Intellectual property rights, complementarity and the firm's economic performance

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Abstract: This paper analyses the optimal use of formal intellectual property rights (IPR) at the firm level. We examine the impact of combinations of IPR on the firm's productivity in order to study the complementarity or substitution relationship between them. Our data are extracted from two sets of community innovation survey (CIS): CIS IV and CIS 2006. We investigate complementarity (substitution) at two levels: in the context of formal IPR strategies and when they are combined with other intangible and managerial assets based on both adoption and productivity approaches. Mixed results are found for the complementarity of IPR alone. However, in combination with other activities, there is high complementarity with innovative and innovation cooperation variables. These results suggest that IPR strategies should be combined with other complementarity assets for the optimal appropriation of innovation profits.

Keywords: intellectual property rights; IPR; innovation; complementarity; substitution; economic performance; intangible assets.

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1 Introduction

The semi-public, non-competitive and non-exclusive nature of knowledge means that companies can only take advantage of their innovations if they are protected. Faced with this problem, countries have developed their own intellectual property rights (IPR) systems. Current, formal IPR instruments include: patents, trademarks, designs and copyrights. Overall, IPR can encourage innovation, reduce information asymmetry, protect market share and improve business competitiveness (Hussinger, 2006; Cohen et al., 2002; Arundel, 2001). There is a substantial body of research into the contribution of individual IPR instruments to the firm's economic performance (Hussinger, 2006; Shapiro, 2000; Munari and Santoni, 2010; Llerena and Millot, 2013).

However, the use of more than one IPR instrument at the same time has received very little attention in both the literature and practice, although, Arora (1997) points out that the combined use of patents and secrecy emerged even before the First World War when German companies in the dyestuff industry used them to prevent the entry of new companies and preserve their own leading market position. Nevertheless, the long history of IPR practices has not been accompanied by a body of research that examines their optimal use and impact on the firm's performance. Nowadays, the deployment of multiple IPR instruments is more widespread than ever. The best-known current example, highlighted by Munari (2012), is the Apple iPhone, which simultaneously includes several patents (e.g., to protect their multi-touch technology), trademarks (e.g., identification of the multi-touch technology), designs and copyrighted software. The question that naturally arises is: What is the impact of the use of combined IPR practices, especially on the firm's performance? This article addresses that question.

The choice of using one or more IPR practice(s) can be explained by the concepts of complementarity and substitutability. These approaches were first introduced into economics by Topkis (1987, 1978) and later developed by Holmstrom and Milgrom (1994). In their definition, authors adopt a mathematical interpretation of complementarity. The idea is that the gain obtained from increasing all components is larger than the sum of gains from separate increases (Milgrom and Roberts, 1990; Mothe et al., 2015).

In organisation studies, complementarities are mainly evaluated using earnings or costs approaches and are analysed with respect to the firm's value or performance. Lybecker (2003) argues that the increased use of one form of IPR can change market conditions and subsequently increase the marginal value of using another form of intellectual property. In this context, a good example is luxury products, which demonstrate complementarity between patents and trademarks. Here, it is very important to protect against brand name infringements, as it strengthens the exclusive character of patented products and decreases the value of imitations. Lybecker (2003) explains that complementarity is also related to production costs. This concerns cost reduction through the use of interrelated strategies that lead to economies of scope due to shared inputs. In other words, combined input costs are less than the total cost if they are used separately. More recent, empirical research into complementarity in the use of IPR (Somaya and Graham, 2006) has failed to reach a consensus. Findings suggest that they are complex and heavily influenced by many factors, such as company size and the phase of innovation. Although many studies have focused on substitutability between IPR practices and innovation (Mansfield, 1986; Friedman et al., 1991; Arundel and Kabla, 1998; Arundel 2001), most have only examined patents and secrecy. For instance, Hussinger (2006) found that secrecy is often used in the early stages of the invention, while patents are used more in the marketing phase. The two strategies become mutually exclusive after the entry of the invention into the market. Llerena and Millot (2013) that two effects counterbalance each other with respect to patents and trademarks. The first is the temporal substitution effect (i.e., the trademark has no impact on company profits during the patent period) and the second is the complementarity effect (i.e., the trademark allows the company to extend the reputation benefits resulting from the patent monopoly period). Which effect dominates, depends on exogenous parameters such as the publicity depreciation rate and the information dissemination rate. For example, the substitution effect is expected to have a greater impact in relation to high-tech enterprises, while complementarity is more significant in pharmaceutical and chemical companies. Munari (2012) explains that different elements of a product can be protected by various forms of IPR. For example, patents can protect its technical and functional characteristics, while trademarks or designs protect its distinctive or aesthetic characteristics. When the unit of analysis shifts from a single invention to the product (or even company) level, the benefits of using multiple forms of IPR become more apparent. While most previous work has only examined the relation between two forms of IPR, here we investigate the relation between the four formal types (patents, trademarks, designs and copyright). We examine complementarity (substitution) at two levels: in the context of formal IPR strategies and in combination with other intangible and managerial assets. For the first level, we use a two-step analysis, including both adoption and productivity approaches. The adoption approach is based on revealed preference theory and looks at conditional correlations between strategies using multivariate probit models. In the productivity approach, we rely on supermodular functions to explore the relation between more than two strategies. Next, we examine complementarity in the broader context of innovation management. Therefore, we include other variables such as cooperation partners and innovation activities. This assessment combines a factor analysis and a productivity approach.

The reminder of this paper is organised as follows: Sections 2 is dedicated to a literature review, while Section 3 describes the data and models we use. Section 4 discusses the empirical results and Section 5 provides the main conclusions.

2 Literature review

2.1 Complementarity in IPR

Complementarity depends on indicators that are inherent to the company or the innovation process. The concept of complementarity in organisational analysis is similar to the synergy approach (Brynjolfsson and Milgrom, 2012). According to the American Heritage Dictionary, a synergy is based on "the interaction of two or more agents or forces so that their combined effect is greater than the sum of their individual effects". More formally, complementarity has been defined as when the cross partial of the firm's value with respect to both strategies is positive (Graham and Somaya, 2004). Crass and Peters (2014) define it as an increase in the total factor productivity of one asset, despite the investment in a second. Mohnen and Hall (2013) simply detect complementarity when the use of one or more assets leads to higher profitability. The principal characteristic of complementarity is that it involves a decision-making process. Somaya and Graham (2006) explain that the complexity of the decision-making process is due to uncertainty in the returns on each strategy, the timing of their implementation and the existence of implicit aspects that remain unchanged even after using the new strategies. Namely, when a company is faced with a set of alternative choices, the final decision depends on potential complementarities that may exist between them. In this section, we discuss IPR practices and compare them with these definitions of complementarity.

The use of formal IPR as an alternative to secrecy is mainly motivated by a significant risk of infringement, (Buss and Peukert, 2015). Patents are used in order to protect technical aspects of the invention, whilst trademarks and designs protect its image, the symbol of the innovation, (Mendonça et al., 2004). The role of the latter is to ensure an efficient means of communication between the company and its clients. They also mitigate consumer myopia; when clients are faced with a choice between multiple products, formal IPR (other than patents) help them to save time and reduce the cost of their decision path. Lawrence and Phillips (2002) use the term 'symbolic value' to designate the returns on intangibles. The definition of these IPR practices emphasises their different functions, which may not be mutually substitutable. In a very competitive context, the development of R&D strategies and the production of patentable output is not enough for a company to survive fierce competition with its rivals. It must also invest in the symbols and images of its products. The WIPO (2013) shows that worldwide, patent applications grew by 9.2% between 2011 and 2012. Similarly, the number of trademark applications rose by 6% and designs by 17% during the same period. One explanation is the complexity of products (smart phones, computers, etc.) in R&D intensive companies where innovation concerns the process rather than the product (Ballot et al., 2015). Although the general trend strongly confirms the increasing use of IPR practices, the question of complementarity or substitutability between them is not evident.

Table 1 show that patents and secrecy are the most-debated issue regarding IPR complementarity. Innovative companies must make an important trade-off between the secrecy of their innovations/inventions, on the one hand and legal protection with a potential risk of infringement, on the other. Historically, the early consensus in the literature was that there is a substitution relationship between the two instruments, (Teece, 1986; Horstmann et al., 1985, Machlup, 1958; Levin et al., 1987, Brouwer and Kleinknecht, 1999, Cohen et al., 2000, 2002; Hall et al., 2013). Clearly, patenting requires the disclosure of information that automatically excludes the secrecy alternative. Hall et al. (2014) offer a more sophisticated explanation of patents versus secrecy practices. They point out that the propensity to patent is heavily influenced by:

1. the strength of intellectual property law
2. the degree of innovation competition
3. the level of innovation
4. the type of the innovation
5. open innovation practises
6. financial constraints.

Table 1 Complementarity in organisation and innovation studies

	Authors	*IPR, innovation proxies*	*Context*	*Complementarity approach*	*Findings*
Complementarity in IPR	Levin et al. (1987), Brouwer and Kleinknecht (1999), Cohen et al. (2000, 2002), Hall et al. (2013); Friedman et al. (1991), Teece (1986), Machlup (1962)	Patents and secrecy	European and US data	Mainly productivity approach	Contradictory results because of additionalexplanatory variables (size effect, innovation stage, etc.)
	Graham and Somaya (2006)	Copyrights and trademarks	The 100-largest companies in the software industry between 1985 and 1999	Residual correlation	Complementarity 'fashion'. The importance of organisational capital to understand complementarities in IPR
	Amara et al. (2008)	Trademarks, designs, patents, secrecy and copyrights	2,123 KIBS companies, data are based on the 2003 Canadian Innovation Survey on Services	Multivariate probit model	Complementarity between patents, designs,copyrights, trademarks
Complementarity in organisational capital	Bresnahan et al. (2002)	Information technology, workplace organisation and services	Cross-sectional analysis, 400 large US companies in 1995 and 1996	Productivity firm level (production function)	Complementarity
	Martínez-Ros and Labeaga (2009), Miravete and Pernías (2006)	Product and process	Spanish companies	Effect on the innovation intensity	Complementarity
	Crass and Peters (2014), Llerenaa and Millot (2013)	Innovation capital (R&D, patents, designs and licences) Human capital (training expenditure and the percentage of skilled employees) organisational capital (introduction of new practices) Patents and trademarks	Panel data in the German context between 2006 and 2010. French listed companies in 2007	Productivity firm level (labour productivity, total factor productivity and value added) Supermodularity analysis	Complementarity in patents and R&D(innovative and human capital) and (innovative and brand capital) Mixed results: Complementarity in the chemical and pharmaceutical industries; substitutability in high-tech fields
	Ballot et al. (2015)	Product, process and organisational innovation	Two subsamples of French and UK firms in 2002 and 2004	Conditional pairwise correlations	Conditional complementarity in innovationonly between the product and the process. No complementarity between the three factors

Some scholars argue that the patenting process simply depends on the strength of IP law. For instance, Kultti et al. (2007) argue that a strong legal protection system will increase the number of patents as the risk of imitations and litigation is lower. Furthermore, they argue that companies rely upon the more risky option of secrecy rather than legal protection only if they hold a monopoly position. Secrecy helps to avoid the risk of litigation and infringements. At the same time, patents reduce information asymmetry between insiders and outsiders and, above all, transmit informational signals about the success of an innovation process that is seen as long and risky. Finally, Mohnen and Hall (2013) and Graham et al. (2009) find that financial constraints can discourage (small) companies from patenting and make it more likely that they will resort to other mechanisms (secrecy, for example). Controversially, large, mature companies value their brand name and image as much as their portfolio of patents. The World's Most Valuable Brands report published by Forbes in 2016 shows that the Apple and Google brand names are worth respectively US$ 154.1 billion and US$ 82.5 billion (Badenhausen, 2016).

However, scholars have called IPR substitutability into question, as it relies on the implicit hypothesis of a single innovation at a fixed point in time. Some authors suggest that innovation should be considered as a set of elements and components which can be protected both separately and simultaneously by IPR (Somaya and Graham, 2006). In their seminal paper Drivers of Complementarity, the latter authors extend the analysis to market demand or cost reduction. A market-driven approach is seen when, for instance, large patent portfolios lead to an increase in the number of imitations and litigation. As a consequence, companies protect their knowledge assets by additional IPR, such as trademarks. Cost complementarity can stem from an optimal use of the resources allocated to IP. If the firm combines its strategies and gains an additional IPR from the same input, there is complementarity between these IPR. On the basis of the 100 largest companies in the software industry, Somaya and Graham (2006) find complementarity between copyrights and trademarks. They explain their findings in terms of the managerial attention given to IPR strategies, i.e., the decision to enhance this capital. They also highlight a leverage effect, based on organisational resources that allow companies to benefit from cost complementarity. Although they make a fundamental contribution to the literature by dismissing the substitutability assumption, Somaya and Graham (2006) do not analyse complementarities between all IPR practices. In addition, their focus is restricted to the software industry. Amara et al. (2008) widened the scope and examined all IPR complementarities, together with secrecy. Their sample was based on what they called KIBS companies (knowledge-intensive business services); those providing engineering consulting, computer system design and management consulting services. Their findings largely endorse complementarities between IPR practices. They explain that simply focusing on patents leads to a loss in synergy between different IPR, especially in large companies where R&D intensity is high and innovation is process-rather than product-oriented. The authors document the extreme complexity of IPR complementarity studies, especially innovation services, where different aspects need to be protected by different tools. Consistent with this literature, we examine complementarity by taking the productivity approach. We estimate the predictive power of complementarity (or substitutability) of IPR practices on the firm's performance. First, we start by examining their individual effects.

2.2 The productivity of intangibles

Most previous work agrees that R&D makes a substantial contribution to productivity. Griliches (1981, 1984) and Hall and Oriani (2006) examine the impact of RandD on the Tobin's Q or market-to-book ratio of listed companies. They find that the shadow value of R&D is significantly larger than the private value of patents. Tsai (2005) and Mansfield (1965) study the effect of R&D on total factor productivity and find similar results. Crass and Peters (2014) find similar results; they show that R&D has the most predictive power on both total factor productivity and labour productivity. On the other hand, some scholars discuss the riskiness of R&D investment and the long time it requires to be transformed into a valuable output. Moreover, some argue that R&D increases the problem of information asymmetry between insiders (managers and highly-skilled employees) and outsiders (investors and market players) (Aboody and Lev, 2000). The hypothesis of a negative impact on market value is often contradicted by the anticipation of high returns in the long run.

While R&D productivity has been shown in several studies, the discussion around patents is more controversial. One thread of the literature finds a positive and significant impact of patents on the market value of companies or their total productivity function (Sandner and Block, 2011; Griliches 1984; Hall et al., 2007). One explanation is that patents reflect successful R&D investment and provide the company with an economically-valuable output. However, other research has found that patents have little or no economic value. First, the trade-off between patenting and secrecy means that not all inventions are patented. Second, increasing the size of the patent portfolio for strategic reasons suggests that not all patented assets create value. Finally, patent productivity is highly influenced by exogenous factors, such as industry characteristics, the size of the company, the nature of the innovation (radical or incremental), etc.

Only a few studies have examined the productivity of other IPRs (e.g., licences, copyright, trademarks and designs). Crass and Peters (2014) find that investing in licences and trademarks enhances productivity but to a lesser extent that other R&D investments. Landes and Posner (1987) were among the first authors to analyse the productivity of trademarks. They find that they enhance productivity and argue that this is because they reduce information asymmetry between the seller and the buyer as the latter is more confident about the quality of the product. Customers' search costs are lowered, the seller can increase prices and consequently increase profitability. Greenhalgh and Rogers (2007) argue that an increase in trademarks seen in the 1990s can be explained by a 'management fad'. They claim that it is due to imitative behaviour between companies that simply followed a fashionable trend. Taking a sample of firms in the UK, they find that the Tobin's Q is higher when a company invests in trademarks. Similarly, they find that these companies have higher productivity (between 10% and 30%) than non-trademarking firms. Finally, they underline decreasing marginal returns on trademarks over time. There is even less literature about the productivity or profitability of copyrights or designs. We assume that these IPR practices do contribute to the value creation process, but to a far lesser extent. Moreover, we argue that the economic value of a design must be maintained by a continuous process of innovation that produces other types of IPR.

To conclude these two sections, we stress the following points. First, the optimal use of IPR is complex and highly influenced by the intrinsic characteristics of the company, the innovation and the industry. A very competitive context highlights both the protective function and the brand capital value offered by the use of IPR, while the current focus on process innovation makes the one single invention hypothesis less relevant. Second, the productivity of individual IPR practices supports the definition of complementarity given by Topkis (1978). Here, we examine the optimal use of IPR from a productivity perspective rather than focusing on the cost function. We look at the utility function and productivity of IPR and show that the literature documents its contribution to increasing the visibility of both the company (as an innovative organisation) and its products. Furthermore, we highlight the complexity of products in the current context, which are very different to the one single invention hypothesis. We support the finding of market-driven complementarity (Somaya and Graham, 2006) in the sense that process innovation requires more than one IPR to protect the company's intangible assets. We argue that if one IPR instrument can have a positive and significant impact on the firm's performance, their combined use can create a synergy. Finally, we note that synergy and complementarity are two very similar concepts (Brynjolfsson and Milgrom, 2012).

Hypothesis 1 The prevalence of complex products in the innovation process and the ability of an individual IPR to enhance productivity fosters complementarity between multiple IPR.

2.3 Complementarity in organisations

The Schumpeterian definition of innovation refers to the introduction of new goods, the management of the organisation, or the opening to a new market, (Hagedoorn 1996; Schumpeter, 2002). In this framework, Crass and Peters (2014) examine complementarity between innovative capital, human capital, branding capital and organisational capital. They use patents, R&D and licences (among other empirical indicators of innovation) and find mixed results for organisational capital. For instance, the introduction of organisational innovation enhances productivity, while modifications to the workplace slows it. The authors find complementarity between patents and R&D expenses, which supports the idea of innovation as an input and an output. Finally, they highlight complementarity between both innovative capital (measured by R&D expenses, licences and patent stocks) and branding capital (marketing expenditure and trademarks), on the one hand and innovative capital and human capital on the other. They base their work on a sample of German companies and data are extracted from the Mannheim Innovation Panel, part of the community innovation survey (CIS).

Barley (1986, p.107) highlights that "Technologies do influence organisational structures in orderly ways". He finds that the introduction of the same technology (CT scanners) generates different results on the organisation of two hospitals in the same geographical area. Autor et al. (2002) report similar results in their investigation of the effect of technology on the workplace. Many studies have looked at complementarities in the relationship between information technology (IT) and human resources, or workplace organisation. Bresnahan et al. (2002) study the complementarity of three factors; IT, workplace reorganisation and new products and services. They find a positive and significant impact on firm-level productivity. Martínez-Ros and Labeaga (2009) and Miravete and Pernías (2006) take an unbalanced panel of Spanish companies and examine complementarity between process innovation and product innovation. They draw attention to the fact that only a few studies have looked at process innovation and its interdependency with product innovation, with the exception of the seminal work of

Cefis and Marsili (2005). These studies highlight the gap in the literature and once again reflect the dominance of substitutability. Nelson (2006) highlights the lack of such studies, notably the use of complementarity theory to examine the impact of IPR on innovation productivity. In conclusion, complementarity in organisations relies on exactly on the same pillars as those presented in the previous section, suggesting that a comparison of the two would be interesting. Another of our contributions is to contextualise the use of IPR in organisational practices. Current markets are characterised by the increasing importance of cooperation between different market players. Companies must expand while monitoring the activities of their competitors, customers and suppliers – and even by cooperating with them. In this paper, we discuss complementarity in innovation given the many aspects of R&D cooperation. Cooperation can reduce the cost of R&D investment, enhance synergies between the innovative company and other organisations and avoid duplicating the work of other companies in the same sector. However, it requires partial disclosure of innovation information. Arora et al. (2014) find that although cooperation with customers and suppliers does not contribute significantly to patent applications, when companies obtain information from partners and universities, they are more likely to patent.

Finally, our work introduces a dummy variable to indicate whether the company is part of a group. Several studies have examined the role of groups in R&D productivity. Filatotchev et al. (2003) and Blanchard et al. (2010) find that R&D intensity is higher in groups in the Italian and the French contexts respectively. Belenzon and Berkovitz (2010) find that group innovation is more prevalent in fields that rely on external finance and higher levels of patenting in groups of businesses.

Hypothesis 2 Additional innovation assets create synergies. We expect that the firm's productivity increases when IPR is combined with other innovation assets and there is therefore complementarity between innovation assets and IPR.

3 Data

Our empirical analysis uses data from two CIS: CIS IV and CIS 2006, which were conducted in 2004 and 2006 and cover the periods 2002–2004 and 2004–2006. We excluded previous surveys as there were significantly different, notably in the classification of industry categories (NACE codes). Subsequent surveys were not used as IPR questions were not included.

In total, the two samples contained 104,717 and 94,347 companies and covered 16 and 14 countries in 2004 and 2006 respectively. Table A1 (see Appendices) shows that Italy had the largest proportion of companies in 2004, followed by Spain and Bulgaria. In 2006, the country with the largest proportion of companies is Spain, followed by Bulgaria and Romania. Note that the sample size is not exactly proportional to the size of the countries because of different response rates. The decrease in the number of companies between 2004 and 2006 is mainly due to the absence of Italy in the sample.

The distribution of firms by size is given in Table A2. Companies are classified into three categories: small (10–49 employees), medium (50–249 employees) and large (over 250 employees). Both samples are dominated by small companies (83.82% in 2004 and

58.89% in 2006), while medium and large companies tend to be merged. For example, in 2004, medium and large companies in some sectors are classified as 'medium-large'. In 2006, both medium and large companies in Cyprus, Estonia and Greece are classified as medium. In this study, we retain the 'medium' classification, given the small proportion of large companies in the samples. Some companies are classified as 'small-medium-large'; we consider these as unclassified. Thus, medium-sized companies are slightly over-represented (by about 0.5%).

The distribution of companies by sector is given in Table A3 and is similar for both samples. The dominant sector in both samples is the wholesale trade (10.69% in 2004 and 13.13% in 2006), followed by construction and textiles and leather in 2004 and textiles and leather and R&D in 2006. The least important sectors in both 2004 and 2006 are machinery and equipment, real estate and telecommunications. Table B.1 shows the combined IPR practices adopted by European companies and shows that overall, it is not widely used. This is true even for innovative companies.[1] Nevertheless, the combined use of IPR instruments is notable, respectively 38.06% and 32.11% based on the IPR subsamples from 2004 and 2006. The most important IPR combinations are design and trademarks, patents and trademarks and design and patents and trademarks.

3.1 Variables and models

3.1.1 The two-step approach

The first part of the analysis determines if there are complementarity or substitutability relations in firms' use of the various types of IPR. To examine this, we adopt the two-step model developed by Schmiedeberg (2008). In the first step the adoption approach is used, which is based on revealed preferences. In this case, a company is assumed to behave rationally and seeks to maximise its profits through adopting two or more complementary strategies, which implies a positive correlation between them. However, there are common (observed and unobserved) factors that may influence the relationship in such a way that activities can be positively correlated without being complementary. At the same time, real correlations can be hidden (Athey and Stern, 1998). Therefore, a positive correlation is a necessary but not sufficient condition for complementarity and exogenous factors that may have an influence on the correlation must be taken into account. Given the foregoing, we use the multivariate logit model presented in equation (1):

$$IPR_i^* = \alpha_n' Z_i + \varepsilon_i \quad (1)$$

where IPR_i^* is a vector composed of the four IPR strategies (patents, trademarks, designs and copyright). Control variables are captured by the vector Z_i. Error terms are assumed to be jointly normally distributed with mean 0 and covariance matrix Σ. Thus, positive pairwise correlations between error terms in the regressions imply complementarity.

Control variables relate to exogenous factors that can impact economic performance and include country, sector and size. In addition, we include a variable that indicates if the firm is part of a group of companies, as Hanel (2006) finds that being part of a group increases the use of trademark and patent protection, but has no effect on the use of design. Innovation efforts are captured by R&D and other innovation expenditure. We also take into account different types of cooperation partnerships and sources of information that reflect the nature and purpose of innovation. For example, cooperation with institutions (universities, government or public research institutes) often involves radical innovation. In contrast, market cooperation (with suppliers, customers or competitors) is more complex and usually aims to reduce costs, improve the production process or develop new products. Therefore, companies engaged in different types of R&D cooperation may have different propensities to use IPR. Finally, we include funding sources as a measure of innovation policy. A summary of the control variables is given in Table 2.

Table 2 Control variables

Variable	*Type*
R&D expenditure	Quantitative
Innovation expenditure (non-R&D)	Quantitative
Sector	Categorical
Size (no. of employees)	Categorical
Country	Categorical
Part of a group	Binary
Market factors[3]	Categorical
Information sources	Categorical
Type of co-operation partner	Categorical
Public financial support	Categorical

The adoption approach has been subject to criticism that there is a lack of evidence of the impact of practice on economic performance (Athey and Stern, 1998). Therefore, we complement it with the productivity approach.[2] In this step, we link IPR and performance measures by exploring a supermodular function, based on lattice theory. The concept of supermodularity was introduced in the seminal work of Topkis (1978) while later (Holmstrom and Milgrom, 1994, 1991) developed related mathematical tools. More recently, researchers have applied supermodularity to study complementarity in innovation economics. For example, Mohnen and Roller (2005) looked for evidence of complementarity in innovation policy by examining barriers to innovation based on the CIS I in four countries: Ireland, Denmark, Germany and Italy. Another example is Cassiman and Veugelers (2006), who tested complementarity between innovation strategies on a sample of 269 Belgian manufacturing companies. Belderbos et al. (2006) also used the concept of supermodularity to study the relationship between different types of R&D cooperation and production statistics on a large sample of innovative companies included in the Dutch CIS of 1996 and 1998.

The advantage of the supermodularity approach is that it makes it possible to study complementarity when more than two practices are involved. As the number of choices increases, the number of inequality constraints to test increases. According to supermodularity theory [Topkis (1978), p.309], a function F is supermodular on a lattice S if and only if all the pairwise components satisfy the following condition:

$$f(x_1) + f(x_2) \le f(x_1 \wedge x_2) + f(x_1 \vee x_2) \quad (2)$$

More specifically, we use the method given in Mohnen and Röller (2005) and test multiple inequality constraints. The model is as follows:

$$\begin{aligned} y_i = {} & a_1 x_{1,i} + a_2 x_{2,i} + a_3 x_{3,i} + a_4 x_{4,i} + a_{12} x_{1,2} x_{2,i} + a_{13} x_{1,i} x_{3,i} + a_{14} x_{1,i} x_{4,i} \\ & + a_{23} x_{2,i} x_{3,i} + a_{24} x_{2,i} x_{4,i} + a_{34} x_{3,i} x_{4,i} + a_{123} x_{1,i} x_{2,i} x_{3,i} + a_{124} x_{1,i} x_{2,i} x_{4,i} \\ & + a_{134} x_{1,i} x_{3,i} x_{4,i} + a_{234} x_{2,i} x_{3,i} x_{4,i} + a_{1234} x_{1,i} x_{2,i} x_{3,i} x_{4,i} + a_j z_j + \varepsilon_i \end{aligned} \quad (3)$$

where y_i represents the dependent variable measuring innovation and economic performance.

Here there are two dependent variables: total turnover and innovation intensity. The CIS survey asks companies to assess the proportion of their total turnover due to goods and services introduced through innovation. Innovation intensity is calculated as the sum of the percentages of innovative goods and services that are new to the market and the company. x_i represents these IPR items and all possible combinations are included in our model. Finally, Z_i represents all of the control variables (shown in Table 2).

For example, to check for complementarity between patents and design, we test the following set of constraints simultaneously:

H0 $\alpha_1 + \alpha_2 < \alpha_{0000} + \alpha_{12}$ and $\alpha_{13} + \alpha_{23} < \alpha_3 + \alpha_{123}$ and $\alpha_{14} + \alpha_{24} < \alpha_4 + \alpha_{124}$ and $\alpha_{134} + \alpha_{234} < \alpha_{34} + \alpha_{1234}$

H1 $\alpha_1 + \alpha_2 \geq \alpha_{0000} + \alpha_{12}$ and $\alpha_{13} + \alpha_{23} \geq \alpha_3 + \alpha_{123}$ and $\alpha_{14} + \alpha_{24} \geq \alpha_4 + \alpha_{124}$ and $\alpha_{134} + \alpha_{234} \geq \alpha_{34} + \alpha_{1234}$

We accept H0 if all of the constraints are jointly negative. However, the rejection of the null hypothesis does not imply a substitution relation, as H1 only implies an 'or' relation, but not an 'and' relation between the constraints. Instead, in order to test the substitution relation, we must test the opposite set of constraints. Thus, we perform both supermodularity and submodularity tests. As there are three outcomes for each test (accepted, rejected and inconclusive) there are nine combinations in total. These combinations are shown in Table 3.

Table 3 Combinations of supermodularity/submodularity tests

Supermodularity test	*Submodularity test*	*Conclusion*
Accepted	Rejected	Strict supermodularity
Accepted	Accepted	Inconclusive
Accepted	Uncertainty	Weak supermodularity
Rejected	Accepted	Strict submodularity
Rejected	Rejected	Inconclusive
Rejected	Uncertainty	Inconclusive
Uncertainty	Accepted	Weak submodularity
Uncertainty	Rejected	Inconclusive
Uncertainty	Uncertainty	Inconclusive

Here, we adopt the terminology of Ballot et al. (2015): For example, if supermodularity is accepted and submodularity is rejected, we conclude that there is a 'strict supermodularity' relation; the opposite case is termed 'strict submodularity'. If supermodularity (submodularity) is accepted while the submodularity (supermodularity) test is inconclusive, we conclude that the relation is one of 'weak supermodularity (submodularity)'. In the remaining cases, we cannot draw any conclusion. Similar tests are run on patents and trademarks, patents and copyright, etc. As there are four IPR practices, there is a total of 12 sets of inequality tests.

3.1.2 Factor analysis

In the second part of the empirical analysis, we study complementarity between IPR and the broader management of innovation activities. In addition to IPR variables, we add factors related to:

1 innovation activities

2 sources of information and cooperation (Table A5), represented in binary form.

We follow the method outlined in studies such as Percival and Cozzarin (2008) that combine a factor analysis and productivity approach. First, we estimate common factors across different variables and second, we study complementarity between factors.

4 Empirical results

4.1 Complementarities between IPR

First, we examine the results of the multivariate probit model shown in Table B2–B3 in order to examine the determinants of using IPR. Findings suggest that larger companies are more likely to adopt formal IPR strategies in both samples. This implies that larger firms face lower financial barriers and consequently apply for more IPR (Mohnen and Hall, 2013; Graham et al., 2009). Graham et al. (2005) find that financial constraints are the main reason why start-ups do not use patents and prefer secrecy, while large, mature companies benefit from economies of scale in their patenting strategy (Arundel and Kabla, 1998). Moreover, size may explain the strategy adopted by large companies that invest heavily in IPR, who seek to acquire a competitive image and present an image of innovation. Tables B2 and B3 show that high levels of financial support considerably increase the probability of applying for patents in both samples. The effect is even stronger in the second panel, where companies from Germany, Italy and Belgium are excluded. Financial support significantly increases the probability of using all forms of IPR (and not just patents as shown in the first subsample). The results are inconclusive regarding the impact of being part of a group on the use of IPR. The first subsample (Table B2) shows a negative relationship, while the second (Table B3) documents an increase. Table B1 shows that the combined use of IPR is greater in the 2004 subsample (5.57% vs. 3.93%). One possible explanation for the divergence in these results could be that being part of a group enhances the use of multiple IPR.

Similarly, Tables B2 and B3 reflect a variety of results for different kinds of cooperation. Cooperation with market partners has a positive and significant impact on the probability of using IPR; the 2006 sample highlights the same impact for internal cooperation. The cooperation knowledge channel is longer and more complex than for intra-mural R&D activities. Formal protection guarantees that the cooperating parties will benefit from a return on their investment with lower risks. We observe the same results when the source of innovation information is controlled for. In addition, innovation expenditure (other than R&D) has a positive and significant effect on the probability of using patents, designs and trademarks in the first sample (see Table B2). The impact is also positive, but non-significant, on the probability of using copyright. The probability of using trademarks is closely related to innovation expenditure (other than R&D) in the second sample (Table B3). Unsurprisingly, R&D expenditure has positive and strong predictive power on the probability of using all IPR practices in both subsamples. It appears that, despite the trade off between disclosing innovation information and keeping it secret, companies use IPR in order to protect their knowledge assets. We observe that in the first subsample (2004), the country effect is more significant than in the second, which excludes companies from Italy, Belgium and Germany. The decrease in the statistical significance in the second sample is explained by lower variance in R&D intensity between countries. Unlike the industrial effect, Tables B2 and B3 do not show a significant impact of industry on the probability of using IPR.

Conditional residual correlations are given in Table B4. These correlations are highly significant, even after the inclusion of control variables. These results, especially between patents and designs, imply complementarity between the two IPR instruments. The relation can be explained by the fact that protecting the functional aspects of an invention (by patenting) and protecting its appearance (by designs and models) are complementary. We also observe that the complementarity between designs, trademarks and copyright is less significant because of similarities in their protective function.

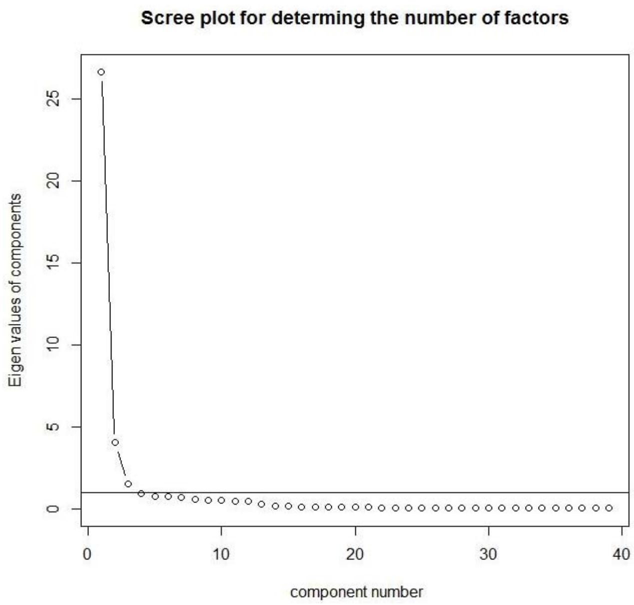
The second step, the productivity approach, consists of the regression of economic performance on IPR choice and testing inequality constraints. The Wald test[4] is used to test inequality constraints. Lower and upper bounds are set at respectively 2.706 and 8.761 with a significance level of 5%. We reject the null hypothesis when the value is greater than 8.761; we cannot reject the null hypothesis when the value is less than 2.706. Values between the lower and upper bounds do not imply conclusive results. Wald statistics for super and submodularity tests are presented in Table B5. Overall, we observe that the substitutability relationship dominates. For example, most IPR show substitutability in terms of innovation intensity in 2006. The only evidence of complementarity is found between patents and copyright in explaining total turnover in 2004.

However, the results vary between sample years and dependent variables. For example, there is no conclusive relationship between IPR instruments with respect to innovation intensity in 2004, while the relation between patents and copyright appears to be complementary. These results are very similar to those of Mohnen and Röller (2005) who studied the complementarity of obstacles in innovation and found that relations varied across phases of innovation and the particular pair of obstacles. In our case, the results suggest that IPR policy should focus on the optimal design of individual IPR strategies. Inconclusive results are found with respect to the protection function of designs/trademarks/copyrights, suggesting that only one is necessary to protect the company's image. At the same time, the complexity of innovation suggests that companies can use all of these IPR instruments, despite their similar function. These results partially confirm Teece (1986): obtaining IPR is only the first step in the appropriation of an innovation, which depends on many other factors (e.g., when to launch a new product onto the market, when to install new production methods, when to license technology to other firms, or whether to work with universities, public institutions or other firms). Furthermore, there are complementary assets. Some examples (given in Greenhalgh and Rogers, 2010) relate to technological capacity, product distribution facilities, after-sales service, or marketing. An examination of complementarity in the more general context of intangible asset management seems in order.

4.2 Complementarities between IPR and other intangible assets

A factor analysis is used to estimate complementarities between IPR instruments and other intangible assets. The first step is to choose how many factors are retained. The most popular method is the scree plot, where the number of factors is determined by the number of eigenvalues greater than one. The result of the scree plot for 2004 is shown in Figure 1 which suggests three factors.[5] However, if we only retain variables with a factor loading of at least 0.3, the results are shown in Table B6. This shows that the third factor contributes very little to an explanation of the variance.[6] Thus we only retained two factors. Specifically, factor 1 includes all of the variables related to questions about innovation cooperation and are termed 'cooperation factors'. Factor 2 includes all the variables related to innovation activities and IPR strategies and is termed 'innovation activities and IPR variables'.

Figure 1 The scree plot for determining the number of factors (2004 subsample)



Next, we link the two factors and performance measurements, while an interactive term captures the complementarity relationship. If the interactive coefficient is significant and positive, we can deduce a complementarity relationship; a significant negative coefficient indicates substitutability and no relationship can be established if the interaction term is not significant. As we can see from Table B7, interaction coefficients for innovation intensity and total turnover are both highly significant, confirming complementarity between the two factors. In other words, there is complementarity between IPR strategies, innovation activities and cooperation. In addition, we observe that analysing IPR in the general context of innovation leads to more conclusive results than in the submodularity study. This confirms the work of Teece (1986), who argues that IPR should be combined with good managerial decisions and other, complementary, assets in order to appropriate profits.

Figure 2 Results of the principle component analysis (see online version for colours)

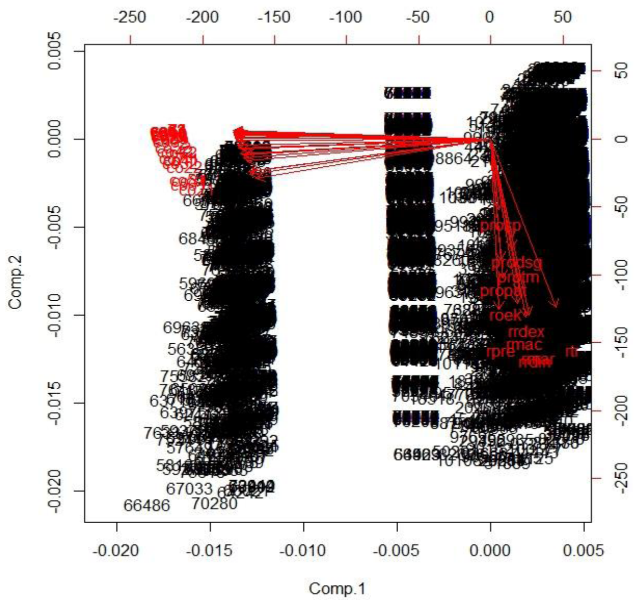


Table 4 Summary of results

Hypothesis	*Approach*	*Results*	*Additional comments*
Complementarity of IPR practices	Adoption approach	Confirmation of the Hypothesis: Pairwise Complementarity between all IPR	The most important complementarity is between designs and trademarks
	Submodularity approach	Mitigated results are found	These results confirm the importance of contextualising the complementarity study of IPR
Complementarity between IPR and Innovation assets	Factor analysis	Complementarity between Cooperation factor and innovation activity and IPR factor	Complementarity on both productivity firm-level and innovation intensity

Table B7 shows results regarding the productivity of innovation proxies in the broader sense. The results confirm our hypotheses regarding the high contribution of R&D to the company's earnings, measured by total turnover. However, we observe a negative and significant impact of R&D on innovation intensity. Namely, the more a company invests in R&D the less it will be able to introduce new goods and services to new markets. This finding can be explained by the average time lag needed to transform R&D into valuable output. In addition, the argument of incremental innovation explains the negative impact of R&D on innovation intensity. In fact, while R&D investments are mainly aimed at creating value through radical innovation, conquering new markets requires less effort and relies on improvements to, or the development of, existing knowledge assets. Similar results are found for innovation expenditure.

5 Conclusions and discussion

This paper investigates complementarity (substitution) at two levels: in the context of formal IPR strategies and between IPR and other intangible and managerial assets. Our study contributes to the very recent literature regarding IPR complementarity, by taking a more general approach to the context (industry/country/size) and extending the scope beyond patents. We employ more than one approach to study complementarity in the classical sense (IPR) and in a broader context (together with other innovation assets).

The results are mixed when formal IPR strategies are used alone, while there is strong evidence of the joint use of IPR by firms in the adoption approach. However, if we examine the impact of these practices in combination on performance, the results are inconclusive in most cases and substitutability prevails in the remaining relationships. Only innovation intensity shows a high level of complementarity for patent and copyright IPR in 2004.Therefore, we examined complementarity between IPR in the broader context of the management of innovation activity. This subsequent analysis included other variables such as cooperation partners and innovation activities. We found that IPR, innovative activities and innovation cooperation variables display a high level of complementarity. These results suggest IPR should be combined with complementarity assets to appropriate the profits of innovation.

The second part of the analysis included other innovation proxies and highlighted additional research questions. First, the inconclusive results shown in Tables B5 and B6 can be examined in depth by measuring company productivity in different ways (i.e., other than based on turnover). Patents, trademarks and designs all take time before their effects can be observed on the company's turnover. The image of the company, especially the smaller ones that dominate in our sample, need a long-term competitive advantage that enables them to acquire a strong image. Moreover, a comparison of the one innovation hypothesis and the product process approach helps to understand the optimal use of IPR. Finally, the role of managers was another significant indicator.

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Notes

1 We define innovative companies as that are involved in product and process innovation, but not organisational innovation.

2 The adoption approach and the productivity approach are also called by Ballot et al. (2015) 'complementarities-in-use' and 'complementarities-in-performance'. As their names indicate, the first involves the simultaneous adoption of practices and the second measures the effect of different practice combinations on performance.

3 According to the 2006 CIS survey, market factors are defined by the dominance of established enterprises and demand certainty for innovative goods and services

4 Statistical tests of the linear regression model with at least one inequality constraint are examined in Gouriéroux et al. (1982) and Wolak (1987). Critical values of lower and upper bounds are derived using the Kodde and Palm (1986) test.

5 The scree plot for the 2006 sample suggests that there are ten factors, but a principal component analysis shows that even these ten factors do not explain 50% of the variance. Therefore, in this case, a factor analysis is not appropriate and we based our analysis on the 2004 sample.

6 The principal component analysis showed that three factors explain 82.27% of the total variance. We note that the first factor alone explains 68.2% of total variance, while the third factor only explains 3.8%. An examination of the second and third components (see Figure 2) shows two clusters of points, which indicate that two of the three factors are closely linked.

Appendix

Table A1 Distribution of firms by country

	2006		*2004*	
	Number	*%*	*Number*	*%*
Belgium			3,322	3.17%
Bulgaria	14,986	15.88%	13,710	13.09%
Cyprus	1,040	1.10%		
Czech Republic	6,807	7.21%	8,370	7.99%
Germany			4,054	3.87%
Estonia	1,924	2.04%	1,747	1.67%
Spain	36,314	38.49%	18,946	18.09%
Greece	522	0.55%	507	0.48%
Hungary	4,947	5.24%	3,950	3.77%
Italy			21,854	20.87%
Lithuania	2,299	2.44%	1,639	1.57%
Latvia	1,155	1.22%	2,990	2.86%
Portugal	4,721	5.00%	4,815	4.60%
Romania	10,153	10.76%	9,180	8.77%
Slovenia	2,502	2.65%	2,789	2.66%
Slovakia	2,678	2.84%	2,195	2.10%
Norway	4,299	4.56%	4,649	4.44%
Total countries	14		16	
Total	94,347	100%	104,717	100%

Table A2 Distribution of firms by size

	2006		*2004*	
	Number	*%*	*Number*	*%*
Small	55,564	58.89%	87,773	83.82%
Medium	29,265	31.02%	15,236	14.55%
Large	9,440	10.00%	1,487	1.42%
No response	78	0.08%	221	0.21%
Total	94,347	100%	104717	100%

Table A3 Distribution of firms by industry

	Number	*%*	*Number*	*%*
Basic metals	1,098	1.16%	1,408	1.34%
Computing	2,651	2.81%	2,773	2.65%
Construction	4,375	4.64%	9,159	8.75%
Electrical and optical	3,743	3.97%	4,681	4.47%
Electricity, gas and water	5,244	5.56%	3,050	2.91%
International finance	2,210	2.34%	2,821	2.69%
Food	6,610	7.01%	6,534	6.24%
Hotel and restaurants	1,548	1.64%	2,142	2.05%
Machinery and equipment	3,806	4.03%	4,051	3.87%
Manufacturing	3,401	3.60%	3,475	3.32%
Metal /Machines and equipment	5,059	5.36%	4,945	4.72%
Mining and quarrying	1,239	1.31%	1,521	1.45%
Motor trade	1,235	1.31%	1,720	1.64%
Other non-metallic minerals	2,887	3.06%	2,851	2.72%
Petrol and chemicals	2,272	2.41%	2,745	2.62%
Post and telecoms	949	1.01%	960	0.92%
R&D and other business	6,871	7.28%	8,315	7.94%
Real estate	575	0,61%	665	0.64%
Renting machinery and equipment/operations	303	0.32%	318	0.30%
Retail	1,764	1.87%	2,531	2.42%
Rubber and plastic	2,377	2.52%	2,357	2.25%
Surface transport and travel agencies	2,124	2.25%	2,363	2.26%
Textile and leather	7,207	7.64%	8,804	8.41%
Transport	4,386	4.65%	4,550	4.35%
Transport equipment	2,336	2.48%	2,588	2.47%
Wholesale	12,388	13.13%	11,199	10.69%
Wood, paper and publishing	5,689	6.03%	6,191	5.91%
Total	94,347	100.00%	104,717	100.00%

Table A4 Additional innovation activities and cooperation variables

Innovation activities
Intramural (in-house) R&D
Extramural R&D
Acquisition of machinery, equipment and software
Acquisition of other external knowledge
Training
Market introduction of innovations
Other preparations
Co-operation partner
Other enterprises within the group
Suppliers of equipment, materials, components, or software
Clients or customers
Competitors or other enterprises in the sector
Consultants, commercial labs, or private R&D institutes
Universities or other higher education institutions
Government or public research institutes

A Results

Table B1 IPR strategy combinations adopted by firms

	2006		*2004*	
	Number	*%*	*Number*	*%*
None	79,372	87.75%	87,661	85.35%
Patent	1,083	1.20%	1,906	1.86%
Design	598	0.66%	808	0.79%
Trademark	5,472	6.05%	6,073	5.91%
Copyright	369	0.41%	529	0.52%
Patent and design	354	0.39%	809	0.79%
Patent and trademark	757	0.84%	1,290	1.26%
Patent and copyright	61	0.07%	132	0.13%
Patent and design and trademark	516	0.57%	1,142	1.11%
Patent and trademark and copyright	104	0.11%	223	0.22%
Patent and design and copyright	28	0.03%	87	0.08%
Design and trademark	1,015	1.12%	873	0.85%
Design and copyright	32	0.04%	41	0.04%
Trademark and copyright	371	0.41%	483	0.47%
Design and trademark and copyright	126	0.14%	149	0.15%
Patent and design and trademark and copyright	194	0.21%	496	0.48%
Joint use (subtotal)	3,558	3.93%	5,725	5.57%
		(32.11%)		(38.06%)
Total	90,452	100.00%	102,702	100.00%

Table B2 Results of multivariate probit model (2006)

		Patent	*Design*	*Trademark*	*Copyright*
Size		0.045	0.1	0.074	0.022
		(2.071)*	(4.922)***	(4.353)***	(0.726)
Country		–0.006	0.001	–0.003	0.026
		(–0.829)	(0.098)	(–0.579)	(3.345)***
Industry		0.001 (0.593)	0 (–0.133)	–0.	0.001
				(–1.575)	(0.455)
Own R&D expenditure		0.045	0.029	0.022	0.023
		(15.898)***	(10.928)***	(9.932)***	(5.579)***
Innovation expenditure (non-R&D)		0.007	0.007	0.008	0.001
		(2.652)**	(2.618)**	(3.501)***	(0.26)
Group		–0.121	–0.205	–0.079	–0.12
		(–3.167)**	(–5.715)***	(–2.685)**	(–2.016)*
Market	Local	0.014 (0.362)	–0.035	0.029	–0.162
			(–0.915)	(0.976)	(–3.03)**
	National	0.175	0.126	0.289	0.16
		(3.837)***	(3.117)**	(8.883)***	(2.689)**
	Other Europe	0.183	0.174	0.101	–0.035
		(5.036)***	(5.21)***	(3.62)***	(–0.699)
	Other	0.227	0.115	0.053	–0.027
		(6.477)***	(3.543)***	(1.829).	(–0.536)
Financial support		0.221	0.07	0.043	–0.016
		(6.942)***	(2.308)*	(1.61)	(–0.332)
Information source	Internal	0.147	0.156	0.079	0.2
		(3.127)**	(3.632)***	(2.296)*	(2.673)**
	Market	–0.013	0.028	0.101	–0.194
		(–0.264)	(0.62)	(2.681)**	(–2.639)**
	Institutional	0.16	0.063	0.032	0.118
		(4.414)***	(1.853).	(1.046)	(2.232)*
	Other	0.039	0.098	0.147	0.173
		(1.209)	(3.159)**	(5.628)***	(3.438)***
Cooperation partner	Internal	0.024	–0.065	–0.018	0.14
		(0.493)	(–1.37)	(–0.478)	(1.987)*
	Market	–0.103	–0.095	0.04	0.146
		(–2.775)**	(–2.761)**	(1.392)	(2.749)**
	Institutional	0.285	0.067	0.039	0.181
		(7.042)***	(1.676).	(1.162)	(3.128)**

Table B3 Estimation results of multivariate probit model (CIS04)

		Patent	*Design*	*Trademark*	*Copyright*
Size		0.231	0.233	0.214	0.098
		(11.351)***	(11.821)***	(12.973)***	(3.779)***
Country		–0.035	–0.048	–0.024	–0.006
		(–7.98)***	(–11.714)***	(–6.332)***	(–1.347)
Industry		–0.001	0.001	0.002	0.001
		(–1.089)	(0.405)	(1.923)	(0.804)
R&D expenditure		0.034	0.021	0.019	0.02
		(14.493)***	(9.371)***	(9.804)***	(6.608)***
Innovation expenditure (non-R&D)		–0.006	0.001	0.01	0.004
		(–2.393)*	(0.513)	(5.31)***	(1.148)
Group		0.21	0.096	0.151	0.204
		(8.557)***	(3.997)***	(7.391)***	(5.842)***
Market	Local	–0.128	–0.081	–0.059	–0.094
		(–5.605)***	(–3.64)***	(–3.167)**	(–3.077)**
	National	0.181	0.136	0.256	0.168
		(6.756)***	(5.376)***	(12.321)***	(4.843)***
	Other Europe	0.428	0.361	0.234	0.013
		(16.542)***	(14.903)***	(11.249)***	(0.38)
	Other	0.465	0.311	0.216	0.14
		(18.066)***	(12.671)***	(9.727)***	(3.884)***
Financial support		0.18	0.058	0.066	–0.151
		(6.522)***	(2.171)*	(2.687)**	(–3.894)***
Information source	Internal	0.225	0.173	0.098	0.034
		(6.463)***	(5.275)***	(3.395)***	(0.724)
	Market	0.247	0.196	0.187	0.272
		(6.21)***	(5.094)***	(5.408)***	(4.516)***
	Institutional	0.215	0.048	0.043	0.081
		(7.078)***	(1.631)	(1.544)	(2.137)*
	Other	0.071	0.133	0.169	0.141
		(2.444)*	(4.812)***	(6.633)***	(3.493)***
Cooperation partner	Internal	–0.26	–0.223	–0.218	–0.193
		(–6.801)***	(–6.142)***	(–6.616)***	(–4.195)***
	Market	–0.099	–0.091	0.025	0.137
		(–2.748)**	(–2.828)**	(0.84)	(2.877)**
	Institutional	0.091	0.036	–0.013	0.099
		(2.298)*	(0.972)	(–0.385)	(2.005)*

Table B4 Residual correlations of multivariate probit model between IPRs

	2006			
	Patent	*Design*	*Trademark*	*Copyright*
Patent	1			
Design	0.713	1		
	(54.685)***			
Trademark	0.488	0.592	1	
	(25.428)***	(44.502)***		
Copyright	0.347	0.431	0.481	1
	(9.748)***	(18.206)***	(21.702)***	
	2004			
	Patent	*Design*	*Trademark*	*Copyright*
Patent	1			
Design	0.803	1		
	(111.144)***			
Trademark	0.545	0.593	1	
	(41.317)***	(59.108)***		
Copyright	0.505	0.51	0.508	1
	(23.643)***	(32.976)***	(33.256)***	

Table B5 Productivity approach

Innovation intensity (% of turnover from innovation) 2004			
IPR pairs	*Supermodularity test*	*Submodularity test*	*Conclusion*
Patent-design	6.664 (U)	50.189 (R)	Inconclusive
Patent-trademark	24.606 (R)	78.070 (R)	Inconclusive
Patent-copyright	1.000 (A)	25.237 (R)	Strong complementarity
Design-trademark	26.978 (R)	25.905 (R)	Inconclusive
Design-copyright	15.326 (R)	16.559 (R)	Inconclusive
Trademark-copyright	35.120 (R)	73.290 (R)	Inconclusive
Total turnover 2004			
IPR pairs	*Supermodularity test*	*Submodularity test*	*Conclusion*
Patent-design	41.745 (R)	16.955 (R)	Inconclusive
Patent-trademark	19.956 (R)	27.077 (R)	Inconclusive
Patent-copyright	21.594 (R)	1.286 (A)	Strong substitutability
Design-trademark	20.452 (R)	23.730 (R)	Inconclusive
Design-copyright	31.227 (R)	75.324 (R)	Inconclusive
Trademark-copyright	58.039 (R)	10.391 (R)	Inconclusive

Table B5 Productivity approach (continued)

Innovation intensity (% of turnover from innovation) 2006			
IPR pairs	Supermodularity test	Submodularity test	Conclusion
Patent-design	6.341 (U)	1.089 (A)	Weak substitutability
Patent-trademark	5.880 (U)	1.271 (A)	Weak substitutability
Patent-copyright	5.228 (U)	1.000 (A)	Weak substitutability
Design-trademark	5.658 (U)	0.989 (A)	Weak substitutability
Design-copyright	5.366 (U)	1.394 (A)	Weak substitutability
Trademark-copyright	4.289 (U)	3.538 (U)	Inconclusive
Total turnover 2006			
IPR pairs	Supermodularity test	Submodularity test	Conclusion
Patent-design	31.338 (R)	30.557 (R)	Inconclusive
Patent-trademark	9.102 (R)	30.885 (R)	Inconclusive
Patent-copyright	18.813 (R)	34.075 (R)	Inconclusive
Design-trademark	48.439 (R)	24.305 (R)	Inconclusive
Design-copyright	35.581 (R)	19.091 (R)	Inconclusive
Trademark-copyright	21.113 (R)	61.524 (R)	Inconclusive

Table B6 Factor analysis

	Factor 1	*Factor 2*	*Factor 3*
co11 (Cooperation with other enterprises within the group – National)	0.951		
co12 (Cooperation with other enterprises within the group – Other European countries)	0.957		
co13 (Cooperation with other enterprises within the group – USA)	0.980		
co14 (Cooperation with other enterprises within the group – All countries)	0.981		
co21 (Cooperation with Suppliers of equipment, materials, components, or software – National)	0.913		
co22 (Cooperation with Suppliers of equipment, materials, components, or software – Other European countries)	0.946		
co23 (Cooperation with Suppliers of equipment, materials, components, or software – USA)	0.979		
co24 (Cooperation with Suppliers of equipment, materials, components, or software – All countries)	0.980		
co31 (Cooperation with Clients or customers – National)	0.933		
co32 (Cooperation with Clients or customers – Other European countries)	0.957		
co33 (Cooperation with Clients or customers – USA)	0.981		
co34 (Cooperation with Clients or customers – All countries)	0.979		

Table B6 Factor analysis (continued)

	Factor 1	*Factor 2*	*Factor 3*
co41 (Cooperation with Competitors or other enterprises in the sector – National)	0.951		
co42 (Cooperation with Competitors or other enterprises in the sector – Other European countries)	0.970		
co43(Cooperation with Competitors or other enterprises in the sector – USA)	0.983		
co44 (Cooperation with Competitors or other enterprises in the sector – All countries)	0.982		
co51 (Cooperation with Consultants, commercial labs, or private R&D institutes – National)	0.941		
co52 (Cooperation with Consultants, commercial labs, or private R&D institutes – Other European countries)	0.974		
co53 (Cooperation with Consultants, commercial labs, or private R&D institutes – USA)	0.983		
co54 (Cooperation with Consultants, commercial labs, or private R&D institutes -All countries)	0.983		
co61 (Cooperation with Consultants, commercial labs, or private R&D institutes – National)	0.938		
co62 (Cooperation with Consultants, commercial labs, or private R&D institutes – Other European countries)	0.978		
co63 (Cooperation with Consultants, commercial labs, or private R&D institutes – USA)	0.984		
co64 (Cooperation with Consultants, commercial labs, or private R&D institutes – All countries)	0.983		
co71 (Cooperation with Universities or other higher education institutions – National)	0.965		
co72 (Cooperation with Universities or other higher education institutions – Other European countries)	0.983		
co73 (Cooperation with Universities or other higher education institutions – USA)	0.984		
co74 (Cooperation with Universities or other higher education institutions – All countries)	0.983		
rrdin (Intramural (in-house) R&D)		0.703	
rrdex (Extramural R&D)		0.578	
rmac (Acquisition of machinery, equipment and software)		0.649	
roek (Acquisition of other external knowledge)		0.511	
rtr (Training)		0.689	
rmar (Market introduction of innovations)		0.703	
rpre (Other preparations)		0.671	
propat (Patents)		0.390	
prodsg (Designs)		0.307	
protm (Trade marks)		0.360	
procp (Copyrights)			

Table B7 Productivity approach, two factors

		Innovation intensity	*Total turnover*
Size		0.856	0.286
		(9.91)***	(14.04)***
Country		0.202	–0.125
		(15.14)***	(–40.27)***
Industry		–0.025	–0.003
		(–5.16)***	(–2.59)**
R&D expenditure		–0.307	0.176
		(–32.31)***	(78.62)***
Innovation expenditure (non-R&D)		–0.243	0.136
		(–26.2)***	(62.37)***
Group		–0.415	1.396
		(–4.32)***	(61.82)***
Market	Local	–0.283	0.241
		(–3.18)**	(11.54)***
	National	–0.047	0.276
		(–0.48)	(12.19)***
	Other Europe	0.299	0.257
		(2.93)**	(10.72)***
	Other	–0.088	0.339
		(–0.75)	(12.41)***
Financial support		3.284	–1.889
		(27.21)***	(–66.8)***
Information Source	Internal	1.542	0.101
		(12.23)***	(3.45)***
CIS04$X_factor13	Market	0.675	0.789
		(4.32)***	(21.67)***
CIS04$X_factor14	Institutional	3.366	–0.9
		(26.48)***	(–30.21)***
CIS04$X_factor15	Other	0.981	–0.375
		(8.31)***	(–13.58)***
factor1		1.481	4.05
		(5.47)***	(64.23)***
factor2		0.445	1.066
		(1.76).	(18.22)***
factor1:factor2		4.144	2.662
		(14.83)***	(40.89)***