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Cross-licensing, Cumulative Inventions and Strategic Patenting

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We analyze the association between the importance of cross-licensing as a motivation for patenting and key characteristics of the patent, the patent holder and the technology. More precisely, we hypothesize that cross-licensing is associated with the cumulativeness of patented inventions and the number of overlapping claims with other patents. Moreover, we expect that cross licensing is positively associated with concentration and complexity of the main technological field of the patent. Finally, we test the hypothesis that intensity of competition in the technological space is positively associated with cross-licensing.

We test these hypotheses by using the PatVal-EU survey data on European inventors of 7,052 patents granted by the EPO with priority dates between 1993 and 1998. We focus our analysis on patents held by firms. We complement the survey data with additional variables at the patent, company and technology level drawn various datasets (EPO-Epasys, Who Owns Whom, Amadeus and Compustat).

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Keywords: licensing strategy, patents, innovation, technological competition
JEL classification: O32; L21

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1. Introduction

This paper focuses on cross-licensing as a reason for patenting. Earlier studies have suggested that cross-licensing is a strategy adopted especially by the owners of large patent portfolios operating in complex products industries like computers, semiconductors and electronics (Cohen, Nelson and Walsh, 2000; Grindley and Teece 1997). The strengthening of patent protection since the 1980s has been accompanied by an increasing number of licensing and cross-licensing deals (see, for example, Arora, Fosfuri and Gambardella, 2001; Arora and Ceccagnoli, 2006; Gambardella, Giuri and Luzzi, 2007; Gambardella and Torrisi, 2010). And a large proportion of patents owned by large firms like IBM, TI and HP is probably used as bargaining chips in litigation and cross-licensing deals (Rivette and Kline, 2000; Hall and Ziedonis, 2001).

Cross-licenses typically do not imply significant transfer of technology as both parties are often interested in gaining the freedom to design or manufacture. Cross-licensing is an important issue for technology and intellectual property management for several reasons. Cross-licensees represent a coordination mechanism that allows the owners of overlapping patent portfolios to moderate the costs of litigation. The declining barriers to patent have probably favored the protection of many low quality inventions (Harhoff, Narin and Vopel, 1999; Gambardella, Harhoff and Verspagen, 2008). Many patents, particularly in subject matters like semiconductors, software and business methods, are not used by the owners, which suggests that several patent applications are filed for purely strategic reasons (patent blocking, patent fences and patent thickets) and are more likely to be litigated (Bessen and Meurer, 2008; Hall, Thoma and Torrisi, 2009). The incentive to use cross-licensing (or similar arrangements) has increased over time with the explosion of patent applications since the 1980s and the associated rising patent litigation costs (Bessen and Meurer, 2008; Harhoff and Reitzig, 2004). As Shapiro (2000) has noted "lawsuits … are a necessary part of (the "threat point" behind) any cross-licensing negotiation: if one party is not happy with the terms offered by the other, it always has the option of initiating patent litigation" (p. 16). The threat of litigation is particularly strong for firms with high capital-intensity because of their sunk costs in technology-related activities (see Hall and Ziedonis, 2001; Beard and Kaserman, 2002; Ziedonis, 2004). These firms then have more incentives to engage in cross-licensing and other forms of out of court agreements.

Besides providing assurance against the risk of accidental patent infringement, cross-licensing presents several advantages for firms engaged in R&D-intensive and patent-intensive industries. First, a firm involved in cross-licensing can avoid the costs of developing a complementary technology that is necessary to develop its own technology. Cross-licensing then helps free resources that can be devoted to R&D activities that do not merely replicate earlier inventive efforts. Usually the development costs saved thanks to a cross-license overcome the royalties paid to partners and, sometimes, cross-licensing agreements are signed on royalty-free basis. Second, cross-licensing speeds-up the firms' development process and therefore allows a faster commercialization of innovation (Fershtman and Kamien, 1992; Beard and Kaserman, 2002). On the drawback side, cross-licensing, like licensing-out in general, increases competition and rent-dissipation effects in the product market (Arora, Fosfuri and Gambardella, 2001). Moreover, some potential anticompetitive implications of cross-licensing and patent pooling have attracted the attention of the economics literature (e.g., Eswaran, 1994; Shapiro, 2000; Beard&Kaserman, 2002; and Choi, 2010).

We analyze the association between the importance of cross-licensing as a motivation for patenting and a series of variables that account for key characteristics of the patent, the patent holder and the underlying technology. More specifically, we hypothesize that cross-licensing is associated with the cumulativeness of patented inventions and the number of overlapping claims with other patents. Moreover, we expect that cross licensing is positively associated with the technological complexity of the patent and two important characteristics of the patent's technological field – concentration and competition intensity.

We test these hypotheses by using the PatVal-EU survey data on European inventors of 6,996 patents granted by the EPO with priority dates between 1993 and 1998. We focus our analysis on patents held by business enterprises. The PatVal-EU survey asked, among other things, about the reasons for patenting, including cross-licensing.

We regress cross-licensing against various measures of cumulativeness, overlapping patent claims, concentration and complexity, controlling for firm characteristics (R&D intensity, size, patent propensity, country) and patent characteristics (application year, technological field, and various measures of patent technical and economic value). The main regressors have been selected and grouped according to what suggested by the theory and previous empirical studies.

The main contributions of the paper to the literature on patent economics and strategic management of intellectual property are twofold. First, we provide novel evidence to fill the gap in the empirical analysis of cross-licensing. While there exist several theoretical studies focusing on the economics of cross-licensing and welfare implications (e.g., Ferschtman and Kamien, 1992; Shapiro, 2000; Beard and Kaserman, 2003; Bessen, 2003, Choi, 2001), we are aware of only few empirical works on the determinants and patterns of patenting and cross-licensing in specific industries (e.g., Grindley and Teece, 1997; Hall and Ziedonis, 2001; Nagaoka and Kwon, 2006). Unlike earlier studies which have examined the determinants of cross-licensing in few case-studies (e.g., Grindley and Teece, 1997; Davis, 2008), our paper provides novel empirical evidence based on a large, representative sample of patents and patent assignees across different technologies and industries. Our focus on patent cross-licensing, rather than cross-licensing in general, is in line with previous studies which show that cross-licensing is higher for patent licensing than that for know-how licensing (Nagaoka and Kwon, 2006). Second, unlike the majority of earlier works on licensing, our study is centered on cross-licensing of specific patents rather than patent cross-licensing strategy in general. Although the holders of large patent portfolios usually engage in cross-licensing of patent portfolios rather than particular patents (e.g., Grindley and Teece, 1997), the focus on single patents allows to identify otherwise unobservable patent-specific characteristics that are associated with the importance of cross-licensing.

The paper is organized as follows. Section 2 introduces the theoretical background of the paper and the research hypotheses. Section 3 illustrates the data and methodology while Section 4 reports the main results. Section 5 concludes the paper.

2. Background and hypotheses

Technological complexity, sunk costs and cross-licensing

In technological fields like semiconductors, biotechnology and software, strong interdependencies among innovations and the increasing use of patents, particularly since the 1980s, have favored a great dispersion of rights among patent holders (Heller and Eisenberg 1998; Shapiro, 2000). Excessive IPR fragmentation or 'overfencing' raises transaction costs in the market for technology and can hamper the efficient use of technology-related resources since the threat of involuntary infringement on multiple patents many discourage investment in the development and commercialization of innovations. This outcome has been described as the 'anti-commons tragedy' (Heller and Eisenberg, 1998).

In line with this body of research, various empirical works have studied the implications of IPR fragmentation and technological interdependencies for the innovation strategy of the firm. Cohen, Nelson and Walsh (2000) have distinguished between complex and discrete product industries. Complexity implies that "a new, commercializable product or process is comprised of numerous separately patentable elements versus relatively few" (Cohen, Nelson and Walsh, 2000: 19). For example, there are several complementary patents that are essential to implement technical standards like the GSM, DVD6 video and the MP3 patents. In the case of GSM, the owners of 'essential' patents (Nokia, Motorola, Ericsson, Siemens and Alcatel) promoted the initial diffusion of the standard by signing a cross-licensing deal which was opened to other participants later on

(Bekkers, Duysters and Verspagen, 2002). By the same token, inventors of new video or audio devices need to access large pools of patents because they cannot control all the technologies required to develop their devices. The importance of cross-licensing in product complex industries is also reported in a recent study of Japanese firms (Nagaoka and Kwon 2006).

As Cohen et al. (2002) have noted, "in complex product industries, firms rarely have proprietary control over all the essential complementary components of the technologies they are developing. Firms hold rights over technologies that others need, and vice versa, creating a condition of mutual dependence that fosters extensive cross-licensing, related negotiations and information sharing." (p. 1356). Instead, there are limited interdependences between patents in "discrete" or "simple" technologies (like chemicals) and therefore inventors do not rely on large pools of earlier patents. Product and technological complexity increase the transaction costs among patent owners and spur them to licensing and cross-licensing. In particular, Cohen, Nelson and Walsh (2000) and Cohen et al (2002) have found that in complex industries one of the most important reasons for patenting is the use of patents in negotiations (including cross-licensing negotiations) and to prevent patent infringement lawsuits. In industries such as semiconductors and biotechnology, firms often find it convenient to engage in cross-licensing or create a patent pool (where all blocking patents can be licensed on the basis of a package license agreement) to reduce "multiple patent burdens" and the hold-up problem (i.e., the risk of infringement complaint by the holders of a patent the firm is not aware of). Cross-licensing allows each part the freedom to design and to manufacture by allowing access to competitors' patents, reducing the risk of unintentional infringement or avoid the problem of mutually blocking patents (Shapiro, 2000, Davis, 2008). Although previous studies have pointed out the importance of cross-licensing in complex products industries, to the best of our knowledge there are no earlier works that explore the association between cross-licensing as a determinant for patenting and technological complexity, controlling for other patent-specific and firm-specific characteristics.

The effects of complexity and IPR fragmentation are particularly strong for high capital-intensity firms (Hall and Ziedonis, 2001, Ziedonis, 2004). A high-capital intensity firm is more vulnerable to the risk of patent infringement and rent expropriation, compared with low-capital intensity firm, because it has invested substantial resources in specific assets embodying technologies that may infringe patents it was not aware of at the time of the investment. For example, significant sunk investments in dedicated manufacturing and commercialization facilities have induced large firms like Intel or Blackberry to settle patent disputes with smaller owners of patents to avoid the costs of longer court litigations and the risk of a possible preliminary injunction to cease production of core products (Rivette and Klein, 2000; Shapiro, 2000).[1] We expect then that the effect of technology complexity on cross-licensing is stronger for high-capital intensity firms.

These considerations lead to the following hypotheses.

> Hp 1.a. Cross-licensing is more likely to occur in more complex technological fields.
>
> Hp 1.b. The effect of technological complexity on the propensity to cross-license is stronger for high capital-intensity firms.

Cumulative change and overlapping claims

Beyond complexity, innovations are characterized by different levels of cumulativeness defined as the degree to which current innovations rely on previous innovations. Cumulativeness, like complexity, prompts innovative firms to enter cross-licensing agreements to minimize the risk of infringement and litigation. In principle, product complexity should be associated with cumulativeness because new complex products are likely to build on several previous or complementary inventions. However, these variables capture two distinct dimensions of technological change and represent different reasons for cross-licensing. In particular,

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[1] Research in Motion has settled a long lasting litigation with NTP, a patent holding company, in 2006 whereas Intel settled with S3, a developer of graphic processors, in 1998. The Intel vs. S3 case is emblematic of the strategic use of patents and cross-licensing: "While it is unclear whether Intel will incorporate any S3 technology into its products, the deal may quell a potential legal problem for Intel. Observers have said that the patents S3 acquired from Exponential earlier this year gave S3 a weighty claim for patent infringement against Intel (source: *S3, Intel in tech licensing deal*, December 17, 1998, http://news.cnet.com).

cumulativeness accounts for firm-specific and invention-specific characteristics (e.g., the firm-specific ability to build upon, absorb and combine previous inventions), whereas complexity indicates the characteristics of a particular technological field or industry – for example, the average level of complementarity among distinct inventions embodied in consumer electronics products is higher than in drugs. Moreover, complexity is likely related to high IPR fragmentation which implies that the average invention of a specific technological class relies on several separately patentable elements (probably owned by different rights holders). Instead, cumulativeness does not necessarily entail a high complexity or IPR fragmentation. Many incremental inventions build on few earlier inventions developed by competitors.

Complexity and cumulativeness likely result in many citation links among patents. However citation links are not all the same. Two patents may be linked by different types of citation links. In the EPO system backward citations or references to earlier patents are classified by patent examiners according to whether the citing and the cited patent have one or more overlapping claims. In this patent system then citations represent an 'objective' measure of links across inventions and are not affected by the firm IPR strategy. Patent applications that, according to the EPO examiner, contain overlapping claims with earlier cited patents are likely to be opposed before the European Patent Office or litigated in a court. Overlapping claims with cited patents then are an indicator of fragility or uncertain validity of a patent (Harhoff and Reitzig, 2004; Hall, Thoma and Torrisi, 2010). Therefore, patents with overlapping claims are more likely to be cross-licensed to moderate transaction costs and the risk of litigation. It should be noted that the probability of cross-licensing should also be high when a patent is cited by subsequent patents with overlapping claims. For the reasons above, we expect that cumulativeness and overlapping claims at the level of the single patent affect the importance of cross-licensing.

> Hp2.a. Patents based on cumulative invention are more likely to give rise to cross-licensing agreements as compared to patents based on less cumulative invention.

> Hp2.b. Patents with many overlapping claims are more likely to give rise to cross-licensing agreements as compared to other patents.

Technology concentration and competition

The accumulation of large patent portfolios or patent 'thickets' leads to a high concentration of the technological space. This can provide a favorable ground for tough competition among the owners of patent portfolios. However, firms involved in highly concentrated technological fields will likely take advantage of the limited search and transaction costs to negotiate their freedom to operate with their rivals. This expectation in consistent with previous works showing that cross-licensing, compared with unilateral licensing, is more prevalent between large and symmetric firms (Nagaoka and Kwon, 2006).

Beyond concentration in the technological field, the decision to cross-license can be affected by the intensity of competition among firms working on similar inventions. In principle, an intense technological competition could hamper cross-license agreements and other forms of collaboration among rivals. Competition makes R&D and IP managers particularly concerned about the risk of information spillovers but it also provide incentives to use patents as a bargaining chip in cross-licensing. One reason is "time to market". More intense competition in general increases the importance of reaching the market first with an innovation. As mentioned before, cross-licensing increases R&D productivity allowing firms to focus on core capabilities, acquire nonstrategic technologies from outside, and reduce development time. Moreover, compared with other collaborative arrangements like joint R&D, cross-licensing guarantees a better control of the know-how transferred between the partners. This is an important benefit of cross-licensing in conditions of intense competition (Pastor and Sandonis, 2000). In addition, in several sectors, including those which are not classified as high complex product industries by Cohen, Nelson and Wash (2000), products and processes have become more and more complex over time. For example, a former Gillette's vice-president for corporate R&D reported that they created a wall of 22 interlocking patents to protect the Sensor razor (Rivette and Kline, 2000: 58). Virtually no firm, even very large multi-product corporations, is able to develop in-house all the technologies required to produce new products in R&D-intensive and highly competitive industries (Granstrand, Pavitt and Patel, 1997). For these reasons we believe that more intense competition makes firms more open to external sources of knowledge and therefore increases the value of patents as a bargaining chip in cross-licensing and other collaborative arrangements.

This discussion leads to the following hypotheses.

Hp. 3.a: Cross-licensing is more likely to occur in concentrated technical fields.

Hp. 3.b: Cross-licensing is more likely to occur when there is intense technological competition among firms.

3. Data and methodology

Our empirical analysis draws on data collected through the PatVal-EU survey on European inventors of 9,550 patents granted by the EPO with priority dates between 1993 and 1998. The PatVal-EU survey asked, among other things, about the reasons for patenting, including cross-licensing. In particular inventors rated the level of importance of cross licensing as a reason for patenting on a 5-point Likert scale (for details about the survey methodology and results see Giuri et al. 2007). We focus our analysis on a sample of 6,966 patents held by business enterprises.

We complement the survey data with additional variables at the patent, company and technology level drawn from the following datasets: EPO-Epasys dataset for patent and citations indicators (see Harhoff, Hoisl and Webb (2006); Who Owns Whom, Amadeus and Compustat for company-level data and the ISI-INPI-OST data for the classification of technological fields of the patent (see Hinze, Reiss, and Schmoch, 1997).

Our empirical analysis is based on ordered probit estimates of the importance of cross licensing as a motivation for patenting. Our dependent variable is CROSSLICENSING, a 0-5 categorical variable measuring the rate of importance of cross licensing as a motivation for patenting. For the sake of simplicity, in commenting results we will often refer to CROSSLICENSING as cross-licensing.

Table 1 describes the dependent variable, the main regressors and controls used in our estimations. Table 2 reports the descriptive statistics for all variables. Our main regressors account for different important dimensions of the patent, the patent holder and the patented technologies.

As mentioned before, technological complexity varies across technological fields and industries. Although Cohen, Nelson and Walsh (2000) distinguished between high and low complexity industries, their classification is based on technological dimensions: "the difference between complex versus simple technologies is typically driven by the technology and physical character of a product (p. 19). For this reason, we classify the patented invention, rather than the firm's sector, according to the level of complexity of its underlying technology (Hp 1.a). To this end, we have generated thirty dummies for each OST technological class (TECH CLASS). We also use a dummy (COMPLEX_TECH) that takes value 1 when the technology of the patent falls in one of the following classes: Electrical devices, engineering, energy, Audio-visual technology, Telecommunications, Information technology, Semiconductors, Optics, Analysis, measurement, control technology, Medical technology, Machine tools, Engines, pumps, turbines, Transport, Nuclear engineering, Space technology weapons.[2]

We control for the fixed assets of the patent applicant by building a variable (FIXED_ASSET) measuring the average value of the annual fixed assets of the applicant of the patent in 1990-1996. This variable, as well as all other variables at the company level, are consolidated at the level of the parent company identified by using Who Owns Whom data.

To test the hypothesis that the effect of complexity on cross-licensing is stronger for high-capital intensity firms (Hp 1.b), we run separate regressions for two subsamples: complex industries (COMPLEX_TECH=1) and discrete industries.

[2] Our classification of complex technologies draws on the definition of complex sectors adopted in Cohen, Nelson and Walsh (2000). Although technological and industrial classifications have different objectives and characteristics, we expect a close correspondence between the two classifications in terms of complexity. For example, OST classes 1 ("Electrical devices, engineering, energy", "3 ("Telecommunications") and 4 ("Information technology") corresponds quite precisely to "Computers", "Telecommunications equipment" and "Electronics" industries. Moreover, several large firms in our sample are diversified and this would make it difficult to assign each firm to a specific industry. We should remind that we might have a similar problem with IPC/OST classification since several patents are assigned two or more IPC classes and when this is the case the EPO system does not indicate which class is the primary IPC class. However, more than 95% of different IPC classes assigned to a patent fall in the same OST class.

Our second hypothesis (Hp 2.a) is about the impact of cumulativeness on the motivations to engage in cross licensing agreements. Cumulativeness is defined as the reliance of the firms' patented inventions on other organizations' (patented and unpatented) inventions. For the purposes of our analysis, we constructed a dummy variable (CUMULATIVE_EXT) that takes value 1 if, according to the respondent to the PatVal_EU survey, the patented invention built on other organizations' inventions.

Another key variable to test our second hypothesis (Hp 2.b) is about the importance of overlapping claims between the patent and earlier cited patent (references or backward citations) and subsequent citing patents (forward citations). We rely on two measures of overlapping claims, SHARE_XY_CITATIONS and SHARE_XY_REFERENCES reported in the EPO-Epasys dataset. References whose claims overlap completely or partially with at least one claim of other patents are classified by EPO examiners as X and Y references respectively.

We also control for the total number of backward citations (N_REFERENCES) and forward citations (N_CITATIONS) of the patent. A large number of citations across patents could reflect high cumulativeness and complexity. However, as discussed before, a large number of overlapping claims across patents conveys additional information about the nature of links among distinct inventive efforts. Specifically, patents with a large share of overlapping claims with earlier patents (XY_REFERENCES) have an uncertain validity and are then likely to be challenged before the EPO or in the court. Since about 95% of patent litigations are settled out of courts (Lanjouw and Schankerman, 2001), a firm filing a patent application with a large share of XY_REFERENCES must be prepared to enter into a licensing or a cross-licensing deal sooner or later.[3] By the same token, a firm whose patents receive XY_CITATIONS may be induced to initiate a patent litigation and engage in cross-licensing negotiations. However, at the time of the application the owner of the cited patent cannot know about future XY_CITATIONS. Therefore the association between future forward citations and cross-licensing as a motivation for patenting is unclear.

[3] Although references are assigned by EPO examiners, at the time of application the applicant (especially if a medium-to-large firm) most probably is aware of relevant earlier patents with overlapping claims.

Two additional key variables are concentration of the technological field of the patent and the intensity of competition with other firms working on similar inventions (Hps 3.a and 3.b).

Our measure of concentration is the cumulative share of the top four patent applicants in each 4-digit IPC class (IPC4_C4). For IPC4 classes with 10 or fewer patents we do not compute the concentration ratio, which would not be meaningful due to the small number of observations, and include a dummy variable equal to 1 for the corresponding observations. The threshold of 10 patents corresponds to the 99th percentile of the distribution of the number of patents across all 4-digit IPC classes.

Instead, the intensity of competition is proxied by the decision to patent the invention as it was – as opposed to further develop it by devoting additional resources, because the invention had to be patented quickly, as the inventor's organization was aware of other inventors, research groups or firms that were working on inventions in the same field (COMPETITION).

Our regressions include several control variables. At the level of the patent applicant we control for the average number of employees (EMPLOYEES) and average R&D expenditures/Sales ratio (R&D_INTENSITY) of its parent company in 1990-1996. We also include a variable indicating the appropriability policy of the company by computing the ratio between number of patents and R&D expenditures of the patent applicant (NPAT/R&D).

Since in Amadeus and Compustat we could not find information about R&D, number of employees and level of fixed assets for all patent applicants in our sample we include three dummies taking value 1 for missing observations of these variables.

Finally, we include seven dummies for the country of the first inventor of the patent (Germany, Denmark, Spain, Italy, Hungary, the Netherlands, UK) and six dummies for the application year of the patent (from 1993 to 1998).

Table 3 reports the correlation among main regressors.

4. Results

4.1 Econometric estimations

Table 4 shows the results of our ordered probit estimations of CROSSLICENSING. Column 1 includes all control variables. Columns 2-5 include controls and progressively add the main regressors testing for our three main hypotheses. In particular, to test Hypotheses 1.a we report in Column 2 the estimates of the impact of the 30 technological classes on the importance of cross licensing. Hypothesis 1.b was tested by estimating the impact of firms' capital intensity (FIXED_ASSET) on cross-licensing in complex and discrete technologies respectively. To test hypotheses 2.a and 2.b Column 3 reports the estimated impact of cumulativeness (CUMULATIVE_EXT) while Column 4 adds overlapping claims (SHARE_XY_CITATIONS and SHARE_XY_REFERENCES). To test hypotheses 3.a and 3.b we report in Columns 5 and 6 the estimates of the full model with our proxies for technological concentration (IPC4_C4) and COMPETITION.

As Table 4 clearly shows, the results support our hypotheses.

We first find that almost all technological classes have a significant impact on the importance of cross licensing. With respect to our baseline dummy (Electrical devices, engineering, Energy), the coefficients on Audio-visual technology, Telecommunications, Information technology, Semiconductors and Optics have a positive and significant sign, while coefficients on other all other classes have a negative sign. This result confirms that cross licensing is driven by technological complexity, which is particularly high in sectors like electronics and semiconductors.

To examine the hypothesis of a positive interaction between capital intensity (FIXED_ASSET) and technological complexity we run separate regressions for complex and discrete technologies by using the dummy COMPLEX_TECH. The coefficient of FIXED_ASSET is positive and significant in both samples. However, the effect of FIXED_ASSET is only slightly larger in the complex technologies sample, which is not in line with our Hp. 1.b.[4] We will turn to this issue in the discussion of robustness checks.

Hypotheses 2a and 2b are corroborated by our estimations. Column 3 shows that CUMULATIVE_EXT is positively and significantly associated with cross licensing. We also find that XY references are positively associated with cross-licensing, suggesting that overlapping claims with earlier patents are a signal of uncertain validity and therefore are more likely to lead to litigation and cross-licensing deals. Instead, XY citations are not significant and this suggests that this variable probably account for patent characteristics (such as quality) that are already captured by other characteristics such as the total number of forward citations received.

Among the controls, we find that the coefficient on N_CITATIONS is positive and significant. Since citations received are a typical indicator of high value inventions, our estimates suggest that inventions patented for cross-licensing purposes are of no lower value relative to other patents.

To test hypotheses 3.a and 3.b we rely on an indicator of concentration of the technological class (IPC4_C4) and a proxy for the intensity of technological competition. The coefficient of IPC4_C4 is positive and significant, suggesting that firms in concentrated sectors are more likely to patent for strategic purposes, i.e. to use patents as bargaining chips in cross-licensing negotiations.

Finally, we find that the coefficient of COMPETITION is positive and significant above and beyond technological concentration.

Our control variables at the firm level (EMPLOYEES and R&D INTENSITY) show that for large firms cross-licensing is an important reason for patenting. Our proxy for the appropriability strategy of the firm (NPAT/R&D) is not significant[5].

In summary, our results show that, controlling for firm characteristics, the characteristics of the technology (complexity and concentration) and patent characteristics (cumulativeness and

[4] We also tried a different definition of COMPLEX_TECH by classifying biotechnology in complex technologies and results do not change.

[5] We performed several estimates by excluding NPAT/R&D, including the number of patents in place of the R&D intensity, and by progressively including the variables related to firm size, like the number of employees and the level of fixed assets and results do not change.

overlapping claims) are important for cross-licensing. These findings confirm that cross-licensing helps patent holders to reduce transaction costs which can be particularly high in the case of complex technologies. On the other hand, our results suggest that cross-licensing is more likely to occur for more controversial, more contestable patents - i.e., patents which heavily build upon earlier patents and patents with more overlapping claims.

Our results are robust to different model specification and estimation methods (ordered logit and probit).[6] We rely on probit estimations for a simple interpretation of the magnitude of the coefficients on the likelihood that cross-licensing is an important determinant for patenting. We tried different cut-offs of the dependent variable. In what follows, we report the marginal effects at different levels of our primary regressors on the probability that cross-licensing is an important reason for cross-licensing (scores 4 and 5). The predicted value of cross-licensing increases by about 8.3 percent points when the patent concerns a COMPLEX technology as opposed to a discrete technology. The marginal effect of some technologies is noteworthy. For example, telecommunications technology patents are characterized by an increase in the importance of cross-licensing of 14.2% points, information technology patents by 10% points and semiconductors patents by 17.9% points. On the contrary, the likelihood of cross-licensing decreases by about 10% points for chemicals patents and 5% points for pharma/biotech patents. Inventions that built in a substantial way on previous inventions known to the inventor are associated with a 2% increase in the likelihood of patenting for cross-licensing while an increase in the share of overlapping claims (SHARE_XY_REFERENCES) from 0.3 to 0.64 (a shift of one S.D.) does not yield any significant change in the probability of patenting for cross-licensing reasons.[7] Instead, increasing the concentration ratio of one S.D. results in a 2.9% increase in cross-licensing. Moreover, strong competition with other inventions increases the likelihood of patenting for cross-licensing of 7.2%

[6] Ordered logit and probit estimations are not reported for reasons of space but are available from the authors. With probit estimations the coefficient of SHARE_XY_REFERENCES becomes not significant at the conventional significance level.

[7] To gain a 1% point increase in the likelihood of cross-licensing SHARE_XY_REFERENCES must increases of two S.D. above its mean.

points. The association between patent value (measured by citations received) and R&D intensity is also substantial. Adding 2.26 citations (one S.D.) to the average number of citations is associated with 8.0% point increase in the probability that the invention is patented for cross-licensing reasons while increasing R&D expenditures from 5% to 8% of sales yields a 2.7% points increase in the probability of cross-licensing.

4.2 Robustness checks

We performed several additional estimates (available from the authors) to check the robustness of our results with different key regressors and controls. Moreover, we included among our controls the information whether the patent has been opposed before the EPO. Opposition is an administrative procedure that anybody can file at the EPO up to 9 months after the grant of the patent in order to challenge the validity of the patent.

This information was provided by the EPOline dataset. We also used another variable drawn from the PatVal_EU survey about whether the patent has been litigated in a court. We include these variables in our estimation and their coefficients are not significant, while all other results do not change. Even if in principle one may expect some association between these two variables and cross-licensing, we should note that our dependent variable is measured at the time of patent application whereas oppositions and litigations, if any, must have occurred only after the time of application. Typically, patent holders engage in a cross-licensing deal after an opposition or litigation has been initiated by a rival, even if it is possible that litigation follows the failure of a cross-licensing deal. In theory, then the association between these controls and cross-licensing is not straightforward.[8]

We also include progressively the following controls: the number of claims, the number of IPC classes assigned to the patent and the number of patent offices where patent protection is sought (patent family size) with no significant results.

[8] We cannot exclude that survey participants (inventors) have limited information about patent litigation and oppositions.

Some of our regressors - CUMULATIVE_EXT and COMPETITION, may be endogenous. To moderate this problem we constructed these variables at the company level rather than the patent level. Although this does not fully account for endogeneity, cumulativeness of the firm's overall innovative activity and the intensity of competition of the overall technological environment are relatively exogenous to the decision to patent a particular invention for cross-licensing purposes. The coefficients of firm-level CUMULATIVE_EXT and COMPETITION remain significant and the overall results do not change.

We also include alternative proxies for the firm's innovativeness and the characteristics of the external technological environment. The first proxy is the importance of competitors as a source of knowledge for the patented invention (ranked on a 5-point Likert scale). Another indicator is the importance of others' patents as a source of knowledge for the invention. These variables enter positively and significantly in our regressions. When we include them together with all other main regressors the significance of cumulativeness fades away. These robustness checks confirm that the patent's level of novelty (measured by cumulativeness) and the characteristics of the external technological environment (measured by competition) are associated with cross-licensing also when we use alternative proxies, alternatively or together with our main regressors.

To control for the technological and product diversification at the firm level we calculated the Herfindhal index based on the distribution of patents across the 30 OST technological classes and the number of distinct 4-digit SIC classes of the firm. The effects on these variables are insignificant and their inclusion in the regressions does not change the results.

Our regressions include three dummies for missing observations on EMPLOYEES, R&D INTENSITY and FIXED_ASSET. Since these dummies are correlated, we generated an aggregated categorical indicator grouping common missing observations for the three variables and the inclusion of this indicator does not modify our results.

As discussed before, we run separate estimations for the two samples of discrete and complex technologies and did not find substantial differences in the size and significance of main regressors, including FIXED_ASSET and COMPETITION (one might expect that the impact of technological competition on cross-licensing is greater in the case of complex technologies).

To investigate further the role of complexity, we generated a dummy variable for complex product industries (COMPLEX_INDUSTRY), using the main SIC industry of the patent assignee. We matched the 4-digit SIC codes of the sample firm with the ISIC codes used by Cohen, Nelson and Walsh (2000). Our dummy is equal to 1 when the main industry of the patent assignee falls in one of the complex product industries reported in Cohen, Nelson and Walsh (2000). In unreported regressions the coefficient of COMPLEX_INDUSTRY (as a substitute for COMPLEX_TECH) is positive and significant. We also run separate regressions for complex product industries and discrete product industries and found that the coefficient of FIXED_ASSET (0.20, p-value<0.01) in complex industries estimations is 3 times as large as the equivalent coefficient in discrete industries estimations. This evidence supports Hp. 1.b and suggests that the association between capital intensity and cross-licensing is affected by product-specific characteristics at the firm level more than technology-specific characteristics at the patent level. However, because of many missing observations on the main SIC code of the patent assignees, these results are not as reliable as those reported in Table 4.[9] In future research we will collect data on the patent assignee's business activity to reduce the number of missing observations.

A final issue that deserves additional analysis is the association between cross-licensing and other motivations for patenting that we have not explicitly considered in this study. Two potential covariates of cross-licensing are blocking patents ("avoid that others patent similar inventions") and out-licensing. To study how the probability of cross-licensing varies conditioning upon blocking patenting and licensing respectively, we run two bivariate probit estimates. The bivariate probit model is a maximum likelihood estimator to estimate two equations with correlated disturbances (Greene, 1997: 906). From simultaneous estimation of each pair of equations we obtain the marginal and conditional probabilities of the dependent variables. For each equation we used the

[9] We have found data on the main SIC industry of the patent assignee for only 5,491 cases.

same set of regressors as those in the univariate probit model of cross-licensing (Table 4, column 7). For the bivariate probit estimation of cross-licensing and blocking patents we obtain the following predicted probabilities, Pr(crosslic=1, blocking patents=1), Pr(crosslic=1, blocking patents=0), Pr(crosslic=0, blocking patents=1) and Pr(crosslic=0, blocking patents=0). A Wald test for correlation between the two equations rejects the null hypothesis of no correlation ($\rho=0$).[10] The bivariate predicted probabilities help better understand the nature of cross-licensing and blocking patenting in our sample.

By and large, the impact of our main regressors on the the bivariate predicted probability of cross-licensing does not vary as compared with that discussed before. However, the predicted univariate (marginal) probability of blocking patents shows a different pattern. Only CUMULATIVE_EXT and COMPETITION have a significant positive impact on blocking patents while other regressors like COMPLEX_TECH have no significant effects. These findings suggest that, although correlated, blocking patents and cross-licensing are driven by different factors. We should also note that a larger share of the sample firms (47.4%) assign importance to blocking patents against only 16.7% of firms for which cross-licensing is an important motivation for patenting. Blocking patents are probably used for a multiplicity of reasons such as "block to fence" and "block to play" and this may explain why it is more difficult to identify the effect of specific explanatory factors. Instead, cross-licensing is, by definition, a more specific strategy aiming to use patents as a bargaining chip in negotiations with other patent holders.

We also conducted bivariate estimates with cross-licensing and licensing. These two equations are also correlated, as indicated by the Wald test. However, patents primarily motivated by licensing-out have different patterns than patent primarily induced by cross-licensing. The marginal (univariate) predicted probability of licensing is not significantly affected by the nature of technology while it is negatively associated with firms size and positively affected by patent quality

[10] Since our observations are clustered to account for links among patents held by the same assignee, observations are not independent and therefore a Wald test (the Wald statistic is the square of the t ratio) is used instead of a likelihood-ratio test to test the null hypothesis.

(measured by citations received). These results are consistent with the idea that smaller firms with limited downstream assets operating in different industries, from semiconductors (e.g., fabless semiconductor companies) to pharmaceuticals (small biotech companies), have more incentives to license-out compared with larger firms. Moreover, unlike cross-licensing, the predicted marginal probability of licensing is negatively associated with the concentration of the technology field while the effect of competition is not significant. Probably, a high technological concentration discourages out-licensing because the negative competition effects overcome the revenue-effects for reasons discussed by Arora, Fosfuri and Gambardella (2001). This also points to substantial differences between the two motivations for patenting.

5. Conclusions

This paper shows that cross-licensing is associated with fundamental characteristics of patented inventions such as complexity, cumulativeness and overlapping rights. When complex products or processes embody a large number of interrelated patents, any patent holder may block or be blocked by other patent holders. In such situations, the costs of negotiation among patent holders can be very high and firms are often exposed to holdup. In high-complex and dynamic industries, like semiconductors, telecommunications and software, cross-licensing may represent an alternative (or a solution) to litigation. Compared to ex-ante mechanisms like joint ventures and collaborative R&D, cross-licensing and patent pools can be viewed as an ex-post mechanism to moderate the hold-up problem and transaction costs. Our results also show that the concentration of technological space and the intensity of technological competition are relevant predictors of the likelihood of cross-licensing.

Our analysis provides novel insights on patent-specific, firm-specific and technology-specific factors associated with cross-licensing. We believe that our findings are relevant to technology and IP management because they highlight some conditions under which it is convenient to engage in cross-licensing as a mechanism to obtain the freedom to design and manufacture. When the firm's technology overlaps with technologies previously or simultaneously developed by competitors cross-licensing helps concentrate R&D resources on technologies where the firm has a comparative advantage and obtain IP rights from other parties in technological fields where the firm has no comparative advantage. Moreover, firms focusing on concentrated technological fields characterized by strong technological competition should rely on cross-licensing or other forms of collaboration rather than adopt an inward-looking strategy which could be detrimental to a sustainable competitive advantage.

Our findings provides evidence that can be useful for public policy. The anticompetitive implications of cross-licensing and package licenses (patent pools) have been debated at length in the literature (Shapiro, 2000; Beard and Kaserman, 2002; Bekkers, Duysters and Verspagen, 2002; Eswaran,1994; Choi, 2010). Various criteria have been suggested to examine the anticompetitive effects of patent pools and cross-licensing such as the existence of scale economies and complementarities among patents, the detection of 'sleeping licensees' (i.e., patents that remain unused by the licensees) (Eswaran,1994) and patent litigation - if the parties have incentives to litigate, the optimal policy is to allow patent pooling after the validity of patents has been contested in the court (Choi, 2010).

Scholars have argued that low barriers to patent and the possibility to engage in ex-post arrangements like cross-licensing lead firms to the accumulation of large patent portfolios for purely strategic reasons, namely to increase the bargaining power in negotiations with rivals. Large patent 'thickets' (or 'minefields') can be used by incumbent firms to force new entrants to share their rents under cross-license contracts thus reducing the newcomers' ex-ante incentive to invest in R&D. Even large, established firms with high sunk investments in complex technologies can be exposed to the attack of technology specialists or IP companies, and be forced to a licensing or cross-licensing deal under the threat of an injunction to halt production and commercialization (Ziedonis, 2004; Bessen, 2003; Beard & Kaserman, 2002).

This discussion shows that the implications of cross-licensing on competition and innovation are not obvious. Patent thickets and cross-licensing can be good for competition and innovation when competitors use these mechanisms to gain the freedom to operate and innovate in complementary technologies. But they can have negative implications when cross patent thickets and cross-licensing are used to collude on substitute technologies and to block the innovative activity of potential competitors.

Our data do not allow any precise conclusion about the welfare implications of cross-licensing. However, we find that cross-licensing is positively associated with the number of citations received by the patent and the firm’s R&D intensity while it is not associated with the firm’s patent propensity (patents/R&D expenditures). This evidence suggests that cross-licensing is a mechanism used by firms that carry out real R&D activity to obtain the freedom to design and manufacture rather than being a mechanism used for purely collusive reasons. Cross-licensing then could be a useful arrangement to facilitate the trade and efficient use of technology. By cross-licensing firms can reduce wasteful duplication of R&D efforts, gain access to third-parties technology and exploit proprietary technologies that would otherwise remain unused. However, we do not know whether patent protection would have been sought anyway, even under an antitrust regime more restrictive towards cross-licensing.

Our research has limitations that we will address in future research. Our analysis focuses on the intent to cross-license but we do not account for whether the firm has used the patent in practice as a bargaining chip in cross-licensing deals. Since the PatVal-EU survey data do not provide this information we will collect information about cross-licensing deals by the patent holder from alternative sources such as Dow Jones Factiva and Thomson Financial SDC. Data on cross-licensing deals before the patent application could also be used to deal with unobserved heterogeneity.

Another limitation that we will explore more thoroughly in future research is about the links between cross-licensing and motivations for patenting other than cross-licensing such as licensing-out and “blocking patents” (i.e., avoid others patent similar or complementary inventions). Our preliminary analysis reported before indicates that these strategies are correlated. However, the drivers of cross-licensing appear to be different from those of licensing-out and blocking patents. This suggests that cross-licensing is a distinct motivation for patenting which deserves finer-grained exploration in future research.

Moreover, as mentioned before, we could not find information on the primary business activity of a large number of sample firms and therefore we cannot fully account for industry-specific effects, although we have considered technology-specific effects. In future research we will collect detailed information on the firm business activity. This will also allow treat the potential endogeneity of some regressors by using the industry averages to identify the effect of endogenous regressors.

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Table 1. Description of variables

Variable name	Definition	Source of data
Dependent variables		
CROSS_LICENSING	Importance of cross licensing as a motivation for patenting the invention (0-5 Likert scale: 0 not important, 5 = very important).	PatVal-EU
Main regressors		
TECHCLASS	Thirty dummies for the technological classes of the patent (ISI-INIPI-OST classification).	EPOline, ISI-INPI-OST
COMPLEX_TECH	Dummy equal to 1 if the technological class of the patent was one of the following: Electrical devices, engineering, energy, Audio-visual technology, Telecommunications, Information technology, Semiconductors, Optics, Analysis, measurement, control technology, Medical technology, Machine tools, Engines, pumps, turbines, Mechanical Elements, Handling, printing, Agricultural&food proc-machin-apparatus, Transport, Nuclear engineering, Space technology weapons.	EPOline, ISI-INPI-OST
COMPLEX_INDUSTRY	Dummy equal to 1 if the core SIC sector of the assignee was one of the following: 351-357; 362-367; 369; 371-375; 379; 381-384.	Amaudeus
CUMULATIVE_EXT	Dummy equal to 1 if the invention built in a substantial way on other organizations' inventions that the inventor knew at the time of invention.	PatVal-EU
SHARE_XY_CITATIONS	Share of citations of X and Y type received by the patent on the total number of citations received by the patent	EPOline
SHARE_XY_REFERENCES	Share of references of X and Y type received by the patent on the total references listed in the patent	EPOline
N_XY_CITATIONS	Number of citations of X and Y type received by the patent (see N_XY_REFERENCES)	EPOline
N_XY_REFERENCES	Number of references (backward citations) of X and Y type listed in the patent. References whose claims overlap completely or partially with at least one claim of other patents are classified by EPO examiners as X and Y references respectively.	EPOline
IPC4_C4	Share of the patents held by the top four applicants in each 4-digit IPC patent class (computed by using the entire sample of EPO-Epasis patents in 1993-1997 of inventors located in the surveyed countries)	EPO-Epasis, Who Owns Whom
COMPETITION	Variable equal to 1 if the inventor answered that it was decided to patent the invention as it was, as opposed to developing it further by devoting additional resources, because the invention had to be patented quickly, since its organization was aware of other inventors, research groups or firms that were working on inventions in the same field	PatVal-EU
Controls		
EMPLOYEES	Average number of employees of the applicant of the patent in 1990-1996. Data are consolidated at the level of the parent company.	Amadeus
MISS_EMPLOYEES	Variable equal to 0 if number of employees is not missing; equal to 1 if number of employees is missing.	
R&D INTENSITY	Average R&D intensity (R&D over sales) of the parent of the patent applicant in 1990-1996.	Compustat
MISS_R&D	Variable equal to 0 if R&D intensity is not missing; equal to 1 if R&D intensity is missing.	
N_PATENT/R&D	Number of patents of the applicant (consolidated) in 1993-1997 / R&D expenditures of the parent of the patent applicant in 1990-1996.	EPOline, Compustat
FIXED_ASSET	Average value of the fixed assets of the applicant of the patent in 1990-1996. Data are consolidated at the level of the parent company.	
MISS_FIXED_ASSET	Variable equal to 0 if fixed_asset is not missing; equal to 1 if fixed_asset is missing.	Amadeus
IPC4_D10	Dummy equal to 1 if there are ten or fewer patents in the 4-digit IPC patent class	EPO-Epasis, Who Owns Whom
DE, DK, ES, IT, HU, NL, UK	Dummies for the seven countries (Germany, Denmark, Spain, Italy, Hungary, the Netherlands, UK) where the first inventor of the PatVal patent is located.	EPO-Epasis
AppYear	Six dummies for application years 1993-1998.	EPO-Epasis

Table 2. Descriptive statistics

	Mean	St dev	Min	Max	N
CROSS_LICENSING	1.8	1.44	0	5	6996
Electrical devices, engineering, energy	0.08	0.27	0	1	6996
Audio-visual technology	0.02	0.14	0	1	6996
Telecommunications	0.03	0.18	0	1	6996
Information technology	0.02	0.14	0	1	6996
Semiconductors	0.01	0.09	0	1	6996
Optics	0.02	0.13	0	1	6996
Analysis, measurement, control technology	0.06	0.23	0	1	6996
Medical technology	0.02	0.15	0	1	6996
Organic fine chemistry	0.07	0.25	0	1	6996
Macromolecular chemistry, polymers	0.06	0.23	0	1	6996
Pharmaceuticals, cosmetics	0.02	0.13	0	1	6996
Biotechnology	0.01	0.09	0	1	6996
Materials, metallurgy	0.03	0.17	0	1	6996
Agriculture, food chemistry	0.01	0.12	0	1	6996
Chemical&petrol, basic materials chem.	0.04	0.19	0	1	6996
Chemical engineering	0.03	0.17	0	1	6996
Surface technology, coating	0.02	0.13	0	1	6996
Materials processing, textiles, paper	0.05	0.23	0	1	6996
Thermal processes and apparatus	0.02	0.14	0	1	6996
Environmental technology	0.02	0.13	0	1	6996
Machine tools	0.04	0.18	0	1	6996
Engines, pumps, turbines	0.03	0.18	0	1	6996
Mechanical Elements	0.04	0.2	0	1	6996
Handling, printing	0.08	0.27	0	1	6996
Agricultural&food proc-machin-apparatus	0.02	0.14	0	1	6996
Transport	0.07	0.25	0	1	6996
Nuclear engineering	0	0.06	0	1	6996
Space technology weapons	0	0.07	0	1	6996
Consumer goods and equipment	0.04	0.21	0	1	6996
Civil engineering, building, mining	0.04	0.19	0	1	6996
COMPLEX_TECH	0.40	0.49	0	1	6996
COMPLEX_INDUSTRY	0.25	0.43	0	1	5491
CUMULATIVE_EXT	0.17	0.37	0	1	6996
SHARE_XY_CITATIONS	0.13	0.28	0	1	6996
SHARE_XY_REFERENCES	0.3	0.34	0	1	6996
IPC4_C4	0.34	0.18	0	1	6996
COMPETITION	0.28	0.45	0	1	6996
N_CITATIONS	1.46	2.26	0	40	6996
N_REFERENCES	4.35	2.23	0	17	6996
EMPLOYEES	83982.18	115107.80	1.00	723328.60	5966
R&D_INTENSITY	0.05	0.03	0.00	0.41	3195
FIXED_ASSET	140.24	444.45	0.00	8173.97	3313
N_PATENT/R&D	0.56	9.85	0	274.73	6996
MISS_FIXED_ASSET	0.53	0.5	0	1	6996
MISS_R&D	0.54	0.5	0	1	6996
MISS_EMPLOYEES	0.15	0.35	0	1	6996
IPC4_D10	0.01	0.1	0	1	6996
IT	0.16	0.36	0	1	6996
ES	0.03	0.17	0	1	6996
NL	0.14	0.35	0	1	6996
DK	0.06	0.23	0	1	6996
HU	0	0.05	0	1	6996
UK	0.19	0.39	0	1	6996

Table 3. Correlation among regressors

	COMPLEX_TECH	CUMULATIVE_EXT	SHARE_XY_CITATIONS	SHARE_XY_REFERENCES	log(IPC4_C4)	COMPETITION	log(FIXED_ASSET)	MISS_FIXED_ASSET	log(N_CITATIONS)	log(N_REFERENCES)	IPC4_D10	log(N_PATENT/R&D)	log(R&D_INTENSITY)	MISS_R&D	log(EMPLOYEES)	MISS_EMPLOYEES
COMPLEX_TECH	1.00															
CUMULATIVE_EXT	-0.03*	1.00														
SHARE_XY_CITATIONS	-0.07*	0.03*	1.00													
SHARE_XY_REFERENCES	-0.05*	0.00	0.08*	1.00												
log(IPC4_C4)	0.22*	-0.01	0.03*	-0.03*	1.00											
COMPETITION	0.00	0.06*	0.02	0.04*	0.03*	1.00										
log(FIXED_ASSET)	-0.05*	0.02	0.06*	0.02	0.14*	-0.01	1.00									
MISS_FIXED_ASSET	0.02	-0.02	-0.05*	-0.02	-0.15*	0.00	-0.93*	1.00								
log(N_CITATIONS)	-0.02*	0.03*	0.36*	0.07*	0.06*	0.07*	0.05*	-0.05*	1.00							
log(N_REFERENCES)	-0.05*	0.02	0.03*	0.12*	-0.03*	0.00	-0.05*	0.04*	0.06*	1.00						
IPC4_D10	-0.01	0.00	-0.04*	-0.01	-0.23*	-0.01	-0.03*	0.03*	-0.05*	-0.01	1.00					
log(N_PATENT/R&D)	0.04*	-0.02	0.01	-0.01	0.09*	0.04*	0.15*	-0.19*	0.02	-0.05*	-0.02	1.00				
log(R&D_INTENSITY)	0.13*	-0.06*	0.02	0.01	0.16*	0.03*	-0.03*	-0.01	0.05*	-0.10*	-0.01	0.33*	1.00			
MISS_R&D	-0.05*	0.05*	-0.04*	-0.02	-0.17*	-0.04*	-0.07*	0.13*	-0.06*	0.05*	0.03*	-0.57*	-0.79*	1.00		
log(EMPLOYEES)	0.09*	-0.05*	0.04*	0.00	0.25*	0.01	0.30*	-0.33*	0.07*	-0.08*	-0.04*	0.34*	0.55*	-0.67*	1.00	
MISS_EMPLOYEES	-0.01	0.02	-0.02	-0.01	-0.15*	0.00	-0.37*	0.39*	-0.04*	0.06*	0.03*	-0.22*	-0.30*	0.37*	-0.80*	1

* $p < 0.10$. ** $p < 0.05$. *** $p < 0.01$.

Table 4. Ordered probit models of cross-licensing

	(1)	(2)	(3)	(4)	(5)	(6)
Audio-visual technology		0.54***	0.55***	0.55***	0.51***	0.52***
		(0.13)	(0.13)	(0.13)	(0.13)	(0.13)
Telecommunications		0.61***	0.61***	0.61***	0.59***	0.61***
		(0.15)	(0.15)	(0.15)	(0.15)	(0.15)
Information technology		0.61***	0.61***	0.61***	0.58***	0.60***
		(0.19)	(0.19)	(0.19)	(0.17)	(0.18)
Semiconductors		0.52***	0.52***	0.52***	0.45***	0.45**
		(0.17)	(0.17)	(0.17)	(0.17)	(0.18)
Optics		0.27*	0.28*	0.27*	0.26	0.26
		(0.16)	(0.16)	(0.16)	(0.16)	(0.16)
Analysis, measurement, control technology		-0.16	-0.16	-0.17	-0.11	-0.11
		(0.12)	(0.12)	(0.12)	(0.11)	(0.12)
Medical technology		-0.33**	-0.34**	-0.34**	-0.25*	-0.25*
		(0.15)	(0.15)	(0.15)	(0.15)	(0.15)
Organic fine chemistry		-0.45***	-0.45***	-0.46***	-0.41***	-0.43***
		(0.13)	(0.13)	(0.13)	(0.13)	(0.13)
Macromolecular chemistry, polymers		-0.45***	-0.46***	-0.47***	-0.45***	-0.46***
		(0.13)	(0.13)	(0.13)	(0.13)	(0.13)
Pharmaceuticals, cosmetics		-0.34**	-0.34**	-0.36**	-0.36**	-0.35**
		(0.17)	(0.16)	(0.16)	(0.16)	(0.16)
Biotechnology		-0.46	-0.47	-0.48	-0.40	-0.42
		(0.32)	(0.31)	(0.32)	(0.32)	(0.31)
Materials, metallurgy		-0.37***	-0.38***	-0.38***	-0.36***	-0.36***
		(0.12)	(0.12)	(0.12)	(0.11)	(0.11)
Agriculture, food chemistry		-0.74***	-0.74***	-0.75***	-0.74***	-0.75***
		(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
Chemical&petrol, basic materials chem.		-0.47***	-0.48***	-0.49***	-0.54***	-0.54***
		(0.13)	(0.13)	(0.13)	(0.13)	(0.13)
Chemical engineering		-0.39***	-0.40***	-0.40***	-0.34***	-0.34***
		(0.13)	(0.13)	(0.13)	(0.13)	(0.13)
Surface technology, coating		-0.36**	-0.37**	-0.37**	-0.31**	-0.31**
		(0.15)	(0.15)	(0.15)	(0.14)	(0.14)
Materials processing, textiles, paper		-0.31**	-0.31***	-0.31***	-0.27**	-0.28**
		(0.12)	(0.12)	(0.12)	(0.12)	(0.12)
Thermal processes and apparatus		-0.48***	-0.48***	-0.48***	-0.44***	-0.44***
		(0.14)	(0.14)	(0.14)	(0.14)	(0.14)
Environmental technology		-0.42***	-0.43***	-0.43***	-0.33**	-0.32**
		(0.15)	(0.15)	(0.15)	(0.14)	(0.14)
Machine tools		-0.49***	-0.49***	-0.49***	-0.44***	-0.46***
		(0.13)	(0.13)	(0.13)	(0.13)	(0.13)
Engines, pumps, turbines		-0.25*	-0.25*	-0.26*	-0.28**	-0.30**
		(0.13)	(0.13)	(0.13)	(0.13)	(0.14)
Mechanical Elements		-0.42***	-0.42***	-0.42***	-0.35***	-0.36***
		(0.11)	(0.11)	(0.11)	(0.11)	(0.11)
Handling, printing		-0.38***	-0.39***	-0.39***	-0.32***	-0.33***
		(0.11)	(0.11)	(0.11)	(0.11)	(0.11)
Agricultural&food proc-machin-apparatus		-0.31	-0.31*	-0.31*	-0.29	-0.29
		(0.19)	(0.19)	(0.19)	(0.19)	(0.19)
Transport		-0.25**	-0.25**	-0.26**	-0.25**	-0.27**
		(0.12)	(0.12)	(0.12)	(0.12)	(0.12)
Nuclear engineering		-0.46**	-0.46**	-0.46**	-0.55**	-0.55**
		(0.23)	(0.23)	(0.23)	(0.23)	(0.24)
Space technology weapons		-0.53***	-0.54***	-0.53***	-0.59***	-0.64***
		(0.19)	(0.19)	(0.19)	(0.19)	(0.18)
Consumer goods and equipment		-0.38***	-0.38***	-0.38***	-0.37***	-0.37***
		(0.13)	(0.13)	(0.13)	(0.13)	(0.13)

Table 4. (continued)

	(1)	(2)	(3)	(4)	(5)	(6)
Civil engineering, building, mining		-0.56***	-0.57***	-0.57***	-0.50***	-0.50***
		(0.12)	(0.12)	(0.12)	(0.12)	(0.12)
CUMULATIVE_EXT			0.09**	0.09**	0.09**	0.08**
			(0.04)	(0.04)	(0.04)	(0.04)
SHARE_XY_CITATIONS				0.01	0.01	0.02
				(0.05)	(0.05)	(0.05)
SHARE_XY_REFERENCES				0.07*	0.08*	0.07*
				(0.04)	(0.04)	(0.04)
log(IPC4_C4)					0.60***	0.58***
					(0.17)	(0.17)
COMPETITION						0.22***
						(0.03)
log(FIXED_ASSET)	0.07**	0.08***	0.08***	0.08***	0.08***	0.08***
	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
MISS_FIXED_ASSET	0.16	0.22**	0.22**	0.22**	0.22**	0.22**
	(0.13)	(0.10)	(0.10)	(0.10)	(0.10)	(0.10)
log(N_CITATIONS)	0.11***	0.12***	0.12***	0.12***	0.12***	0.10***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
log(N_REFERENCES)	-0.10***	-0.03	-0.03	-0.03	-0.03	-0.03
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
IPC4_D10	-0.25**	-0.12	-0.12	-0.12	0.06	0.06
	(0.11)	(0.11)	(0.11)	(0.11)	(0.12)	(0.12)
log(N_PATENT/R&D)	0.13	0.08	0.08	0.08	0.08	0.08
	(0.17)	(0.13)	(0.13)	(0.14)	(0.13)	(0.13)
log(R&D INTENSITY)	4.40***	1.97*	1.99*	1.98*	1.96*	1.92*
	(1.62)	(1.11)	(1.12)	(1.12)	(1.12)	(1.14)
MISS_R&D	0.38***	0.15	0.15	0.15	0.15	0.15
	(0.14)	(0.10)	(0.10)	(0.10)	(0.10)	(0.10)
log(EMPLOYEES)	0.09***	0.06***	0.06***	0.06***	0.06***	0.06***
	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
MISS_EMPLOYEES	0.61***	0.40***	0.40***	0.40***	0.39***	0.39***
	(0.13)	(0.10)	(0.10)	(0.10)	(0.10)	(0.10)
DE	-0.13**	-0.03	-0.02	-0.01	-0.01	0.03
	(0.06)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)
IT	-0.62***	-0.62***	-0.61***	-0.61***	-0.61***	-0.58***
	(0.12)	(0.09)	(0.09)	(0.09)	(0.08)	(0.08)
ES	-0.23**	-0.15	-0.15	-0.14	-0.13	-0.11
	(0.10)	(0.10)	(0.10)	(0.10)	(0.10)	(0.10)
NL	-0.49**	-0.54***	-0.53***	-0.52***	-0.52***	-0.52***
	(0.24)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
DK	-0.38***	-0.29***	-0.29***	-0.29***	-0.28***	-0.28***
	(0.11)	(0.10)	(0.10)	(0.10)	(0.10)	(0.10)
HU	-0.63*	-0.46	-0.44	-0.43	-0.44	-0.39
	(0.36)	(0.35)	(0.35)	(0.35)	(0.35)	(0.35)
AppYears	Yes	Yes	Yes	Yes	Yes	Yes
N	6996	6996	6996	6996	6996	6996
Ll	-46999.65	-45871.61	-45856.45	-45848.24	-45796.16	-45668.66
chi2	272.50	926.09	947.3	948.92	961.96	1014.05

Robust standard errors in parenthesis adjusted for clusters by firms' identifier. * $p < 0.10$. ** $p < 0.05$. *** $p < 0.01$.
Baseline for technological class dummies: Electrical devices, electrical engineering, electrical energy.