a larger impact on that which is NTF.

Results for the Tobit models, which examine how patents, trade marks and registered designs influence the proportion of business turnover from goods and services that were new to the firm and the proportion of business turnover from goods and services that were new to the firm or new to the market, are shown in Table 4 and summarised in Table 5. In the whole-sample model and the four sub-group models, an increase in a firm's stock of patents at the beginning of the UKIS period (ceteris paribus) has a negative, insignificant effect on both the proportion of business turnover from NTF product/service innovation and the proportion of business turnover from NTF or NTM (hereafter NTFM) product/service innovation at the end of the survey period. In contrast, an increase in a firm's stock of trade marks at the beginning of the UKIS period (ceteris paribus) has a negative, significant effect (at the 5 per cent level) on both the NTF and NTFM proportions in the whole-sample model. Across the sub-group models, trade mark effects are also negative, but they are insignificant in several cases. However, in manufacturing and high-tech/knowledge-intensive firms, trade marks have a negative, significant effect on the proportion of business turnover from NTFM product/service innovation, and in service firms, they have a significant, negative effect on the proportion of business turnover from NTF product/service innovation. As with the probit model results, the impact of registered designs on our dependent variables is quite different to the effects we see for patents and trade marks. The registered design parameters are positive in all cases, but only significant in the NTFM models. In these NTFM models, we see the largest impact in service firms and high-tech/knowledge intensive firms. In manufacturing and low-tech/less knowledge-intensive firms, the effects are smaller.

Results for the control variables included in the Tobit models uncover some differences between the determinants of innovation success in firms that engage solely in NTF product/service innovation and the determinants of innovation success in firms that engage in NTM product/service innovation, either solely or in conjunction with NTF product/service innovation. For example, science graduates are particularly important for the proportion of business turnover from NTFM product/service innovation, suggesting that they matter for NTM innovation success, whereas other graduates help boost both NTF and NTM product/service innovation.

6. DISCUSSION AND CONCLUSIONS

For all UK firms, our analysis of the BSD-IP suggests that around 5.5 per cent of firms with employees held either a patent, trade mark or registered design at some point during the 1998-2018 period. Significant differences emerge in IP protection use between sectors. The proportion of firms using formal IP protection exceeds 10 per cent in only seven 2-digit sectors: food/beverages/tobacco products; coke/petroleum products/nuclear fuel; chemicals/chemical products; office machinery/equipment; medical/precision/optical/ watches/clocks; collection/purification/ distribution of water; and R&D. Non-parametric tests of the use of IP protection with firm performance across these sectors suggest a strong positive association reflecting the results of earlier studies (Athreye 2019; Schmock 2013; Greenhalgh et al. 2011). Perhaps surprisingly, IP protection use is more consistently linked to productivity (turnover per employee) than to either turnover or employment growth (Table 1). This is consistent with the notion that IP protection may be helping firms to overcome the appropriability problem – contributing to returns or margins – while having less effect on driving growth (Ceccagnoli and Rothaermel 2008).

Looking at the relationship between IP protection and innovation, we find significant differences in the effects of each IP instrument on both the probability of innovating and the returns to innovation. Three key results emerge. First, we find no significant relationship between firms' patent holdings and either the propensity to innovate or the returns to innovation (Table 5). This finding proves consistent across all of the groups of firms we examined. In one sense, this result is perhaps not surprising given the generally low propensity to patent – even among innovating firms – and the strong sectoral concentration of patenting in manufacturing sectors (Figure 2). Previous studies have noted the weakness of the patent-to-innovation link in broad groups of firms (e.g. Roper and Hewitt-Dundas 2015), but the stronger linkage in specific sectors such as life sciences covered by stronger appropriation regimes (Hall et al. 2014).

Second, the weakness of the patent-to-innovation linkage we identify is also reflected in our results for trade marks. In general, our results suggest that trade marks have little effect on a firm's propensity to introduce a new product/service innovation. However, in manufacturing firms, we find a significant and positive effect on the probability that firms will introduce new product/service innovations. This is consistent with earlier studies (e.g. Jensen and Webster 2009) that suggest correlations between innovation and trade mark applications vary across sectors, with the highest correlations occurring in the manufacturing sector and in those firms undertaking product innovation. Perhaps more surprising than the relatively weak trade mark-to-innovation link we find is that contrary to most previous studies (e.g. Schmock 2003), we also identify some significant and negative relationships between trade marks and the percentage of sales derived from innovative products. This may arise as trade marks are rarely linked to individual innovations but tend instead to cover a range of different products or services. As a result trade marks, differently to patents or registered designs, may not have a one-to-one relationship with innovations (IPO 2018b). Where trade marks make a contribution to the sales of both existing and innovative products, this may therefore either increase or decrease the proportion of sales from innovative products. Our results suggest that trade marks may be more strongly linked to the sales of established rather than new products/services (in the first three years of their lifetime).

Third, while trade marks may not have a one-to-one relationship with new innovations, this is more likely with registered designs (IPO 2018b) and we find strong and consistently positive registered design-to-innovation linkages. Firms holding registered designs are more likely to undertake new-to-the-market innovation and to have higher innovative sales than firms which do not have registered designs (Table 5). This emphasises the importance of design as a driver of innovation across the manufacturing and services sector, but also across high and low-tech sectors. Prior evidence on the design-to-innovation relationship is limited, but our positive results here reflect those of Bascavusoglu-Moreu and Tether

(2011) rather than the negative design-to-innovation relationship found by Jensen and Webster (2009).

Our contrasting results for the different IP instruments suggest the potential need to re-evaluate the contribution of patents, trade marks and registered designs to innovation. Policy attention has often focussed predominantly on patenting as a driver of innovation, paying significantly less – if any – attention to the role of registered designs. This perspective seems mistaken, particularly where interest focuses on supporting innovation across the whole (service dominated) economy. The regulations covering R&D tax credits in the UK, for example, mean that while more than half of firms in the creative industries report conducting R&D, only 1:4 of these firms are eligible for support under the current HMRC regulations (OMB Research 2020). Our results suggest the potential role of extending this support to firms' investments in developing registered designs which would have significant and positive innovation benefits (Innovate UK 2020). In more methodological terms, the weakness of the patents-to-innovation relationship for the economy as a whole again suggest the limitations of patents as an indicator of 'innovation' beyond patent-intensive sectors such as life sciences (Roper and Hewitt-Dundas 2015).

Our analysis also suggests some avenues for future research. First, our results on registered designs suggest the value of further investigation of the design-to-innovation relationship. What are the mechanisms which link designs to innovation and innovation returns? How important are registered designs, or are unregistered designs equally or more important? Also, how is the value of registered designs related to other innovation investments such as training or R&D? In some previous work, we found a strong positive complementarity between design involvement in innovation and firms' R&D investments (Roper et al. 2016). Second, while existing evidence points to synergies between patents and trade marks, we have no evidence on potential synergies between registered designs and patents and registered designs and trade marks. Thirdly, we have little or no information about the geographical distribution of IP protection use or its relationship to firms' position in the productivity distribution. Both would be helpful in understanding how IP protection development can contribute to recovery from the COVID-19 crisis and other national agendas such as levelling-up.

Table 1: Wilcoxon rank-sum non-parametric tests for the performance of IP protection users and non-users (2012-2016)

2-digit sector	Turnover growth (2012 - 2016)		Probability that turnover growth in firms that use IP protection is greater than the turnover growth in firms that do not use IP protection	Employment growth (2012-2016)		Probability that employment growth in firms that use IP protection is greater than the employment growth in firms that do not use IP protection	Productivity in 2016		Probability that productivity in firms that use IP protection is greater than the productivity in firms that do not use IP protection
	IP protection users	Non-users		IP protection users	Non-users		IP protection users	Non-users	
Food/beverages/tobacco products	N=745	N=3115		N=747	N=3210		N=790	N=5385	
	p=0.00		**0.57**	p=0.04		**0.52**	p=0.00		**0.72**
Coke/petroleum products/nuclear fuel	N=25	N=82		N=25	N=93		N=25	N=101	
	p=0.70			p=0.77			p=0.02		**0.65**
Chemicals/chemical products	N=487	N=1450		N=498	N=1519		N=509	N=2089	
	p=0.02		**0.53**	p=0.04		**0.53**	p=0.00		**0.63**
Office machinery/equipment	N=70	N=370		N=73	N=388		N=74	N=616	
	p=0.32			p=0.48			p=0.00		**0.71**
Medical/precision/optical/watches/ clocks	N=384	N=2081		N=397	N=2173		N=409	N=2971	
	p=0.25			p=0.00		**0.55**	p=0.00		**0.62**
Collection/purification/distribution of water	N=14	N=54		N=14	N=56		N=16	N=71	
	p=0.07		**0.65**	p=0.53			p=0.00		**0.86**
R&D	N=170	N=889		N=194	N=1017		N=222	N=1972	
	p=0.04		**0.55**	p=0.25			p=0.37		

Source: BSD (2012, 2016) and IPO IP protection data (1998-2016)

Table 2: Descriptives

	All firms		Manufacturing		Services		High-tech		Low-tech	
	N=58831		N=14760		N=44071		N=25048		N=33783	
	Mean	Std Dev.	Mean	Std Dev.	Mean	Std Dev.	Mean	Std Dev.	Mean	Std Dev.
Product/service innovator (0/1)	0.28	0.45	0.40	0.49	0.25	0.43	0.35	0.48	0.23	0.42
New-to-the-market product/service innovator (0/1)	0.12	0.33	0.20	0.40	0.10	0.31	0.17	0.38	0.10	0.30
New-to-the-firm product/service innovator (0/1)	0.15	0.36	0.22	0.41	0.14	0.35	0.20	0.40	0.13	0.34
New-to-the-firm innovation success (%)	2.47	10.20	3.31	10.45	2.30	10.13	3.31	12.18	2.05	9.00
New-to-the-firm-and-market innovation success (%)	4.39	14.12	6.29	14.98	3.97	13.88	6.20	17.16	3.46	12.18
Patents (log)	0.00	0.05	0.00	0.08	0.00	0.04	0.00	0.06	0.00	0.04
Trade marks (log)	0.11	0.48	0.24	0.70	0.08	0.40	0.13	0.49	0.10	0.47
Registered designs (log)	0.01	0.13	0.03	0.22	0.00	0.10	0.01	0.12	0.01	0.14
Employment (log)	3.17	1.15	3.46	1.10	3.10	1.15	3.25	1.25	3.12	1.10
Science graduates (%)	6.45	16.25	4.99	11.12	6.79	17.20	13.17	23.33	2.85	8.74
Other graduates (%)	9.61	19.62	5.12	12.71	10.64	20.76	16.93	24.75	5.69	14.79
Design-engaged firm (0/1)	0.17	0.37	0.30	0.46	0.14	0.34	0.23	0.42	0.14	0.34
Training-engaged firm (0/1)	0.27	0.45	0.32	0.47	0.26	0.44	0.34	0.47	0.24	0.43
Exporting firm (0/1)	0.30	0.46	0.55	0.50	0.24	0.43	0.39	0.49	0.24	0.43
Int R&D (0/1)	0.27	0.44	0.44	0.50	0.23	0.42	0.37	0.48	0.21	0.41
Ext R&D (0/1)	0.09	0.29	0.14	0.34	0.08	0.27	0.12	0.33	0.07	0.26
Innovation partners (0 to 7)	0.87	1.79	1.04	1.80	0.83	1.78	1.08	1.91	0.76	1.71
Innovation partners (squared) (0 to 49)	3.95	10.76	4.33	10.36	3.87	10.85	4.81	11.38	3.49	10.38
Acquisition of existing knowledge (0/1)	0.09	0.29	0.12	0.33	0.09	0.28	0.12	0.32	0.08	0.27
Market introduction of innovation (0/1)	0.28	0.45	0.37	0.48	0.26	0.44	0.33	0.47	0.25	0.43
Acquisition of advanced machinery (0/1)	0.43	0.50	0.56	0.50	0.40	0.49	0.47	0.50	0.41	0.49

Source: UKIS (2002-2016) and IPO IP protection data (1998-2018)

Table 3: The probability of product/service innovation, NTM innovation and NTF innovation - Probit models, marginal effects

	All firms	All firms NTM	All firms NTF	Manuf firms	Manuf firms NTM	Manuf firms NTF	Serv firms	Serv firms NTM	Serv firms NTF	High-tech firms	High-tech firms NTM	High-tech firms NTF	Low-tech firms	Low-tech firms NTM	Low-tech firms NTF
Patents (log)	-0.008	0.014	-0.033	-0.008	0.034	-0.045	-0.004	0.010	-0.028	-0.042	0.013	-0.051	0.017	0.016	-0.023
	(0.027)	(0.010)	(0.023)	(0.053)	(0.026)	(0.046)	(0.034)	(0.010)	(0.029)	(0.046)	(0.018)	(0.040)	(0.032)	(0.011)	(0.028)
Trade marks (log)	0.006	0.002	0.000	0.017**	0.002	0.009	0.002	0.002	-0.002	0.009	-0.001	0.003	0.004	0.003	-0.001
	(0.005)	(0.002)	(0.003)	(0.008)	(0.004)	(0.006)	(0.006)	(0.002)	(0.004)	(0.009)	(0.004)	(0.007)	(0.005)	(0.002)	(0.004)
Registered designs (log)	0.033**	0.018***	-0.008	0.038*	0.024**	0.003	0.035	0.020***	-0.018	0.019	0.026**	-0.030	0.034**	0.015***	-0.002
	(0.016)	(0.005)	(0.011)	(0.022)	(0.011)	(0.017)	(0.024)	(0.007)	(0.018)	(0.030)	(0.013)	(0.022)	(0.017)	(0.005)	(0.011)
Employment (log)	-0.001	-0.001	0.003*	-0.010*	-0.002	-0.001	0.000	-0.001	0.004**	0.003	0.000	0.006**	-0.003	-0.002	0.001
	(0.002)	(0.001)	(0.002)	(0.006)	(0.003)	(0.004)	(0.002)	(0.001)	(0.002)	(0.004)	(0.002)	(0.003)	(0.003)	(0.001)	(0.002)
Science graduates (%)	0.001***	0.001***	0.000	0.000	0.001***	-0.001	0.001***	0.000***	0.000	0.000	0.001***	-0.000	0.001***	0.001***	0.001**
	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Other graduates (%)	0.000**	0.000*	0.000**	0.000	0.000	0.000	0.000**	0.000*	0.000*	0.000	-0.000	0.000*	0.001*	0.000**	0.000
	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Design-engaged firm (0/1)	0.091***	0.034***	0.045***	0.123***	0.056***	0.059***	0.081***	0.030***	0.043***	0.104***	0.051***	0.046***	0.083***	0.026***	0.045***
	(0.010)	(0.004)	(0.008)	(0.016)	(0.010)	(0.014)	(0.012)	(0.005)	(0.009)	(0.015)	(0.008)	(0.012)	(0.013)	(0.005)	(0.010)
Training-engaged firm (0/1)	0.085***	0.017***	0.058***	0.051***	0.010	0.036***	0.090***	0.018***	0.061***	0.081***	0.015**	0.059***	0.085***	0.017***	0.058***
	(0.012)	(0.004)	(0.010)	(0.015)	(0.009)	(0.013)	(0.013)	(0.004)	(0.012)	(0.013)	(0.007)	(0.010)	(0.016)	(0.004)	(0.014)
Exporting firm (0/1)	0.051***	0.025***	0.023***	0.063***	0.056***	0.017	0.048***	0.019***	0.025***	0.047***	0.037***	0.016*	0.054***	0.020***	0.027***
	(0.007)	(0.003)	(0.006)	(0.014)	(0.009)	(0.011)	(0.008)	(0.004)	(0.007)	(0.013)	(0.007)	(0.010)	(0.009)	(0.004)	(0.007)
Int R&D (0/1)	0.186***	0.082***	0.100***	0.229***	0.144***	0.115***	0.171***	0.067***	0.096***	0.213***	0.111***	0.113***	0.170***	0.067***	0.095***
	(0.014)	(0.005)	(0.013)	(0.015)	(0.010)	(0.013)	(0.017)	(0.006)	(0.015)	(0.013)	(0.008)	(0.012)	(0.020)	(0.007)	(0.018)
Ext R&D (0/1)	0.004	0.010**	-0.011	0.022	0.042***	-0.008	-0.000	0.004	-0.012	0.009	0.017**	-0.008	-0.000	0.007	-0.013
	(0.010)	(0.004)	(0.007)	(0.019)	(0.011)	(0.015)	(0.012)	(0.005)	(0.008)	(0.016)	(0.008)	(0.012)	(0.013)	(0.005)	(0.009)
Innovation partners (0 to 7)	0.143***	0.039***	0.079***	0.197***	0.067***	0.122***	0.129***	0.033***	0.071***	0.179***	0.055***	0.102***	0.122***	0.031***	0.068***
	(0.006)	(0.002)	(0.004)	(0.011)	(0.006)	(0.009)	(0.007)	(0.003)	(0.005)	(0.009)	(0.004)	(0.007)	(0.008)	(0.003)	(0.005)
Innovation partners (squared) (0 to 49)	-0.016***	-0.004***	-0.009***	-0.024***	-0.008***	-0.015***	-0.014***	-0.003***	-0.008***	-0.021***	-0.006***	-0.012***	-0.013***	-0.003***	-0.008***
	(0.001)	(0.000)	(0.001)	(0.002)	(0.001)	(0.002)	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)
Acquisition of existing knowledge (0/1)	0.012	0.008*	0.003	0.003	0.014	-0.014	0.015	0.007	0.007	0.010	0.001	0.006	0.013	0.012*	0.002
	(0.010)	(0.005)	(0.007)	(0.020)	(0.011)	(0.016)	(0.012)	(0.005)	(0.008)	(0.016)	(0.007)	(0.012)	(0.013)	(0.006)	(0.009)
Market introduction of innovation (0/1)	0.188***	0.074***	0.109***	0.245***	0.108***	0.159***	0.172***	0.067***	0.099***	0.228***	0.107***	0.133***	0.164***	0.057***	0.097***
	(0.010)	(0.005)	(0.009)	(0.015)	(0.010)	(0.014)	(0.012)	(0.006)	(0.010)	(0.013)	(0.009)	(0.012)	(0.013)	(0.006)	(0.012)
Acquisition of advanced machinery (0/1)	0.073***	0.015***	0.044***	0.093***	0.033***	0.058***	0.069***	0.011***	0.042***	0.087***	0.017**	0.054***	0.065***	0.014***	0.039***
	(0.009)	(0.003)	(0.007)	(0.014)	(0.009)	(0.011)	(0.010)	(0.004)	(0.008)	(0.013)	(0.007)	(0.010)	(0.011)	(0.004)	(0.009)
N	58831	58831	50470	14756	14756	11280	44061	44045	39178	25048	25048	20565	33783	33783	29905
Chi-squared	8544.902	6422.013	4566.916	.	.	1642.706	5644.328	4017.892	3155.969	3939.227	3190.752	2092.621	4571.029	3233.170	2509.482
p	0.000	0.000	0.000	.	.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
bic	46845.5	30126.4	33957.8	13541.5	10906.9	9466.4	33982.7	20425.6	25135.6	21294.2	15642.0	15750.2	25989.5	15341.9	18834.4

Notes: Coefficients are reported with standard errors below. Models contain both wave and sector dummies. * denotes significance at the 10 per cent level, ** denotes significance at the 5 per cent level and *** denotes significance at the 1 per cent level.

Source: UKIS (2002-2016) and IPO IP protection data (1998-2018)

Table 4: NTF and NTFM innovation success (proportion of sales coming from NTF and NTFM innovation) - Tobit models

	All firms NTF	All firms NTFM	Manuf firms NTF	Manuf firms NTFM	Serv firms NTF	Serv firms NTFM	High-tech firms NTF	High-tech firms NTFM	Low-tech firms NTF	Low-tech firms NTFM
Patents (log)	-4.324	-1.780	-2.030	-0.730	-4.865	-0.823	-3.382	0.286	-5.965	-4.362
	(2.734)	(2.476)	(2.946)	(3.032)	(4.487)	(3.793)	(4.071)	(3.648)	(3.756)	(3.012)
Trade marks (log)	-1.240**	-1.290**	-0.203	-1.032**	-1.780*	-1.312	-1.245	-1.965**	-1.141	-0.872
	(0.584)	(0.517)	(0.555)	(0.496)	(0.943)	(0.846)	(0.952)	(0.777)	(0.727)	(0.677)
Registered designs (log)	0.530	4.007**	0.062	2.815*	2.125	5.964*	-3.705	5.080*	1.414	3.393*
	(2.087)	(1.638)	(1.828)	(1.439)	(3.729)	(3.070)	(3.086)	(2.736)	(2.351)	(1.988)
Employment (log)	0.018	-1.057***	-0.540	-1.414***	0.345	-0.850**	0.263	-1.126**	-0.164	-0.983**
	(0.342)	(0.331)	(0.448)	(0.400)	(0.427)	(0.424)	(0.531)	(0.476)	(0.442)	(0.454)
Science graduates (%)	-0.055*	0.096***	-0.063	0.099**	-0.059*	0.095***	-0.070**	0.069**	0.044	0.195***
	(0.029)	(0.027)	(0.051)	(0.045)	(0.034)	(0.033)	(0.034)	(0.030)	(0.064)	(0.061)
Other graduates (%)	0.077***	0.103***	0.050	0.083**	0.082***	0.109***	0.081***	0.073***	0.060	0.131***
	(0.024)	(0.024)	(0.044)	(0.040)	(0.029)	(0.028)	(0.031)	(0.028)	(0.040)	(0.039)
Design-engaged firm (0/1)	4.942***	8.237***	4.152***	7.865***	5.467***	8.398***	4.656***	8.970***	5.386***	8.004***
	(1.220)	(1.121)	(1.204)	(1.234)	(1.645)	(1.520)	(1.601)	(1.420)	(1.693)	(1.578)
Training-engaged firm (0/1)	8.691***	9.582***	4.370***	4.831***	10.223***	11.648***	7.514***	7.356***	9.456***	10.968***
	(1.451)	(1.477)	(1.291)	(1.195)	(1.896)	(2.004)	(1.631)	(1.453)	(2.032)	(2.103)
Exporting firm (0/1)	3.477***	4.919***	1.187	4.157***	4.529***	5.408***	2.380	4.016**	4.289***	5.690***
	(1.092)	(1.007)	(1.227)	(1.194)	(1.436)	(1.322)	(1.769)	(1.565)	(1.349)	(1.279)
Int R&D (0/1)	16.468***	21.841***	10.626***	17.664***	18.341***	23.309***	16.913***	21.159***	16.077***	21.998***
	(1.560)	(1.611)	(1.286)	(1.310)	(2.049)	(2.162)	(1.767)	(1.587)	(2.136)	(2.224)
Ext R&D (0/1)	-1.590	-0.263	-3.155**	1.724	-0.946	-1.022	0.250	-0.081	-3.293*	-0.514
	(1.378)	(1.181)	(1.389)	(1.278)	(1.880)	(1.662)	(1.967)	(1.563)	(1.897)	(1.732)
Innovation partners (0 to 7)	10.837***	13.346***	9.656***	9.709***	11.425***	14.833***	11.628***	14.749***	10.272***	12.313***
	(0.899)	(0.861)	(0.929)	(0.785)	(1.188)	(1.180)	(1.190)	(1.081)	(1.245)	(1.211)
Innovation partners (squared) (0 to 49)	-1.145***	-1.386***	-1.137***	-1.054***	-1.185***	-1.533***	-1.286***	-1.652***	-1.051***	-1.196***
	(0.132)	(0.125)	(0.150)	(0.129)	(0.170)	(0.168)	(0.173)	(0.162)	(0.184)	(0.177)
Acquisition of existing knowledge (0/1)	0.429	2.037*	0.938	1.894	0.353	2.335	1.194	2.398	-0.071	1.699
	(1.277)	(1.152)	(1.468)	(1.365)	(1.685)	(1.553)	(1.854)	(1.590)	(1.745)	(1.620)
Market introduction of innovation (0/1)	16.496***	20.005***	14.389***	16.302***	17.159***	21.203***	14.563***	21.017***	17.432***	19.053***
	(1.395)	(1.376)	(1.307)	(1.275)	(1.849)	(1.880)	(1.909)	(1.517)	(1.893)	(1.981)
Acquisition of advanced machinery (0/1)	7.848***	7.005***	5.699***	6.336***	8.976***	7.605***	7.472***	7.012***	7.821***	7.059***
	(1.368)	(1.416)	(1.267)	(1.225)	(1.828)	(1.955)	(1.806)	(1.651)	(1.821)	(1.944)
N	51049	52340	11835	12701	39214	39639	21031	21709	30018	30631
p	0.000	0.000	0.000	.	.	.	0.000	0.000	0.000	0.000
bic	1.05e+06	1.33e+06	2.65e+05	3.66e+05	7.81e+05	9.58e+05	4.39e+05	5.74e+05	6.10e+05	7.54e+05

Notes: Coefficients are reported with standard errors below. Models contain both wave and sector dummies. * denotes significance at the 10 per cent level, ** denotes significance at the 5 per cent level and *** denotes significance at the 1 per cent level.

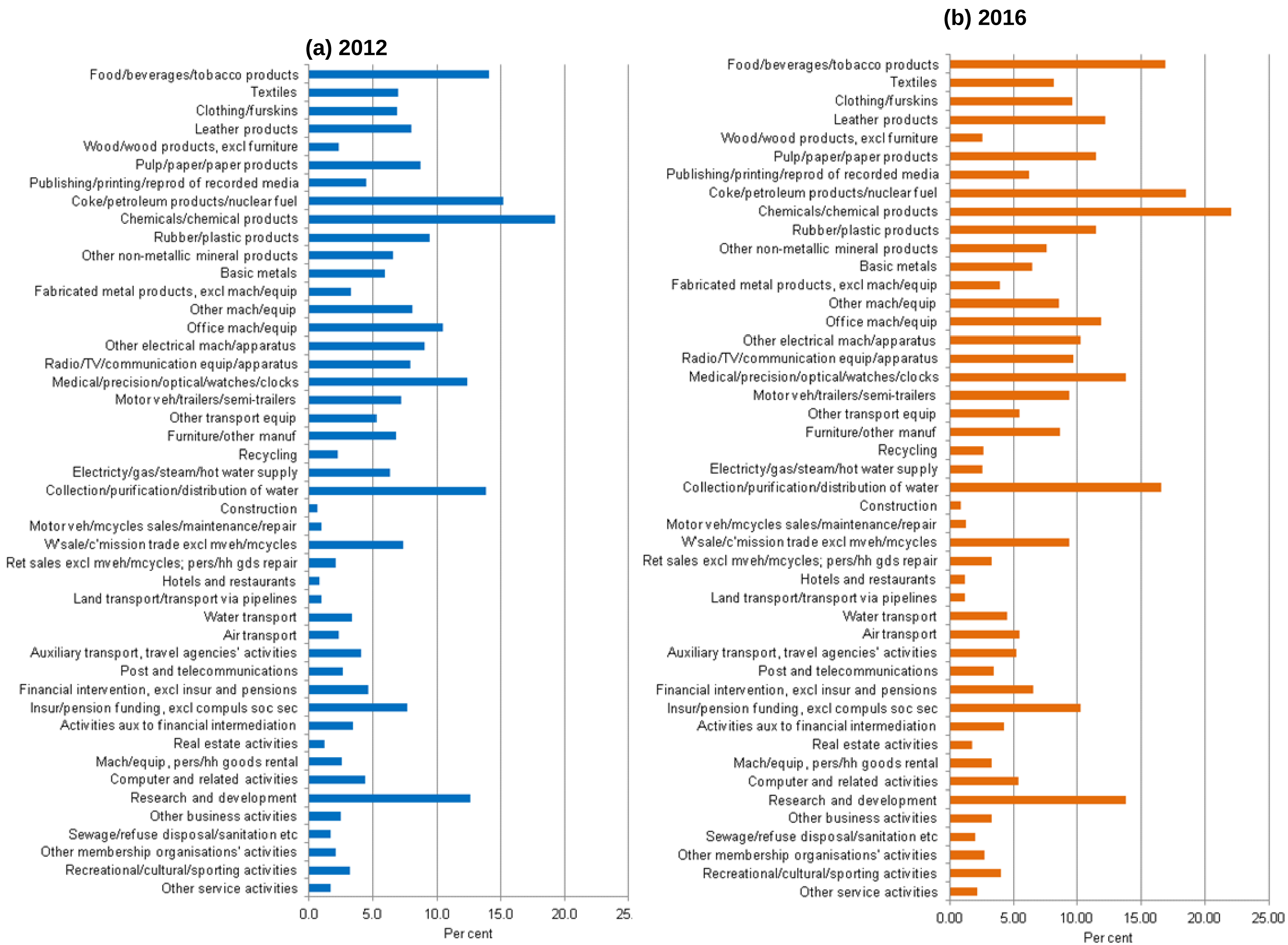
Source: UKIS (2002-2016) and IPO IP protection data (1998-2018)

Table 5: Summary of key results

	Patents	Trade Marks	Registered Designs
Product/service innovation			
All firms	(-)	(+)	+
Manufacturing	(-)	+	+
Services	(-)	(+)	(+)
High-tech/Knowledge intensive	(-)	(+)	(+)
Low-tech/Less knowledge intensive	(+)	(+)	+
New-to-market innovation			
All firms	(+)	(+)	+
Manufacturing	(+)	(+)	+
Services	(+)	(+)	+
High-tech/Knowledge intensive	(+)	(-)	+
Low-tech/Less knowledge intensive	(+)	(+)	+
New-to-firm innovation			
All firms	(-)	(+)	(-)
Manufacturing	(-)	(+)	(+)
Services	(-)	(-)	(-)
High-tech/Knowledge intensive	(-)	(+)	(-)
Low-tech/Less knowledge intensive	(-)	(-)	(-)
New-to-firm innovation sales			
All firms	(-)	-	(+)
Manufacturing	(-)	(-)	(+)
Services	(-)	-	(+)
High-tech/Knowledge intensive	(-)	(-)	(-)
Low-tech/Less knowledge intensive	(-)	(-)	(+)
New-to-firm-and-market innovation sales			
All firms	(-)	-	+
Manufacturing	(-)	-	+
Services	(-)	(-)	+
High-tech/Knowledge intensive	(+)	-	+
Low-tech/Less knowledge intensive	(-)	(-)	+

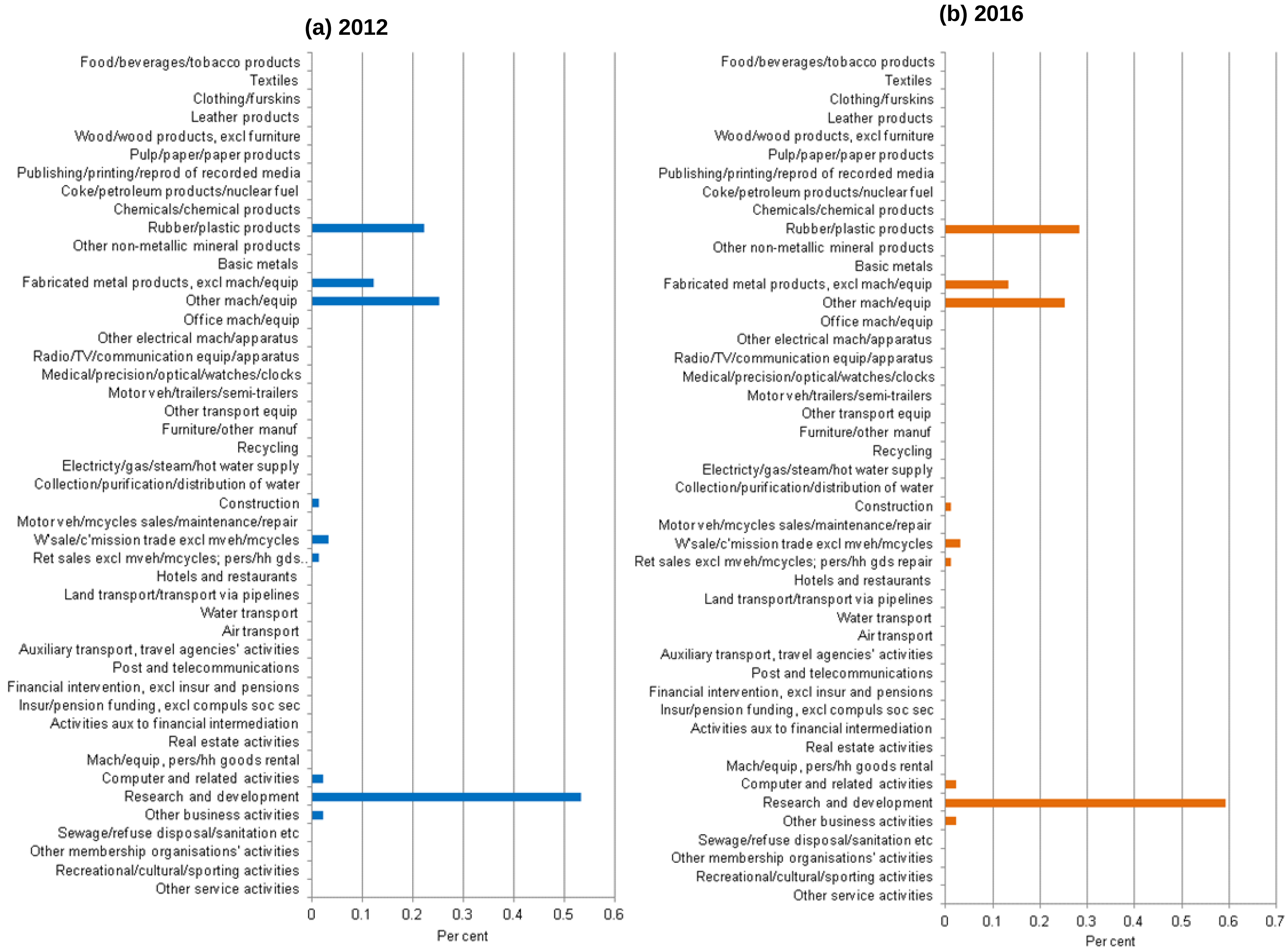
Notes: (+) denotes a positive but insignificant relationship; (-) negative and insignificant; '+' positive and significant; '-' negative and significant. Coefficients derived from Tables 3 and 4.

Figure 1: Proportion of firms within a sector with one of the three forms of IP protection



Source: BSD (2012, 2016) and IPO IP protection data (1998-2016)

Figure 2: Proportion of firms within a sector with at least one patent



Source: BSD (2012, 2016) and IPO IP protection data (1998-2016)

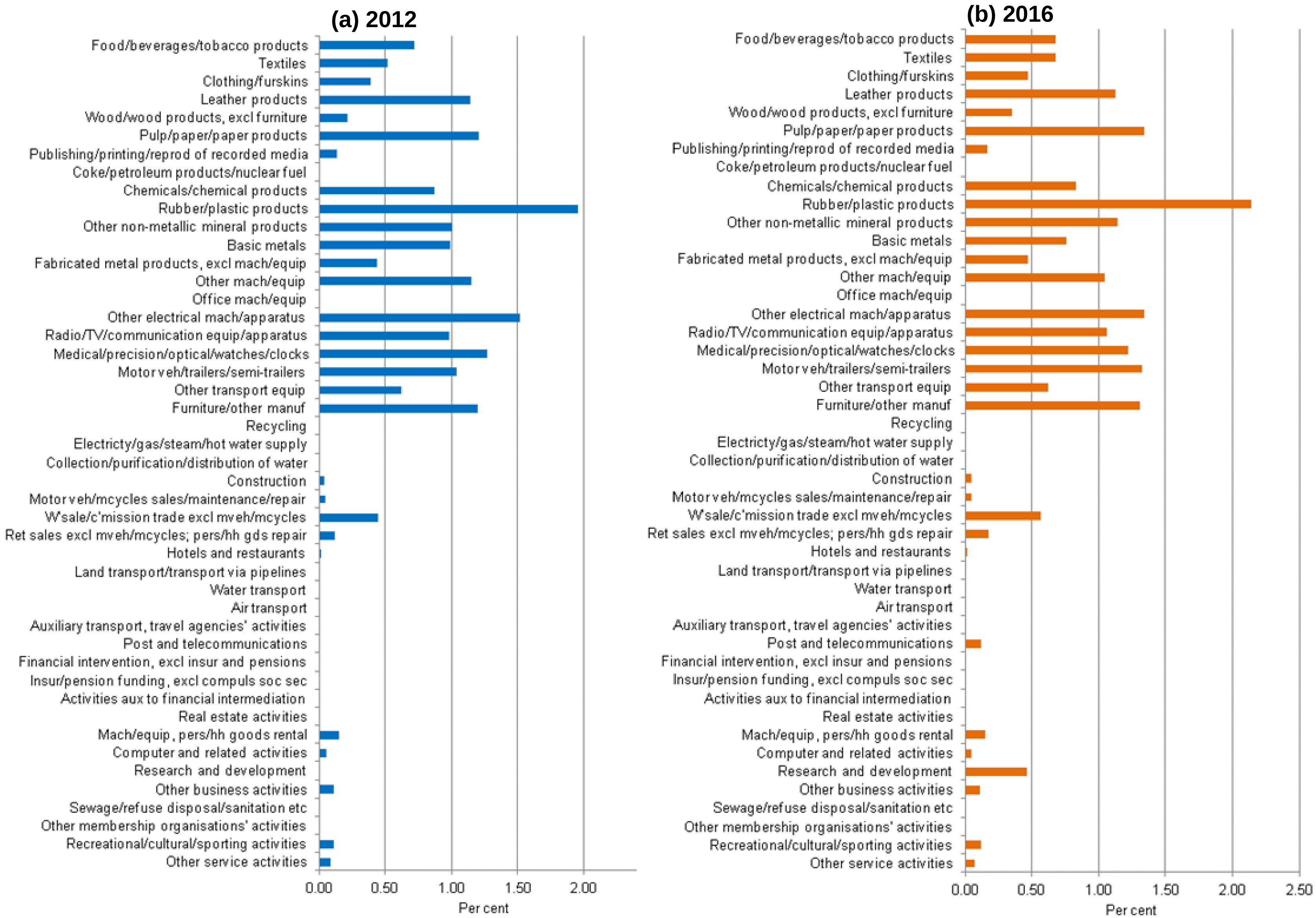
Figure 3: Proportion of firms within a sector with at least one trade mark

(a) 2012

(b) 2016

Source: BSD (2012, 2016) and IPO IP protection data (1998-2016)

Figure 4: Proportion of firms within a sector with at least one registered design



Source: BSD (2012, 2016) and IPO IP protection data (1998-2016)

Table A1.1: Use of IP protection by sector - 2012

2-digit SIC	Industry	Total no. of live firms	No. of live firms with at least one of the three forms of IP protection	No. of live firms with at least one patent	No. of live firms with at least one trade mark	No. of live firms with at least one registered design
15, 16	Food/beverages/tobacco products	5663	792	-	788	40
17	Textiles	3350	229	-	224	17
18	Clothing/furskins	2858	195	-	188	11
19	Leather products	883	70	-	66	10
20	Wood/wood products, excl furniture	5722	127	-	122	12
21	Pulp/paper/paper products	1411	122	-	115	17
22	Publishing/printing/reprod of recorded media	14887	652	-	642	19
23	Coke/petroleum products/nuclear fuel	179	27	-	26	-
24	Chemicals/chemical products	2791	536	-	526	24
25	Rubber/plastic products	4457	418	10	385	87
26	Other non-metallic mineral products	3295	214	-	205	33
27	Basic metals	1535	89	-	83	15
28	Fabricated metal products, excl mach/equip	17742	564	21	529	76
29	Other mach/equip	8123	651	20	612	93
30	Office mach/equip	733	76	-	72	-
31	Other electrical mach/apparatus	3240	291	-	268	49
32	Radio/TV/communication equip/apparatus	1650	129	-	120	16
33	Medical/precision/optical/watches/clocks	3423	422	-	404	43
34	Motor veh/trailers/semi-trailers	2046	146	-	136	21
35	Other transport equip	1793	93	-	86	11
36	Furniture/other manuf	10468	701	-	640	125
37	Recycling	1310	28	-	24	-
40	Electricty/gas/steam/hot water supply	531	33	-	33	-
41	Collection/purification/distribution of water	102	14	-	14	-
45	Construction	130222	755	13	729	39
50	Motor veh/mcycles sales/maintenance/repair	42502	383	-	378	17
51	W'sale/c'mission trade excl mveh/mcycles	59921	4344	18	4236	264
52	Ret sales excl mveh/mcycles; pers/hh gds repair	123429	2444	12	2382	136
55	Hotels and restaurants	118150	886	-	874	12
60	Land transport/transport via pipelines	22100	188	-	188	-
61	Water transport	861	28	-	28	-
62	Air transport	532	12	-	12	-
63	Auxiliary transport, travel agencies' activities	10036	399	-	396	-
64	Post and telecommunications	8243	211	-	209	-
65	Financial intervention, excl insur and pensions	5583	253	-	252	-
66	Insur/pension funding, excl compuls soc sec	1156	88	-	88	-
67	Activities aux to financial intermediation	10555	357	-	357	-
70	Real estate activities	49822	578	-	578	-
71	Mach/equip, pers/hh goods rental	8627	212	-	205	12
72	Computer and related activities	52921	2276	11	2254	26
73	Research and development	1881	236	10	228	-
74	Other business activities	238717	5753	48	5586	239
90	Sewage/refuse disposal/sanitation etc	3731	60	-	59	-
91	Other membership organisations' activities	15768	315	-	314	-
92	Recreational/cultural/sporting activities	35107	1095	-	1078	35
93	Other service activities	54859	889	-	861	44

Notes: Numbers less than 10 are unavailable due to confidentiality constraints.
Source: BSD (2012) and IPO IP protection data (1998-2012)

Table A1.2: Use of IP protection by sector - 2016

2-digit SIC	Industry	Total no. of live firms	No. of live firms with at least one of the three forms of IP protection	No. of live firms with at least one patent	No. of live firms with at least one trade mark	No. of live firms with at least one registered design
15, 16	Food/beverages/tobacco products	6274	1056	-	1053	42
17	Textiles	3285	264	-	255	22
18	Clothing/furskins	2830	269	-	261	13
19	Leather products	890	108	-	104	10
20	Wood/wood products, excl furniture	5938	148	-	138	20
21	Pulp/paper/paper products	1279	146	-	138	17
22	Publishing/printing/reprod of recorded media	13337	823	-	810	21
23	Coke/petroleum products/nuclear fuel	141	26	-	25	-
24	Chemicals/chemical products	2678	588	-	579	22
25	Rubber/plastic products	3986	454	11	419	85
26	Other non-metallic mineral products	2996	224	-	213	34
27	Basic metals	1475	94	-	90	11
28	Fabricated metal products, excl mach/equip	16438	638	21	597	76
29	Other mach/equip	8251	696	21	659	86
30	Office mach/equip	694	82	-	80	-
31	Other electrical mach/apparatus	3231	329	-	312	43
32	Radio/TV/communication equip/apparatus	1714	164	-	155	18
33	Medical/precision/optical/watches/clocks	3396	467	-	454	41
34	Motor veh/trailers/semi-trailers	1963	183	-	167	26
35	Other transport equip	1973	106	-	101	12
36	Furniture/other manuf	9642	825	-	765	125
37	Recycling	1283	33	-	30	-
40	Electricty/gas/steam/hot water supply	1871	47	-	47	-
41	Collection/purification/distribution of water	91	15	-	15	-
45	Construction	128825	1056	13	1018	52
50	Motor veh/mcycles sales/maintenance/repair	44634	540	-	531	18
51	W'sale/c'mission trade excl mveh/mcycles	57532	5339	17	5218	322
52	Ret sales excl mveh/mcycles; pers/hh gds repair	124457	4057	12	3958	212
55	Hotels and restaurants	128259	1475	-	1462	13
60	Land transport/transport via pipelines	22963	262	-	262	-
61	Water transport	792	35	-	35	-
62	Air transport	483	26	-	26	-
63	Auxiliary transport, travel agencies' activities	10188	524	-	518	-
64	Post and telecommunications	9297	311	-	306	10
65	Financial intervention, excl insur and pensions	5503	354	-	354	-
66	Insur/pension funding, excl compuls soc sec	1073	109	-	109	-
67	Activities aux to financial intermediation	11807	496	-	496	-
70	Real estate activities	51680	884	-	879	-
71	Mach/equip, pers/hh goods rental	8356	269	-	264	12
72	Computer and related activities	61901	3281	12	3256	25
73	Research and development	2214	304	13	293	10
74	Other business activities	258101	8259	52	8104	258
90	Sewage/refuse disposal/sanitation etc	4932	94	-	93	-
91	Other membership organisations' activities	15496	412	-	411	-
92	Recreational/cultural/sporting activities	38413	1510	-	1490	42
93	Other service activities	53983	1128	-	1112	32

Notes: Numbers less than 10 are unavailable due to confidentiality constraints.
Source: BSD (2016) and IPO IP protection data (1998-2016)

Annex 2: Variable definitions for econometric analysis

Variable	Definition
Patents (log)	Patent count at the start of the period (UKIS wave)
Trade marks (log)	Trade mark count at the start of the period (UKIS wave)
Registered designs (log)	Registered design count at the start of the period (UKIS wave)
Product/service innovator (0/1)	Firms introducing a new or improved product or service
NTF Product/service innovator (0/1)	Firms introducing a new or improved product or service which is new to the firm (NTF)
NTM Product/service innovator (0/1)	Firms introducing a new or improved product or service which is new to the market (NTM)
NTF innovation success (%)	Proportion of firm's turnover coming from innovation which is new to the firm
NTFM innovation success (%)	Proportion of firm's turnover coming from new-to-the-firm and new-to-the-market innovation combined
Int R&D (0/1)	Firms undertaking in-house R&D
Ext R&D (0/1)	Firms undertaking external R&D
Employment (log)	Employment at the end of the survey period
Science graduates (%)	Proportion of the workforce that are science or engineering graduates
Other graduates (%)	Proportion of the workforce that are graduates in subjects other than science or engineering
Exporting firm (0/1)	Firms that are exporting
Innovation partners (0 to 7)	Number of innovation partners
Innovation partners (squared) (0 to 49)	Number of innovation partners squared
Design-engaged firm (0/1)	Firms investing in design
Training-engaged firm (0/1)	Firms investing in training related to innovation
Acquisition of existing knowledge (0/1)	Firms investing in external knowledge acquisition related to innovation
Acquisition of market intelligence (0/1)	Firms investing in the acquisition of market intelligence related to innovation
Acquisition of advanced machinery (0/1)	Firms investing in the acquisition of machinery related to innovation

Annex 3: Pair-wise correlation matrix

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	Product/service innovator (0/1)	1.00																				
2	NTM product/service innovator (0/1)	0.61	1.00																			
3	NTF product/service innovator (0/1)	0.93	.	1.00																		
4	NTF innovation success (%)	0.49	0.06	0.53	1.00																	
5	Innovation success (%)	0.60	0.55	0.54	0.79	1.00																
6	Patents (log)	0.04	0.04	0.02	0.01	0.02	1.00															
7	Trade marks (log)	0.14	0.14	0.08	0.02	0.06	0.09	1.00														
8	Registered designs	0.08	0.09	0.03	0.01	0.05	0.06	0.34	1.00													
9	Employment (log)	0.10	0.08	0.08	0.02	0.01	0.05	0.33	0.10	1.00												
10	Science graduates (%)	0.18	0.20	0.09	0.07	0.18	0.03	0.05	0.01	0.05	1.00											
11	Other graduates (%)	0.08	0.06	0.06	0.05	0.07	0.00	0.05	0.00	0.08	0.16	1.00										
12	Design engaged (0/1)	0.40	0.35	0.28	0.17	0.29	0.04	0.15	0.09	0.12	0.16	0.07	1.00									
13	Training engaged (0/1)	0.35	0.27	0.25	0.16	0.25	0.02	0.08	0.04	0.11	0.15	0.09	0.37	1.00								
14	Export engaged (0/1)	0.24	0.23	0.15	0.08	0.15	0.05	0.20	0.09	0.17	0.24	0.12	0.24	0.13	1.00							
15	In-house R&D (0/1)	0.49	0.40	0.34	0.21	0.32	0.04	0.17	0.08	0.15	0.25	0.10	0.49	0.41	0.31	1.00						
16	External R&D (0/1)	0.29	0.27	0.19	0.13	0.23	0.03	0.15	0.08	0.12	0.14	0.07	0.34	0.29	0.17	0.43	1.00					
17	Innov partners (0-7)	0.39	0.32	0.29	0.17	0.27	0.04	0.13	0.05	0.14	0.22	0.09	0.31	0.28	0.17	0.36	0.30	1.00				
18	Innov partners squared (0-49)	0.29	0.25	0.20	0.13	0.22	0.03	0.11	0.04	0.10	0.19	0.08	0.24	0.23	0.12	0.27	0.25	0.95	1.00			
19	Aquistion of ex knowledge (0/1)	0.24	0.21	0.16	0.12	0.20	0.03	0.09	0.06	0.07	0.12	0.07	0.31	0.34	0.12	0.30	0.38	0.22	0.19	1.00		
20	Mkt intro of innov (0/1)	0.44	0.35	0.31	0.19	0.28	0.03	0.14	0.07	0.11	0.12	0.08	0.45	0.40	0.20	0.46	0.31	0.26	0.19	0.29	1.00	
21	Aquisition of adv machinery (0/1)	0.29	0.21	0.21	0.14	0.19	0.02	0.04	0.03	0.09	0.09	0.03	0.30	0.43	0.13	0.34	0.23	0.19	0.14	0.26	0.39	1.00

Source: UKIS (2002-2016) and IPO IP protection data (1998-2018)

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