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DETERMINANTS OF THE ECONOMIC USE OF PATENTED INVENTIONS: AN ANALYSIS OF EUROPEAN PATENTS

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ABSTRACT

The purpose of this research is to provide empirical evidence on determinants of the economic use of patented inventions in order to contribute to the literature on technology and innovation management. The current work consists of three main parts, each of which constitutes a self-consistent research paper. The first paper uses a meta-analytic approach to review and synthesize the existing body of empirical research on the determinants of technology licensing. The second paper investigates the factors affecting the choice between the following alternative economic uses of patented inventions: pure internal use, pure licensing, and mixed use. Finally, the third paper explores the least studied option of the economic use of patented inventions, namely, the sale of patent rights. The data to empirically test the hypotheses come from a large-scale survey of European Patent inventors resident in 21 European countries, Japan, and US. The findings provided in this dissertation contribute to a better understanding of the economic use of patented inventions by expanding the limits of previous research in several different dimensions.

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ABBREVIATIONS

EP	European Patent
EPC	European Patent Convention
EPO	European Patent Office
EPR	European Patent Register
ICT	Information and Communication Technology
IP	Intellectual Property
IPC	International Patent Classification
IPR	Intellectual Property Right
MPEP	The Manual of Patent Examining Procedure, UPSTO
NBER	The National Bureau of Economic Research
NBO	Non-business organization
NPE	Non-practicing entity
NPR	National Patent Register
PCT	Patent Cooperation Treaty
SIC	Standard Industrial Classification
SSRN	Social Science Research Network
USPTO	United States Patent and Trademark Office

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CHAPTER 1

INTRODUCTION

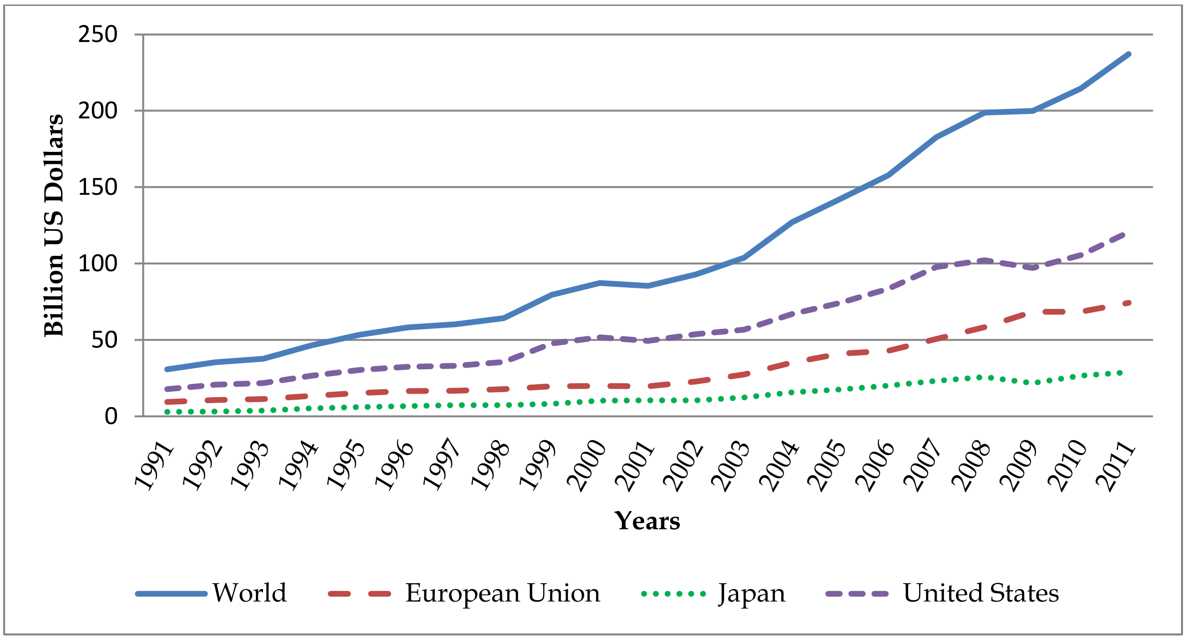
Economic use of patented inventions: patent licensing and sale

Last decades were characterized by an increasing awareness for the importance of intellectual property rights (IPR) and knowledge-based technologies. The number of business and scientific publications in this area has been steadily growing since the 1990's. The literature has been emphasizing the importance of protecting and profitably exploiting available technologies (Rivette & Kline, 2000b). During the same time, the development of the markets for technology has increased a variety of arrangements for the use and exchange of technologies (Arora, Fosfuri, & Gambardella, 2001b).

One of these technology transfer arrangements, namely, technology licensing, deserves a particular attention and can contribute to a better understanding of the markets for technology. According to a definition provided by the United States Patent and Trademark Office (USPTO), a license is a contractual agreement that the patent owner will not sue the licensee for patent infringement if the licensee makes, uses, offers for sale, sells, or imports the technology, as long as the licensee fulfills its obligations and operates within the limits specified by the license agreement (USPTO, 2012). Licensing payments usually consist of lump-sum up-front fee and running royalty payments, which usually depend on the volume of output (or on sales) (Rockett, 1990a). The licensing of a technology transfers a bundle of rights which is less than the entire ownership interest, e.g. rights may be limited as to time, geographical area, or field of use (USPTO, 2012). The patent owner may also grant an exclusive license that prevents the patent owner or other parties from competing with the exclusive licensee, as to the geographic region, the length of time, and/or the field of use, according to the license agreement.

The managerial and technological literature has long recognized the importance of licensing for the transfer of technologies (Gallini, 1984; Rockett, 1990b; Shephard, 1987; Teece, 1986). Anand & Khanna (2000) describe licensing as one of only a few significant methods of technology transfer, and one of the most commonly observed inter-firm contractual agreements. The available empirical evidence also supports the importance of technology licensing. For instance, Arora et al. (2001b) calculated that over 15,000 technology transactions involving licensing rights with a total value of over 320 billion dollars took place worldwide in the period of 1985-1995. According to the World Bank reports, receipts from royalty and licensing fees (including patents, copyrights, and trademarks) have soared from $30.8 billion in 1991 to $237.2 billion in 2011, with more than 94% of these receipts going to the following three major OECD regions: the European Union, Japan, and US (World Bank, 2012).[1] Figure 1.1 clearly shows that the tendency toward increasing licensing revenues is common for all three regions.

FIGURE 1.1 Revenues from licenses for patents, copyright, trademarks and similar IPRs in the World, Europe, Japan and US between 1991 and 2011



Source: World Development Indicators, World Bank

[1] OECD data do not take into account inflation during this time span.

Another technology transfer mechanism between economic entities is a sale of intellectual property rights for a patented invention. Unlike licensing arrangement, the sale of patent rights implies a transfer by initial patent owner to another economic or legal entity the entirety of the bundle of rights, title, and interest in a patent (USPTO, 2012). In the case if the bundle of rights transferred is less than the entire ownership interests, such technology transfer is considered as a patent license. Hereafter, in this dissertation we clearly differentiate between patent licensing and patent sale and consider them as two distinct technology transfer arrangements and study them separately.

In contrast to patent licensing, the management literature has largely overlooked the patent sale component of the markets for technology. Recently, few scholars attempted to fill up this gap by collecting novel data and developing theories that could explain factors affecting the patent sale decision by individuals and firms (Galasso, Schankerman, & Serrano, 2011; Serrano, 2006, 2010). For instance, using a pooling of all US patents granted from 1983 to 2001, Serrano (2010) shows that 13.5% of all granted patents were sold at least once over their lifetime. This evidence suggests that the markets for patents are substantial and deserve more attention by the scholarly community.

Interestingly, despite the recent increased interest to the topic, patent licensing and sale are not novel phenomena. As described by Lamoreaux & Sokoloff (1999, 2001, 2007), organized markets for technology existed in the late nineteenth and early twentieth centuries. However, starting from the beginning of the twentieth century, many firms started to internalize their inventive activity and for most of the twentieth century have followed so called "closed innovation paradigm" (Chesbrough, 2003). Mowery (1983) in his study of the rise of the corporate R&D laboratory in American manufacturing attributed this tendency to a relative cost advantage of organizing innovation within the firm boundaries instead of acquiring technology through market based arrangements. According to Mowery (2012), the development of in-house R&D laboratories within US firms resembled other tendencies within modern corporations in replacing market-based mechanisms with administrative control within the firm. Thus, throughout the twentieth century firms relied on their internal R&D capabilities and avoided an extensive use of the markets for technology to acquire outside technologies or to license and sell their own.

However, as argued by Chesbrough (2003), by the end of the twentieth century the knowledge environment has changed. Under new conditions, it became clear that the integration of technology creation and exploitation within a single firm is not always a superior source of economic performance. Instead, firms started to realize that they could benefit from the use of outside technologies or appropriate rents from their own technologies by licensing or selling them in the markets for technology (Arora et al., 2001b). In their seminal paper, Rivette and Kline (2000b, p. 56) have suggested managers to "unlock the hidden power of patents" by properly deploying firm's patent portfolio and considering the market opportunities.

The presence of markets for technology enables to appropriate innovative rents alternative to internal use. At the same time, the use of markets for technology may enhance both economic growth and social welfare in several ways. First, as noted by Arora et al. (2001b), the markets for technology allow for specialization and division of innovative labor. Patent licensing or sale may be optimal solutions for small technology-based firms that lack downstream manufacturing, distribution and marketing capabilities (Fosfuri, 2006). Second, technology markets may decrease duplicative R&D and enhance the rate of technological development by better diffusing information about already existing technologies. Third, market based arrangements can be perceived as an additional option to generate revenues from unused technologies, for which internal use options were not identified or unfeasible (Rivette & Kline, 2000b). Therefore, the markets for technology may produce benefits associated with a better utilization of valuable technologies that otherwise would remain underutilized by their owners. Finally, as highlighted by Serrano (2006), the existence of technology markets allows for surplus-enhancing transfers of patent rights, where the alternative owner has greater valuation for a patent than the current owner.

However, the markets for technology are subject to inefficiencies and imperfections caused by a number of reasons, which can be either due to supply side problems, demand side problems or both. Moreover, some imperfections can be structural in nature, whereas others can be artificially created by market participants. These inefficiencies and imperfections limit the growth of the markets for technology by precluding some potential transactions, requiring long and complicated bargaining procedures, and discouraging technology specialization and division of innovative labor (e.g. Arora et al., 2001b). Hereafter, we provide a review of the reasons for these inefficiencies and imperfections in the markets for technology.

One source of inefficiency in the markets for technology is inherent in the very nature of technological knowledge. The first obstacle is associated to a paradox highlighted by Kenneth Arrow (1962). A potential buyer is able to evaluate a technology only if a seller discloses sufficient information about the invention, however, when the seller reveals the information the buyer partly acquires it without paying for it (Arrow, 1962). In theory, by defining property rights for technology, patents provide a way for technology owners to disclose information while preventing its unauthorized use, which should also reduce the challenges of assessing the value of invention highlighted by Arrow (1962). However, the evidence suggests that patents do not work in practice as they do in theory (Levin, Klevorick, Nelson, & Winter, 1987). Although patents afford considerable protection for inventions in some industries, in others they do not confer perfect appropriability and can be "invented around" at modest costs (Teece, 1986).

Another characteristic of technological knowledge that hampers its transfer in the markets for technology is its tacitness (Polanyi, 1966; Winter, 1987). Technological knowledge, as any other forms of knowledge, has both codifiable and tacit components. While the codified knowledge about an invention is relatively easy to transfer through patent documents, blueprints, and other documents, the tacit knowledge is more difficult to communicate and costly to transfer to other parties. As Polanyi (1966, p. 136) puts it in his seminal work, "we can know more than we can tell". Teece (1988b) also points out that the production of technology is a cumulative process based on tacit knowledge, which is organizationally embedded and difficult to transfer. It is necessary to note that, as recognized by Winter (1987), the levels of tacit and codified components are not inherent properties of knowledge, and the extent to which knowledge is codified and, therefore, easy to transfer is a result of an economic decision. Thus, technology suppliers can codify and "unstick" knowledge to facilitate its transfer across firm boundaries (Arora & Gambardella, 1994a; von Hippel, 1994). However, the codification of tacit knowledge comes at certain costs and has its limits.

Asymmetric information has long been identified as one of the main reasons for inefficiencies in technology markets and a barrier for technology transfer in general (Gallini & Wright, 1990). For instance, a patent seller that has better information about the potential value of technology by knowing detailed characteristics of the invention and areas of its possible application may set a relatively high reservation price (i.e. the minimum price at which the seller is willing to sell the patent). However, if potential buyers are unable to ascertain the future value of the technology, they will fear the "lemons problem" (Akerlof, 1970) and will refrain from paying that high reservation price for the technology. Moreover, similarly to Akerlof's (1970) conclusion that owners of good cars will not place their cars on the used car market, potential buyers that are unable to directly assess the value of the technology may consider that good patents are not offered for licensing or sale, and, thus, avoid participating in the markets for technology. As a consequence, the asymmetric information may cause an adverse selection problem which may bring down the overall quality of patents offered for licensing and sale.

While asymmetric information is definitely important, uncertainty about the value of the technology is another relevant problem impeding technology transfer and trade. As noted by Arora & Gambardella (2010), uncertainty about technical success and commercial applicability can be more serious problem than asymmetric information. Uncertainty does not necessarily involve information asymmetry, i.e. both parties may symmetrically lack information about the true value of the technology. When both the seller and the potential buyer of the invention are uncertain about its future value patent transaction can be jeopardized because the seller will try to overprice to avoid underpayment while the buyer will try to underbid to avoid the "winner's curse" (Kagel & Levin, 2002).

Drawing on the concepts and principles developed by Roth (2007), Gans & Stern (2010) argue that technology markets are characterized by a lack of thickness, which means that there are few participants at both supply and demand sides that makes matching difficult and causes market inefficiency. Moreover, the lack of thickness creates conditions of *monopoly, monopsony* (i.e. market with a single buyer and many sellers), or *bilateral monopoly*, situation when there is only one seller and one potential buyer without any possibility of competition among potential sellers or among potential buyers (Gans & Stern, 2010). Such conditions result in a difficulty of setting efficient equilibrium price and complicated strategic bargaining and negotiations.

Another reason for inefficiency in the markets for technology noted by Gans & Stern (2010) is a high congestion defined as a situation when conditions of potential trades require that trades are completed without assessing and adequately comparing alternative options (Roth, 2007). Rather than having information about all potentially interesting technologies that are currently available or will be soon available in the market, the buyer usually has information about a particular technology and has to make a strategic decision whether to buy it or forego it in order to look or wait for other alternatives, which at the end may or may not appear.

Technology markets can also be characterized by a lack of market safety, when parties have incentives for a misrepresentation or strategic action in order to undermine others' ability to evaluate a potential transaction (Gans & Stern, 2010; Roth, 2007). Since in the markets for technology information about the other party can be strategically exploited during a bargaining process, parties will try to strategically disclose information about their true preferences (e.g. the highest price the buyer is willing to pay for the technology) or their type (e.g. willingness of the buyer to use the technology to compete with the seller). For instance, under conditions of asymmetric information the party that has superior information about the potential value of the technology may act opportunistically during the bargaining process in an attempt to capture as much value as possible. Therefore, the lack of market safety may jeopardize the efficiency of technology markets and discourage firms from participating.

In order to participate in the markets for technology, the potential buyer should be willing and able to evaluate and utilize the technology that it may license or purchase. Ability to evaluate and utilize acquired technologies requires in-house technological expertise (Arora & Gambardella, 1994b; Cohen & Levinthal, 1990). Ability and willingness to use external technologies may also depend on existing organizational structure, norms, and culture. Some firms tend to favor only internally developed technologies and completely disregard external technology options despite their potential superiority. This tendency is known as a "not invented here" syndrome (Katz & Allen, 1982). Firms suffering from such syndrome may ignore or underestimate the value of external technologies offered in the market and, therefore, waive or limit their participation in the markets for technology. However, as noted by Arora et al. (2001a), technology markets may increase the penalty for the "not invented here" syndrome because these firms may indulge in a duplicative activity and end up "reinventing the wheel". Nevertheless, the "not invented here" syndrome may cause an underexploitation of opportunities offered by the markets for technology.

Technologies are very heterogeneous commodities. Therefore, they are difficult to compare one with another in order to set a market price or to have some benchmark to estimate their value. Depending on the level of heterogeneity of technologies, the problem is sounder for some industries such as telecommunication or electronics and less an issue for other industries such as pharmaceuticals. As noted by Gambardella & Torrisi (2010b) in their study of barriers to licensing, in pharmaceuticals and biotech sectors firms may try to acquire information on similar market transactions to find market benchmark. Yanagisawa & Guellec (2009) also argue that establishing a shared understanding of reasonable market price for a patent based on past similar transactions would be important to facilitate patent transactions. However, it is often very difficult for market participants to obtain comparative data to make an informed decision about appropriate price for a patent because most transactions related to patent licensing and sale have traditionally been conducted confidentially (Yanagisawa & Guellec, 2009). However, even if the information on previous transactions were available, it often would not very useful because technologies are not easily comparable one with another. Arora & Gambardella (2001b) argue that the problem of heterogeneity of technologies could be removed naturally by intensive trading, which would allow to more precisely estimate the market value of the technology from previous experience and performance of similar technologies.

All these reasons discussed above create inefficiencies and imperfections in the markets for technology. They increase the cost of use of the markets and exclude from participation firms that otherwise would be willing to trade (Gambardella & Torrisi, 2010b). As a consequence, business and society are unable to fully enjoy the economic and social benefits offered by the use of technology markets.

The literature in the field of technology and innovation management has been studying the factors and determinants that facilitate and prevent technology transfer in the markets for technology. However, as we will demonstrate and discuss in this dissertation, there are several important issues that were not well covered and studied in the literature. Therefore, by addressing some of this research questions we intend to contribute to this stream of literature in order to better understand the functioning of the markets for technology.

Description of data

There are various ways to protect an invention from imitation. These mechanisms include the use of patents, lead time advantage, trade secrecy, and use of complementary marketing and manufacturing capabilities (Cohen, Nelson, & Walsh, 2000). The preference of one method or another depends on characteristics of the industry and the technology requiring protection. For instance, trade secrets can be viable only if the product can be sold while underlying technology remains secret (Teece, 1986). Therefore, patents represent one of several alternative options available to a firm to protect its invention from imitation.

Although not all inventions are patented, and, therefore, patent data provide imperfect coverage of inventive activity, we choose patented inventions as a unit of our empirical analysis for the following reasons. First, although technology licensing is possible even without patenting (Anton & Yao, 1994; Arora, 1996), available evidence suggests that firms that do not patent rarely license; and the empirical importance of the alternative mechanisms remains unknown (Arora & Ceccagnoli, 2006). Second, since the patent data provide relatively extensive information about an invention in a highly standardized way it allows collecting and analyzing data for each invention using automated procedures that are easily comparable across inventions, which is particularly valuable for an empirical analysis with a large number of observations. Rivette & Kline (2000b), for instance, describe patent databases as "a virtual Alexandrian library of information". Collecting the equivalent data for a large number of unpatented inventions is a difficult and impractical task. Third, previous studies based on patent data have developed a number of generally accepted indicators affecting the economic use of patented inventions. Thus, the use of patent data in our studies allows using similar indicators and comparing our findings with earlier empirical works.

The data to empirically test our hypotheses come from a large scale European Patent inventor survey developed and conducted within the InnoS&T project (Gambardella et al., 2012). The survey collects cross-sectional data on a number of issues related to the invention process, its determinants, the value of the invention, and its economic use. The dataset has been constructed by combining initial invention level survey data with additional firm and industry level information from Amadeus, EPOSYS, Orbis, Osiris, PATSTAT databases.

The self-administered survey of inventors is global in scope and covers patented inventions from 21 European countries, Japan, and US. The sample was drawn at the level of patent applications with priority years between 2003 and 2005. The final composition of the sample is the following: Europe – 62,148 observations, US – 45,861, and Japan – 16,125. After sampling the patents, one inventor listed on the patent document was randomly chosen and was sent an invitation letter to participate in the survey. The letter asked the inventors to fill out an online questionnaire on a website that they can access through an identification number and a password, generated for the specific inventor. The number of responses for the survey by the inventors in all surveyed countries is equal to 23,044, which corresponds to a corrected response rate of 20%.

For our analysis, we use a part of the survey that contains only patented inventions owned by private for-profit firms. The patented inventions that belong to individuals and non-profit organizations are excluded from the analysis. The exclusion of non-profit organizations such as universities and research institutes is justified by the fact that these organizations have entirely different institutional settings and different motivations for the use and transfer of their patented inventions. For instance, due to the lack of necessary complementary assets, universities tend to specialize in the creation of knowledge assets, the commercialization of which is usually left to other organizations.

Structure of the dissertation and summary of studies

The core of the dissertation is constituted by three self-consistent studies: meta-analysis on technology licensing and two empirical papers addressing different aspects of the economic use of patented inventions. The overarching research question of the dissertation is: *What factors determine the likelihood of various economic uses of patented inventions?* Throughout the dissertation the following sub-questions are posed:

1. *What factors affect a firm's decision to license its technologies? What are the patterns of relationships between these determinants and technology licensing? Is there a consistency between theoretical predictions and empirical findings?*

2. What determines the choice between pure internal use, pure licensing, and mixed use of patented inventions? Are there any interaction or moderation effects between explanatory factors?

3. What factors determine the likelihood that a patented invention is sold? What are the characteristics of patent sellers in the markets for patents?

As follows from the research questions above, although three studies included in the dissertation are self-consistent, they are closely interrelated to each other and cover different aspects of the overall research question. By systematically reviewing the literature on technology licensing, the meta-analysis paper provides a theoretical background and serves as a benchmark for other two papers. For instance, many explanatory factors identified and discussed in the first paper are also used in the subsequent empirical papers. Moreover, following the results and suggestions given in the meta-analysis, in the second paper we identify non-linear relationships, and consider a moderation effect of the presence of complementary assets on other key explanatory variables. The second paper extends the scope of the empirical papers considered in the meta-analysis by studying alternative economic uses of patented inventions such as pure internal use, pure licensing, and mixed use (i.e. a combination of internal use and licensing). Finally, the third paper complements earlier studies and focuses on the issue of patent sale, which is another relevant method of externally exploiting patented inventions through market-based mechanisms. Therefore, the three papers presented and described below can be considered as integral components of a wider research agenda.

The first paper uses a meta-analytic approach to review and synthesize the existing body of empirical research on determinants of technology licensing. Meta-analysis integrates findings across studies to reveal patterns of relationships that underlie research literature, thus, allowing to test the consistency of previous empirical findings and to provide a basis for further theory development. The paper systematically reviews and classifies various factors that, according to the literature, affect a likelihood of technology licensing. Our analysis reveals that a significant share of empirical findings is inconclusive not only in terms of magnitude and relative importance, but also in terms of the direction of relationships between technology licensing and its determinants. For instance, out of 13 relationships reviewed in the meta-analysis only 7 found full or partial support for their hypotheses. Results for remaining relationships either disconfirmed the generalizability of theoretical predictions or partially supported alternative hypotheses, e.g. hypotheses suggesting a non-linear relationship between dependent and independent constructs. The overall evidence provided by the meta-analysis calls for reconsidering and fine-tuning some of the existing theoretical arguments and their propositions. More specifically, the analysis suggests considering non-linear relationships between dependent and independent variables, examining possible interaction and moderation effects, and collecting more comprehensive data that use more persuasive and less ambiguous proxies to measure theoretical constructs.

The second paper investigates factors affecting the choice between the following alternative economic uses of patented inventions: pure internal use, pure licensing, and mixed use (both internal use and licensing). In this study, we contribute to the literature on technology and innovation management in several ways. First, a descriptive analysis presented in the study provides an overview of the alternative economic uses of patented inventions that may have valuable research implications. For instance, our data reveals that even licensed patents are often exploited internally; and this mixed use is actually 2.7 times more frequent than pure licensing. Second, we compare the determinants of alternative uses of patented inventions. The main explanatory factors are the presence and type of complementary assets, technological competition, distance, and generality of patented inventions. These key explanatory variables, by and large, have the expected association with patent internal use, pure licensing and mixed use. Third, we adopt a multidimensional view on complementary assets necessary to turn an invention into a success (technological, commercial and both) and explore their role in detail. We find that various types of complementary assets are differently associated with the economic use of patented inventions. In particular, organization-specific complementary assets are relevant only for pure internal use and absolutely irrelevant for pure licensing and mixed use. Moreover, our findings indicate that the presence of complementary assets has a strong moderating influence on different key explanatory factors. For instance, we find that technological competition facilitates technology licensing only if the patent owner does not possess in-house necessary complementary assets.

Finally, the third paper explores the least studied option of the economic use of patented inventions, namely, the sale of patent rights. Existing literature on the markets for technology has primarily focused on patent licensing and largely overlooked an aspect of patent sale. Recently, few scholars attempted to fill up this gap by developing theories that could explain factors affecting the patent sale. The current paper aims at contributing to this novel stream of research. We provide theoretical reasoning and empirical tests for a number of patent, firm, and industry level factors that may affect the likelihood that a patent is sold in the markets for technology. Most notably, our empirical findings suggest that the effectiveness of patent protection, presence of complementary assets, and technological fit are negatively associated with the likelihood of patent sale; whereas the scientific nature of the invention (i.e. substantial reliance on scientific publications) is positively associated with the likelihood of patent sale. We also find that, compared to European firms, US firms are more likely to sell their inventions, while Japanese firms are less likely to do that. We believe that empirical findings provided in this study will enhance our knowledge about patent sale and foster future research in this field.

CHAPTER 2

THE DETERMINANTS OF TECHNOLOGY LICENSING:
A META-ANALYTIC REVIEW

ABSTRACT

Technology licensing as one of the most significant methods of technology transfer between both start-up and established firms has been growing rapidly during the last two decades. Increasing number of scientific research in the field of technology and innovation management has been studying factors and determinants that facilitate and prevent licensing behavior of firms. However, the empirical findings in terms of the magnitude and the relative importance of different factors are inconclusive. The meta-analytic approach allows us to review and synthesize the existing body of empirical research in order to investigate the determinants of technology licensing. The current paper contributes to a better understanding of technology licensing that, in turn, can enhance our knowledge about the functioning of the markets for technology. The paper also builds a theoretical background for our next two studies presented in the dissertation.

2.1. INTRODUCTION

By the end of the twentieth century, it became clear that the earlier vision suggesting the integration of technology creation and technology use within a single firm as a superior source of economic performance compared to other arrangements that involve an exchange of technologies between firms is not always adequate. The existence of the markets for technology can enhance both economic growth and social welfare at least in three respects. First, by decreasing duplicative R&D they can better allocate existing resources for technological innovations. Second, by better diffusing the information about already existing technologies they can enhance the rate of technological development. Third, the markets for technology can produce benefits associated with a better utilization of valuable technologies that otherwise remain underutilized by their owners.

Over the past several decades, there has been an increase in a variety of arrangements for the exchange of technologies or technological services, ranging from R&D joint ventures and partnerships, to licensing agreements, to contracted R&D (Arora et al., 2001b). One of these technology transfer arrangements, namely, technology licensing, deserves a particular attention and can contribute to our understanding of the markets for technology. The managerial and technological literature have long recognized the importance of licensing for the transfer of technologies (Gallini, 1984; Rockett, 1990a; Shephard, 1987; Teece, 1986). Anand & Khanna (2000) describe it as one of only a few significant methods of technology transfer, and one of the most commonly observed inter-firm contractual agreements. The available empirical evidence also supports this view. For instance, Arora et al. (2001b) calculate that over 15,000 technology transactions involving licensing rights with a total value of over 320 billion dollars took place worldwide in the period of 1985-1995. According to the World Bank reports, receipts from royalty and licensing fees (including patents, copyrights, and trademarks) have soared from $30.8 billion in 1991 to $237.2 billion in 2011 (World Bank, 2012). Since the literature and the evidence suggest that technology licensing has been one of the most significant methods of technology transfer between firms during the last several decades, we would like to focus this meta-analytic review on determinants of technology licensing in order to contribute to our understanding of antecedents of effective markets for technology.

Although theoretical literature has been considerably interested in rationales for technology licensing at least since late 1980's, empirical studies on technology licensing are relatively scarce and recent. One of the reasons for such scarcity of empirical studies is limited availability of comprehensive data that could allow to empirically test theoretical propositions. There are no formal requirements to systematically report licensing agreements, and many transactions related to technology licensing have traditionally been conducted confidentially (Yanagisawa & Guellec, 2009). Nevertheless, we think that currently available empirical research is sufficient to attempt to review determinants of technology licensing using a meta-analytic approach in order to draw some valuable conclusions.

The existing body of theoretical literature suggests that firm's decision to license a technology is mainly affected by an interplay of two effects: a revenue effect and a rent dissipation effect (Arora et al., 2001b). The revenue effect is driven by the flow of licensing payments by the licensee. The rent dissipation effect is caused by erosion of profits in licensor's product market due to additional competition coming from the licensee (Arora & Fosfuri, 2003; Fosfuri, 2006). Prior research proposes a long list of determinants that influence the licensing decision either directly or through the revenue and profit dissipation effects. These determinants can be grouped into industry level (e.g. the effectiveness of patent protection, technological competition), firm level (e.g. the presence of complementary assets, R&D intensity), and technology level determinants (e.g. the technological fit, value of technology). Recent empirical studies on licensing have attempted to utilize different measures in order to capture these constructs and empirically test the existing theoretical hypotheses. However, even precursory look at the empirical findings reveal that they are inconclusive not only in terms of magnitude and relative importance, but sometimes in terms of the direction of relationships. Therefore, there is a need for a systematic effort to identify and analyze the full set of factors that determine technology licensing.

Considering the above, the main research questions to be addressed using the meta-analytic approach are: *What factors affect a firm's decision to license its technologies? What are the patterns of relationships between these determinants and technology licensing? Is there a consistency between theoretical predictions and empirical findings?*

The goal of any science is to cumulate knowledge. Meta-analysis integrates findings across studies to reveal patterns of relationships that underlie research literature and, thus, provides a basis for further theory development. Moreover, meta-analysis can correct for some artifacts such as sampling error and measurement error that produce the illusion of conflicting results (Hunter & Schmidt, 2004). The meta-analytic approach can also be considered as a form of survey research in which research results, rather than individuals, are surveyed (Lipsey & Wilson, 2001). Meta-analysis allows comparing or combining the results of empirical studies by employing either effect size or significance level (Hunter, Schmidt, & Jackson, 1982). Since for the studies selected for our meta-analysis it was problematic to estimate, compare and combine effect sizes, we focused our analysis on the directionality and significance of the effects rather than on their magnitude (Sobrero & Schrader, 1998).

The aim of the current paper is to review and analyze the consistency of empirical findings in terms of direction of the relationships between the firm's licensing decision and its various determinants. We also try to understand the reasons for existing inconsistencies. We argue that these inconsistencies may partly stem from the interaction and moderating effects between various key factors, the presence of non-linear relationships, or the use of different proxies to measure theoretical constructs. Most of these issues are not fully addressed in the licensing literature and constitute an area for further research that could help to resolve some of these inconsistencies.

The rest of the paper is organized as follows. The next section reviews the theoretical literature on determinants of technology licensing and proposes several hypotheses. The third section describes procedures for search and selection of studies, meta-analytic method, and data coding technique. The fourth section reports the results of our meta-analysis, while the last section discusses and concludes.

2.2. THEORY AND HYPOTHESES

2.2.1. Technology licensing and its measures

As described in the previous section, technology licensing has long been considered as one of the most significant methods of technology transfer between firms during the last several decades. Although theoretical literature has long been considerably interested in rationales for technology licensing, empirical studies on technology licensing are relatively scarce and recent. This scarcity of empirical studies is partly caused by limited availability of comprehensive data that could allow to empirically test theoretical propositions about technology licensing. In many countries, there are no legal requirements for firms to systematically report their licensing agreements. Therefore, data on licensing agreements need to be collected either by using various survey questionnaires and interviews (e.g. Carnegie Mellon survey by Cohen et al., 2000) or by collecting and analyzing information from financial documents and press publications in the media (e.g. Thomson Financial's SDC Platinum database).

In order to systematically review factors that affect technology licensing described in the empirical studies, there is a need to differentiate between two theoretical constructs of our dependent variable. As suggested by Gambardella et al. (2007), it is necessary to disentangle the willingness to license and actual technology licensing because there is a fair share of patents are not licensed despite the owner's willingness to license them. Therefore, in our study we will account for the difference between these two dependent variable constructs.

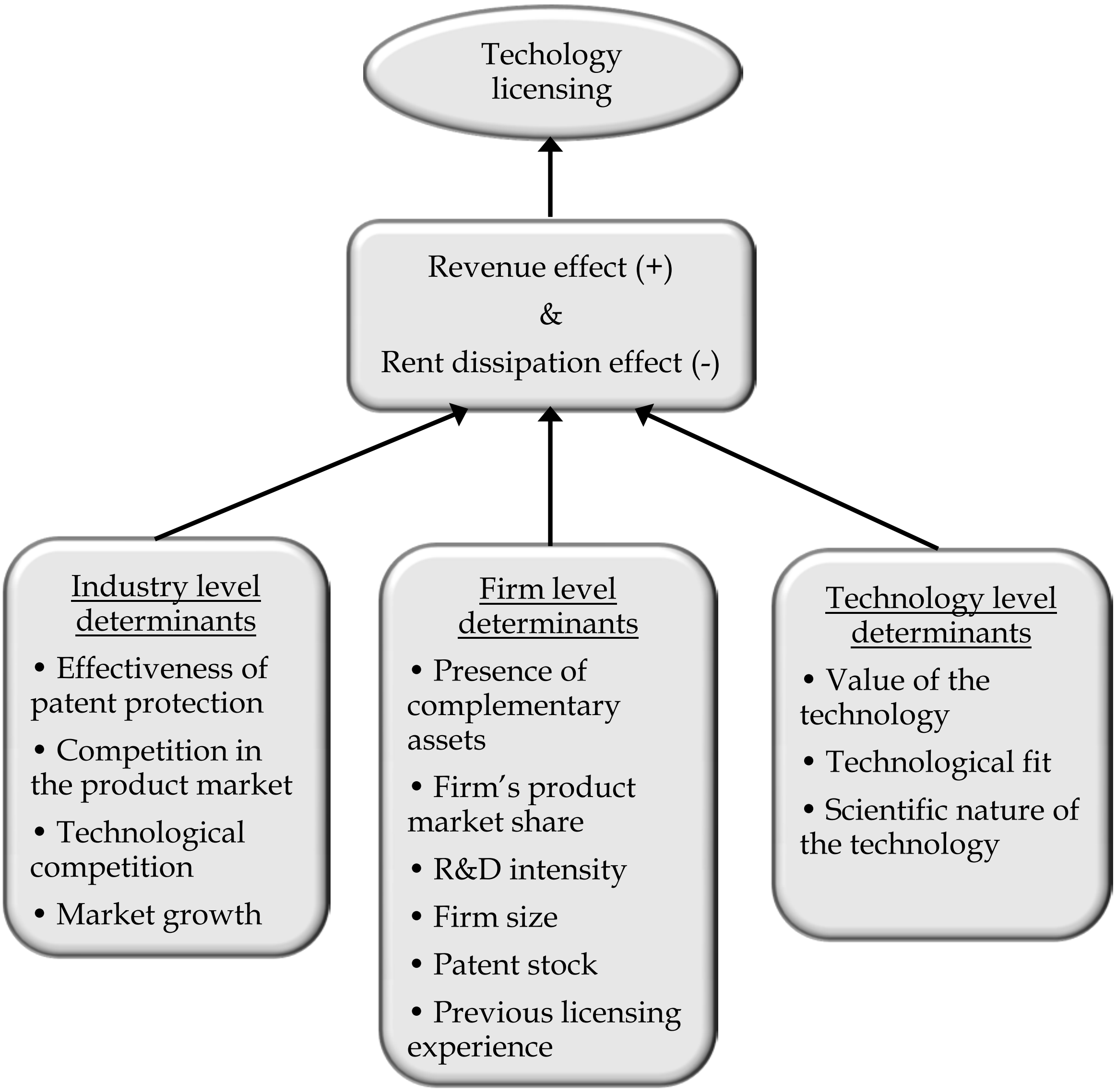
There are various measures of technology licensing used in the reviewed empirical studies. Some studies that use a survey method measure technology licensing by asking respondents whether the patented invention was licensed or owner wanted to license it (Gambardella, Giuri, & Luzzi, 2007). Other studies, using various databases on firm characteristics and licensing agreements, distinguish between licensing and non-licensing firms (Ceccagnoli & Hicks, 2009; Kim, 2005; Novelli, Padula, & Rao, 2007). Another set of studies considers the number of licensed technologies (Kim & Vonortas, 2006) or the percentage of licensed technologies (Arora & Ceccagnoli, 2006) by a firm as the dependent variable in their studies. Finally, some studies operationalize the dependent variable as a ratio of out-licensed patents to the total number of patents owned (Motohashi, 2008).

2.2.2. Determinants of technology licensing

The literature suggests that a firm's decision to license a technology is mainly affected by the interplay of two effects: the revenue effect and the rent dissipation effect (Arora et al., 2001b). The revenue effect is driven by the flow of licensing payments by the licensee, net of all transaction costs carried by licensor. The rent dissipation effect is caused by erosion of profits in licensor's product market due to additional competition coming from the licensee that either reduces price-cost margin and/or erodes market share (Arora & Fosfuri, 2003; Fosfuri, 2006). Therefore, the licensing decision is expected to be positively affected by the revenue effect and negatively affected by the rent dissipation effect. The trade-off between these opposite effects, where licensing payments net of transaction costs must be compared with the lower price margin and reduced share implied by higher competition from the licensee, determines the technology owner's licensing propensity (Fosfuri, 2006).

There is an extensive literature that identifies several theoretical determinants of technology licensing that affect the revenue and the rent dissipation effects. Depending on whether they represent the characteristics of an industry, firm, or specific technology, these determinants can be classified into three groups. The first set of determinants represents the characteristics of an innovating firm's primary industry. The second set of factors describes the features of potential or actual licensor such as its technological and commercial capabilities. Finally, the last set of determinants reveals the characteristics of the specific technology that can be licensed out.

FIGURE 2.1 Determinants of technology licensing



Industry level determinants

Effectiveness of patent protection. By defining property rights for technology or knowledge, patents provide a way for technology owners to publicly disclose information while preventing its unauthorized use for a limited time period. The main social function of the patent system is to create the incentive to engage in inventive activity and to undertake costly investments required to further develop an invention and embed it into economically valuable products and services (Levin, 1986). However, the evidence suggests that patents do not work in practice as they do in theory (Levin et al., 1987). Although patents afford considerable protection for inventions in some industries, in others they do not confer perfect appropriability. Teece (1986) defines the effectiveness of patent protection as the efficacy of the legal system to assign and protect intellectual property.

Anand & Khanna (2000) argue that more effective patent protection reduces transaction costs of technology licensing and induces firms to license more. Arora et al. (2001) argue that stronger IPRs can enhance the efficiency of technology transfers by reducing opportunistic behavior and, thus, enhance technology diffusion through licensing, even including the technologies such as know-how that are not protected by the patents (Arora et al., 2001b; Merges, 1998). Gambardella et al. (2007) also assert that, since licensor cannot fully control licensees' actions and fully prevent opportunistic behavior, licensing implies lower control over diffusion of the technology. Therefore, more effective patent protection makes it more problematic for anyone to "free ride" on the right to use the technology.

However, the effectiveness of patent protection may have an opposite effect on licensing propensity since it can increase the opportunity cost of licensing by enhancing the payoff from exclusive commercialization of technology (Arora & Ceccagnoli, 2006; Gans, Hsu, & Stern, 2002). The effective patent protection as a mechanism that prevents imitation by rivals secures a larger market for products made using the patented invention. However, Gans et al. (2002) argue that the returns to cooperation through licensing are more sensitive to the effectiveness of patent protection than the returns to competition through commercializing the technology internally. While expropriation may occur under both competition and cooperation, more effective patent protection should increase the relative returns of the latter by enhancing the bargaining power of the licensor and lowering the transaction costs (Gans et al., 2002).

Considering the measurement of the construct in the literature, as summarized by Gambardella et al. (2007), most of the patent level measures use the scope and the length of patent protection. The main justification is that a patent with a broader scope or length of protection covers larger number of applications and, therefore, decreases a possibility for other parties to "invent around" it. Thus, they measure patent scope by the number of claims listed in the patent (Gambardella et al., 2007; Palomeras, 2007). Another proxy for patent scope used by Gambardella et al. (2007) is the number of 4-digit IPC technological classes in which patent has been classified. However, authors admit that they cannot unambiguously interpret if this variable measures patent protection or the generality of technology (Gambardella et al., 2007). Arora & Ceccagnoli (2006) use the Carnegie Mellon survey, which asks respondents to indicate the percentage of their product and process innovations for which patent protection had been effective for their firm's competitive advantage (Arora & Ceccagnoli, 2006). Kim (2004) argues that the total number of patents granted in a firm's primary two-digit Standard Industrial Classification (SIC) industry divided by total R&D expenditures in the industry at a given period (i.e. propensity to receive patents) partly reflects the effectiveness of IPR (Kim, 2004; Kim, 2005).

Hypothesis 1: Technology licensing is positively related with the effectiveness of patent protection in the industry.

Competition in the product market. The literature suggests that another determinant affecting the licensing decision is the level of competition in the product market. In an extreme case, there is only one monopolist firm operating in the product market. In this case, the rent dissipation effect is higher than the revenue effect because licensing eliminates a possibility to earn monopoly profits. By contrast, when there are several firms in the product market, losses due to increased competition are shared with other firms in the product market and, thus, the rent dissipation effect is only partially internalized by each firm. Therefore, in a highly competitive market, the rent dissipation effect can be lower than the revenue effect (Arora et al., 2001b). In other words, the existence of many competitors in the patent owner's current primary product market makes technology licensing more likely, since creating an additional competitor in already highly competitive market will be less costly for the firm with respect to rent dissipation effect, while the revenue effect due to licensing payments can be still significant (Gambardella et al., 2007; Kim, 2004;

Kim, 2005). Moreover, one would also expect to have a negative correlation between product market competition and the market share of a firm.

Empirical studies measure the product market competition in the industry through a market concentration operationalized as a cumulative market share of the four dominant firms in the primary operating industry of a firm (Kim, 2004; Kim, 2005; Kim & Vonortas, 2006).

Hypothesis 2: Technology licensing is positively related with the intensity of competition in the product market.

Technological competition. The markets for technology imply that there can be several firms that have similar or substitutable technologies. The existence of multiple parties with similar or interchangeable technologies extends the earlier economic literature that has typically analyzed licensing decision of a monopolist innovator (Arora et al., 2001b). Each of these multiple firms that has developed the technology can potentially license it to a market entrant. Therefore, Fosfuri (2006) reasons that the presence of multiple sources for technology creates a strategic incentive to license because a technology holder's refusal to license not only will fail to keep technology secret and block entry to the product market but also will deprive the possibility of receiving licensing payments (Fosfuri, 2006). For the same reason, Gambardella et al. (2007) argue that when there are many firms operating in a technological area, licensing is more likely. Arora et al. (2001) find that this is especially true if there is a high share of small specialized firms without downstream capabilities and with no stake in the final product market. These firms, in addition to supplying technology themselves, may also induce firms with downstream capabilities to license out their technologies by creating a so called "inducement effect" (Arora et al., 2001b).

To measure technological competition, Arora & Ceccagnoli (2006) use the Carnegie Mellon survey, which asks respondents to indicate the number of technological rivals (Arora & Ceccagnoli, 2006). Gambardella et al. (2007) use the share of patents held by the top four applicants in each 4-digit IPC patent class.

Fosfuri (2006), in turn, uses the number of firms that have licensed a process technology to produce a given product or have built a plant in-house using their own technology during a period prior to one analyzed in the study.

Hypothesis 3: Technology licensing is positively related with the intensity of technological competition in the industry.

Market growth. The previous studies hypothesize that there should be a positive relationship between demand growth in an industry and technology licensing. These studies argue that increasing demand partly reduces the negative consequences of the rent dissipation effect, which is caused by additional competition from the licensee (Fosfuri, 2006; Kim, 2004). Moreover, by increasing the number of potential licensees, the market growth can positively affect the licensor's bargaining power and, thus, make licensing a more attractive strategy (Fosfuri, 2006).

Fosfuri (2006) measures the market growth potential in the industry using the ratio between the total number of plants constructed in a given product sector in a given geographical area during two time frames before and during a period analyzed in the study. Other studies measure the market growth through the percentage change in total sales of the primary industry of a firm at a given period (Kim, 2004; Kim, 2005; Kim & Vonortas, 2006).

Hypothesis 4: Technology licensing is positively related with the demand growth in the industry.

Firm level determinants

Presence of complementary assets. Starting with the seminal paper by Teece (1986), a significant body of theoretical literature has considered the role of complementary assets in appropriating returns from commercializing innovations (Arora & Ceccagnoli, 2006). Complementary assets are assets owned by an innovating firm that are valuable in production and commercialization of a technology. These complementarities arise if the assets are rare and difficult to create or if extensive coordination between activities is required (Arora & Ceccagnoli, 2006).

The literature suggests that if a producer of a technology does not have necessary complementary assets to commercialize it, such as manufacturing, distribution, and marketing capabilities, it can obtain higher economic value from its technology by supplying it to other parties that already posses these complementary assets or can create them at lower costs (Arora et al., 2001b; Fosfuri, 2006). Arora & Ceccagnoli (2006) also argue that firms with weak complementary assets are more likely to license their technologies, while firms that have capabilities and resources to appropriate returns by commercializing innovations in-house have lower incentives to license. Another perspective relating complementary assets and licensing decision is given by Somaya, Kim & Vonortas (2011). They note that managers and technology commercialization professionals often view licensing as a way to get access to complementary capabilities owned by the licensee in order to develop and commercialize their own technologies (Somaya, Kim, & Vonortas, 2011).

On the contrary, when downstream complementary assets are available, they need to be fed with production activities to avoid underutilization. Therefore, in such cases firms tend to use their technologies internally to produce a final product (Gambardella & Giarratana, 2006).

Arora & Ceccagnoli (2006) use the Carnegie Mellon survey to measure the presence of specialized manufacturing capabilities. By looking at the frequency of face to face interactions between personnel from R&D and production departments, they code their complementary asset dummy as 1 if the interaction is daily (Arora & Ceccagnoli, 2006; Ceccagnoli & Hicks, 2009). Gambardella & Giarratana (2006) construct two measures as proxies for downstream assets in software: the share of live software trademarks on the total trademark multiplied by firm fixed assets, and the share of live software trademarks on the total trademark multiplied by firm sales.

Hypothesis 5: Technology licensing is negatively related with the presence of complementary assets necessary to commercialize the technology.

Firm's product market share. The impact of licensor's market share in the product market on licensing decision is mainly explained by the rent dissipation effect. Firms with smaller market shares have stronger incentives to license out their technologies because compared to firms with larger market shares they suffer less from the rent dissipation effect (Gambardella et al., 2007; Kim, 2004). Increased competition may reduce the price-cost margin producing negative effect on all incumbent producers proportional to their current market share. Similarly, market share erosion can damage more those firms that are the product market leaders. Put differently, smaller the profits the licensor gets from direct production before licensing smaller the negative effect from the rent dissipation (Fosfuri, 2006). By the same token, firms specializing in technology production with no share in the product market will have higher incentives to license.

Fosfuri (2006) measures the market share of the firm as the ratio between the capacity built by the firm in a given product and geographical area and the total capacity. Kim (2004) measures the market share as the firm's proportion of sales in primary industry at a given period.

Hypothesis 6: Technology licensing is negatively related with the firm's product market share.

R&D intensity. Another relevant factor that affects the rate of technology licensing is the R&D intensity, which is defined as a ratio between firm's R&D expenditures and sales. The higher level of R&D intensity is usually associated with a higher possibility of new inventions. Therefore, it implies that the firm is more likely to have valuable technological assets to license out (Fosfuri, 2006; Kim, 2005). R&D intensive firms may be more predisposed to license out their technologies because they can have more technologies available than they can commercialize internally. The R&D intensity is empirically measured as a ratio between R&D expenditures and sales (Fosfuri, 2006; Gambardella & Giarratana, 2006; Kim, 2005).

Hypothesis 7: Technology licensing is positively related with the firm's R&D intensity.

Firm size. As theoretical and empirical literature assert, firm size affects the rate of technology licensing and this effect is expected to be negative (Arora & Ceccagnoli, 2006; Arora et al., 2001b; Fosfuri, 2006; Gambardella et al., 2007; Kim, 2005). Large firms with well-established downstream production capabilities have less to gain and more to lose from a competition created by licensee due to the rent dissipation effect (Arora et al., 2001b). Moreover, larger firms may have less financial constraints and, therefore, be less enforced to license out their technologies for revenue. Kim (2005) argues that small firms are less likely to commercialize their inventions on their own because they have cash flow constraints and often lack a sales network.

On the other hand, there are some alternative arguments for the relationship between the firm size and the likelihood of technology licensing. For instance, Fosfuri (2006) argues that larger firms have stronger bargaining power in the licensing negotiations, which is expected to be positively associated with the revenue effect and, consequently, with the propensity to profitably license out technology.

Considering the measurement aspect, some studies use the amount of aggregate sales (Gambardella & Giarratana, 2006) or the log of sales of a firm (Fosfuri, 2006; Kim, 2005; Kim & Vonortas, 2006) to control for the firm size. Gambardella et al. (2007) measure the firm size by the number of employees. Arora & Ceccagnoli (2006) measure the firm size by the log of the number of business unit employees (Arora & Ceccagnoli, 2006), but note that the firm size, measured by the log of the total employees of unit's parent firm, give similar results.

Hypothesis 8: Technology licensing is negatively related with the firm size.

Patent stock. Another important firm-specific determinant that can affect licensing behavior is the stock of patents that a firm has received up to a certain point in time. Kim (2004) argues that patent-intensive firms may be more predisposed to license out their technologies because they can have more technologies available than they can use in-house. Kim & Vonortas (2006) highlight that patent-intensive firms may also be interested in extending revenue frame from technologies that have past time of their internal use but which can be still valuable to others. Moreover, larger patent stock increases the likelihood that a company has non-core or peripheral technologies to license out.

Most of the studies measure the patent stock as a number of patents received by the firm up to a given point in time (Kim, 2004; Kim, 2005; Palomeras, 2007). Kim & Vonortas (2006) use a more sophisticated measure for the patent stock that also accounts for technology depreciation due to the technological obsolescence.

Hypothesis 9: Technology licensing is positively related with the firm's patent stock.

Previous licensing experience. The transaction costs associated with gathering information about potential licensees, negotiating, writing and enforcing licensing contracts decrease licensor's profits and discourage the licensing behavior of the firm. Therefore, as suggested by the literature previous licensing experience lowers these types of transaction costs and, thus, should have a positive effect on further technology licensing decisions (Fosfuri, 2006; Kim, 2004; Kim, 2005).

Empirical studies measure previous licensing experience with the average number of licenses granted by the firm during the pre-sample period (Kim, 2004) or use a dummy variable to account for previous licensing experience (Fosfuri, 2006; Kim, 2004; Kim, 2005).

Hypothesis 10: Technology licensing is positively related with the firm's previous licensing experience.

Technology level determinants

Value of the technology. An essential factor that may affect the licensing likelihood is the technical importance or the value of the technology. The technological value was found to be positively correlated with the economic value of innovation (Hall, Jaffe, & Trajtenberg, 2005; Harhoff, Narin, Scherer, & Vopel, 1999). On the one hand, valuable innovation raises interest by potential licensees to be commercially exploited, which means that the licensor can extract a larger payment from the licensees for the valuable technology (Fosfuri, 2006; Palomeras, 2007). On the other hand, innovator can also be interested in exploiting the valuable innovation in-house or can decide to avoid potential competition caused by licensing out valuable innovation (Palomeras, 2007). Gambardella et al. (2007) argue that although not all valuable patents are licensed, licensed patents are selected from a subset of better patents, thus, licensed patents, on average, have a higher economic value. Therefore, we hypothesize a positive relationship between these two variables.

Palomeras (2007) measures the value of the technology by the number of citations patent receives. Gambardella et al. (2007) measure the economic value of the technology by the occurrence of opposition, the occurrence of presented observations to the EPO by a third party, and the number of designated countries in the application. Ceccagnoli & Hicks (2009) use the number of forward citations to measure the value of the technology.

Hypothesis 11: Technology licensing is positively related with the value of the technology.

Technological fit. The literature suggests that the technological fit is another determinant of technology licensing. Palomeras (2007) defines the technological fit as a degree to which a given innovation falls within core activity of the firm. As it was emphasized by Prahalad & Hamel (1990), firms should invest in and protect their core technologies, which are key to their sustainable competitive advantage (Prahalad & Hamel, 1990). Since the transfer of core technology through licensing implies disclosure of innovator's source of competitive advantage, it can have significant negative effect on its competitive position in the product market (Fosfuri, 2006; Palomeras, 2007). Moreover, in the area of their core activity firms develop particular organizational and technological capabilities and, therefore, have some cost advantages in exploiting the innovation, which implies that the core technology can be more valuable to innovating firm than to potential licensees that lack these capabilities (Palomeras, 2007). Hence, firms are less likely to license out their core technologies.

On the contrary, non-core technologies are more likely to be licensed out for revenue. Arora et al. (2001) argue that even a large well-established firm may decide to license out its technology because of inability to exploit its technology to full effect or because the technology has application in markets in which the innovator does not typically operate. Such non-core technologies may exist, for instance, because large firms invest in peripheral technologies in order to develop an "absorptive capacity" (Cohen & Levinthal, 1990) or as a by-product of their main R&D activities. Moreover, for non-core technology firms do not usually posses relevant downstream manufacturing and marketing capabilities (Gambardella et al., 2007).

The technological fit is measured by a share of patents in the firm's overall patent portfolio that belongs to the same 3-digit International Patent Classification (IPC) class as the focal patent (Palomeras, 2007). Gambardella et al. (2007) distinguish between core, background, marginal and niche technologies by using the two measures: the patent share and the revealed technology advantage (RTA).

Hypothesis 12: Technology licensing is negatively related with the technological fit of technology.

Scientific nature of the technology. Finally, another factor that may affect the technology licensing is the level of tacitness and codifiability of technological knowledge (Nelson & Winter, 1982; Polanyi, 1966). Tacit knowledge is difficult to communicate and transfer to others, while codified knowledge can be easily transferred through patents, blueprints, and articles (Arora et al., 2001b; Teece, 1986). Winter (1987) developed a taxonomy that distinguished eight pairs of attributes of knowledge: articulable or tacit, teachable or unteachable, articulated or nonarticulated, observable or nonobservable, simple or complicated, system-independent or system dependent, context-independent or context dependent, monodisciplinary or transdisciplinary. The first attribute in each pair makes knowledge easier to transfer while the second attribute makes it more difficult (Arora et al., 2001b).

Generally, technologies that are strongly science-based are more likely to be codifiable and not tacit (Arora & Ceccagnoli, 2006; Arora & Gambardella, 1994a; Winter, 1987). Codifiability makes it easier to protect the technology since the object of protection is clearer (Gambardella et al., 2007). Moreover, tacit technology is costly to transfer, which implies lower licensing payoffs (Teece, 1977). Thus, the relationship between codifiability and technology licensing should be positive, whereas tacitness will assume the negative relationship.

There are different measures of the degree to which the firm's knowledge is science based and, therefore, likely to be codifiable and nontacit. Arora & Ceccagnoli (2006) use measures labeled as "importance of basic science", "importance of medical science", "% of R&D efforts devoted to basic research" to assess the degree of codifiability. Gambardella et al. (2007) measure the scientific nature of knowledge (codifiability) by asking respondents to rank on the 5-point Likert scale the importance of the scientific literature, the importance of university or other public labs as a source of knowledge. Tacitness is measured by asking respondents to rate on the 5-point scale the importance of users, suppliers and competitors as a source of knowledge (Gambardella et al., 2007). Ceccagnoli & Hicks (2009) consider the number of patent references to scientific papers as the science linkage indicator.

Hypothesis 13: Technology licensing is positively related with the scientific nature of the technology.

2.3. DATA AND METHODS

2.3.1. Search Strategy

The current study investigates the determinants of technology licensing. The main research questions that are expected to be addressed using the meta-analytic approach are: *What factors affect a firm's decision to license its technologies? What are the patterns of relationships between these determinants and technology licensing?*

Therefore, we select research studies, code and analyze data from these studies according to these research questions. Before starting the search for the relevant empirical literature, we have set the following eligibility criteria in order to include studies in the meta-analysis. First, the studies should empirically investigate the relationship between technology licensing and its various determinants. Second, the studies have to focus on decisions to license by for-profit firms rather than non-profit organizations or universities, which have different motives and reasons for licensing their technologies. For instance, university licensing decisions differ considerably from those made by for-profit firms, primarily because universities do not have stakes in the product market (Fosfuri, 2006). Third, the studies should provide some theoretical interpretation of expected direction of the relationship between the technology licensing and a given determinant.

Following the suggestions in the relevant methodological literature (Lipsey & Wilson, 2001), in the meta-analysis we have used multiple methods to identify, locate, and retrieve studies reporting relationship between technology licensing and its various determinants. First, we have conducted keyword searches in specialized computer-based bibliographic databases (ProQuest, ABI/INFORM, EBSCO, Scopus, Google Scholar). The following variation of keywords was used to search for relevant literature: "markets for technology", "licensing", "patent use", "technology management", "technology use", "technology transfer", "technology licensing", "technology commercialization", "technology exploitation".

Second, we have conducted a manual search in the following journals that were found to be the source of already retrieved studies: *Applied Economics Letters, California Management Review, Industrial and Corporate Change, Journal of Economics and*

Business, Journal of Economics & Management Strategy, Journal of Technology Transfer, Management Science, Managerial and Decision Economics, Research Policy, S.A.M. Advanced Management Journal, Strategic Management Journal, The Journal of Industrial Economic.

Third, since meta-analysis is frequently criticized as being based on biased data sets of published studies, in order to decrease possible publication bias we have decided to include unpublished works in our meta-analysis, even though we admit that inclusion of unpublished research is controversial (Hunter & Schmidt, 2004; Rosenthal, 1991). Additional argument for inclusion of unpublished papers in our analysis stems from the fact that empirical research on this issue is quite recent, and the number of published papers is limited. Thus, some relevant studies may still be under the review process. The main sources of unpublished and working papers are the following two databases: Social Science Research Network (SSRN) and The National Bureau of Economic Research (NBER) Working Papers. We have also consulted other unpublished papers from conference proceedings (e.g. DRUID Summer Conference). Finally, we have used so-called "snow ball" technique to find additional studies on the topic using the references contained in the already selected studies.

The search procedure resulted in 11 relevant studies that reported 18 samples with a total of 66,165 observations (see Table 2.1). Among the 8 published studies included, 2 were published between 2000 and 2005, and 6 of them - between 2006 and 2011. Other 3 unpublished works used in the analysis also fall into the 2006-2011 interval. This also indicates a recent increasing interest in the topic of technology licensing and its various determinants.

Although for testing some hypotheses we do not have many empirical studies investigating the relationship, the use of several major methods for combining levels of significance suggested by Rosenthal (1991) allows us to conduct meta-analysis with two or more empirical studies (e.g. Sobrero & Schrader, 1998).

TABLE 2.1 List of studies included in the meta-analysis

Authors	Year	Source
Arora & Ceccagnoli	2006	Management Science
Ceccagnoli & Hicks	2009	Working Paper
Fosfuri	2006	Strategic Management Journal
Gambardella, Giuri & Luzzi	2007	Research Policy
Gambardella & Giarratana	2006	Working Paper
Kim	2004	Applied Economics Letters
Kim	2005	S.A.M. Advanced Management Journal
Kim & Vonortas	2006	Managerial and Decision Economics
Motohashi	2008	Research Policy
Novelli	2007	Working Paper, DRUID Summer Conference 2007
Palomeras	2007	Journal of Economics & Management Strategy

2.3.2. Methods

During the last several decades, meta-analysis has been increasing in its importance as a way to conduct a literature review in a more quantitative manner. Meta-analysis integrates findings across studies to reveal patterns of relationships between various constructs and can be understood as a form of survey research in which research results, rather than individuals, are surveyed (Lipsey & Wilson, 2001). Meta-analysis allows comparing or combining the results of empirical studies by employing either effect sizes or significance levels (Hunter et al., 1982).

In order to fully exploit the possibilities offered by the meta-analytic technique, there is a need to calculate effect sizes from the reviewed studies. However, in social sciences many reports of multiple regressions fail to report the full correlation matrices (Hunter & Schmidt, 2004). Most of studies in our sample also lack correlation matrices for their key variables. Moreover, unlike other sciences where experimental studies are very common, social sciences often use non-experimental studies that usually include different sets of explanatory and control variables.

Therefore, for these studies comparing or combining effect sizes is quite problematic since it is impossible to single out the effects of different explanatory variables. For these reasons, following Sobrero & Schrader (1998), we would like to focus on the directionality and significance of effects rather than on their magnitude.

An alternative approach to the problem of the absence of correlation matrices is to estimate missing Pearson correlation coefficients using standardized regression (beta) coefficients (Peterson & Brown, 2005). Peterson & Brown (2005) report that the use of corresponding beta coefficients to impute missing correlations coefficients (effect sizes) generally produces relatively accurate and precise population effect-size estimates. However, the conventional view of meta-analysts is that beta coefficients should not be used as substitutes for correlation coefficients in meta-analysis (Hunter & Schmidt, 2004). Moreover, as highlighted by Peterson & Brown (2005), this imputation approach can be successfully utilized only when missing data constitutes a relatively small percentage of all studies. In our case majority of studies fail to report their correlation matrices. Therefore, this alternative approach can only be used if more complete information for the majority of studies is collected by directly contacting the authors.

Although we have tried to address a possible problem of publication bias by including unpublished studies in our meta-analysis, it is likely that we could not successfully retrieve the majority of unpublished studies. Therefore, as suggested by Rosenthal (1991), we also conducted the file drawer test. This test allows to assess how many unpublished studies reporting non-significant or contradicting to theoretical expectations results are needed to invalidate conclusions of the meta-analysis (Rosenthal, 1991).

2.3.3. Data Coding

As it was described in the previous sections, the focus of our meta-analysis is the relationship between technology licensing and its various determinants. Each paper selected for meta-analysis was coded in a database, by collecting key methodological and descriptive characteristics including authors' name, year of publication, source, unit of analysis, used methodology, research context, constructs of interest, and key statistics useful for the meta-analysis (Lipsey & Wilson, 2001).

The review of the selected sample of studies revealed that there is a need to distinguish between two types of dependent variables: willingness to license and actual licensing. Considering explanatory variables, we have coded the following determinants of technology licensing: the effectiveness of patent protection, the competition in the product market, the technological competition, the market size and growth, the presence of complementary assets, the firm's product market share, the R&D intensity, the firm size, the previous licensing experience, the technological fit, the value of the technology, and the scientific nature of the technology.

During the coding process, we retained information about research design and method in order to distinguish between studies that used survey data, databases or both to measure the relationship of interest. Further, to account for differences in research contexts represented in the selected studies we coded each study on the base of the composition of its sample. To see the distinction in the results between empirical studies that used firm level measures and studies that used technology level measures, we also coded level of measurement for each study.

By reviewing theoretical sections of the studies, we have determined and coded the theoretically predicted direction of the relationship between technology licensing and its determinants. Whereas next sections gave us the sign of the relationship suggested by empirical findings that could either support theoretical prediction or contradict it.

For each relationship of interest in our studies, we coded the one-tailed p-value associated with the significance test. Whenever p-values were not available or were reported as threshold levels (e.g. $p<0.01$), the exact p-values were calculated from reported t-statistics and associated distributions. It should be noted that one-tailed p's are always less than 0,5 when the results are in the consistent direction, but they are always greater than 0,5 when the results are not consistent with theoretical predictions (Rosenthal, 1991). Moreover, we have calculated the corresponding standard normal deviate (Z). The sign of the Z-score was coded as positive if the empirical evidence supported theoretical prediction, and was coded as negative otherwise (Sobrero & Schrader, 1998).

As recommended by Rosenthal (1991), when for a given construct several measures were used we found the standard normal deviate (Z) that corresponds to the p-value associated to each measure, calculated average Z-score, and converted it into corresponding p-value. Finally, following Sobrero & Schrader (1998), we used a similar procedure for calculating p-value, when two or more models that tested the relationship of interest were present in the same study based on the same sample. Analyses performed on different samples within the same study were considered as independent observations.

2.3.4. Statistical Procedure

In order to compare the relationships in the reviewed studies according to their significance levels, as suggested by Rosenthal & Rubin (1979), we, first, tested for the homogeneity of the Z-scores corresponding to p-values using the following formula:

$$\sum_{j=1}^{K}\left(Z_j - \overline{Z}\right)^2,$$

where K equals to the number of reviewed studies, Z_j is the standard normal deviates computed for each study, $\bar{Z}$ is the mean of the Z_j. The test for homogeneity is distributed as χ^2 with K – 1 degrees of freedom. Whenever the results of studies failed the homogeneity test, we attempted to assess and explain the reasons for this heterogeneity. Whereas when the results of studies were found to be homogeneous, they were further analyzed using the statistical procedures of combining the results suggested by Rosenthal (1991).

There are several major methods for combining the levels of significance obtained from two or more studies testing the same directional hypothesis (Rosenthal, 1991). Taking into account their advantages and drawbacks, for our study we decided to use several methods to combine probabilities, namely *adding p's, adding t's, adding Z's, testing the mean p*, and *testing the mean* Z.

Adding p's. This powerful method that has been described by Edgington (1972a) uses the following formula:

$$\boldsymbol{P} = \frac{(\sum \boldsymbol{p})^{\boldsymbol{N}}}{\boldsymbol{N}!}.$$

However, this method is useful only for small sets of studies because it requires that the sum of p levels doesn't exceed unity by very much, otherwise, the results tend to be too conservative (Rosenthal, 1991).

Adding t's. Another method of combining probabilities described by Winer (1971) involves the following calculations:

$$\boldsymbol{Z} = \frac{\sum \boldsymbol{t}}{\sqrt{\sum[\boldsymbol{df}/(\boldsymbol{df}-\boldsymbol{2})]}}.$$

Unlike previous one, this method is not affected by the number of studies reviewed. Nevertheless, its limitation is that it may not give good approximations when df < 10 for each t (Rosenthal, 1991).

Adding Z's. The main advantage of the Stouffer method is that it is the simplest of all to apply:

$$\boldsymbol{Z} = \frac{\sum \boldsymbol{Z}}{\sqrt{\boldsymbol{N}}}.$$

In order to effectively employ this method, number of studies reviewed should not be too small (Rosenthal, 1991).

Testing the mean p. Another method proposed by Edgington (1972b) that can be used when there are four or more studies to be combined is a normal curve method:

$$\boldsymbol{Z} = (\boldsymbol{0,5} - \overline{\boldsymbol{p}})\sqrt{\boldsymbol{12N}}.$$

Testing the mean Z. Finally, the fifth method is the one suggested by Mosteller & Bush (1954), which represents a modification of the Stouffer method:

$$\boldsymbol{t} = \frac{\sum \boldsymbol{Z}/\boldsymbol{N}}{\sqrt{\boldsymbol{S}^{2}{}_{(\boldsymbol{Z})}/\boldsymbol{N}}}.$$

The authors discourage from the usage of this method when there are fewer than five studies to be combined because of the lower power of the t-test when based on few observations (Rosenthal, 1991). Therefore, we use this additional test only when number of studies exceeds five.

As we have mentioned earlier, to examine how many unpublished studies reporting non-significant, or contradicting to theoretical expectations are needed to invalidate results of the meta-analysis, we also conducted a file drawer test for subsample of published studies using the following formula suggested by Rosenthal (1991):

$$\boldsymbol{X} = \frac{\boldsymbol{K}[\boldsymbol{K}\bar{\boldsymbol{Z}}^{2} - \mathbf{2{,}706}]}{\mathbf{2{,}706}},$$

where K equals to the number of reviewed studies, $\bar{Z}$ is the mean of the Z_j. The idea behind the file drawer test is to calculate the number of studies reporting null results that must be in file drawers in order to lower the overall probability of a type I ("false positive") error in the results of our combination procedures to 0,05 (Rosenthal, 1991).

2.4. RESULTS

Even precursory look at the empirical findings reveals that some of them inconclusive not only in terms of magnitude and relative importance, but also in terms of direction of the relationships between technology licensing and its various determinants. Table 2.2 describes all the studies reviewed, whether they have been published or not, the dependent and independent constructs, the size of the firms in the samples, the level of measurement, the theoretically predicted and empirically observed relationships between the dependent and independent variables, corresponding p-values and degrees of freedom. The studies in the table are presented in 13 groups according to the independent construct, each of them investigating a different relationship. The number of studies in each of these groups varies from 2, as in the case of the relationship between technology licensing and firm's product market share, to 14, as in the case of the relationship between technology licensing and the effectiveness of patent protection. As noted earlier, methods for combining levels of significance used in the paper allow us to conduct meta-analysis with two or more empirical studies (Rosenthal, 1991).

The analysis points out to the heterogeneity of the results both in terms of reported significance levels and directionality of the relationships. Therefore, the remaining of this section describes our findings for each of the relationships.

Most of the studies addressing the relationship between licensing and the effectiveness of the patent protection report positive relationship, which is in accordance with theoretical expectation. However, the heterogeneity test shows that the p-values are statistically different (χ^2=22.26, df=13, p<0.1). One possible reason for such heterogeneity is the difference in operationalization of the construct in different studies. For instance, more detailed analysis reveals that studies that use technology level measures for the independent construct such as the number of claims and the number of 4-digit IPC technological classes in which patent has been classified get more homogeneous results that can be combined (χ^2=1.86, df=3, p=0.6). As shown in Table 2.3, for these subgroups of studies all the different combining procedures confirm the positive relationship.

TABLE 2.2 Summary of reviewed studies

Determinants of technology licensing	Study Reviewed	Published Study	Dependent Construct	Size of firms in the sample	Level of measurement	Expected Direction	Observed Direction	p-value one tailed	df
Industry level determinants									
Effectiveness of patent protection	Arora & Ceccagnoli (2006)	Yes	Willingness to license	Large	Firm	+	+	0.0001	747
	Gambardella, Giuri & Luzzi (2007)	Yes	Actual licensing	Small & large	Technology	+	+	0.0087	7,087
	Gambardella, Giuri & Luzzi (2007)	Yes	Willingness to license	Small & large	Technology	+	+	0.0187	6,137
	Kim (2005)	Yes	Actual licensing	Large	Firm	+	+	0.4678	4,044
	Kim (2005)	Yes	Actual licensing	Large	Firm	+	+	0.0285	2,931
	Kim (2005)	Yes	Actual licensing	Large	Firm	+	-	0.8280	1,299
	Kim (2004)	Yes	Actual licensing	Large	Firm	+	+	0.0001	12,184
	Palomeras (2007)	Yes	Willingness to license	Small & large	Technology	+	+	0.0385	8,551
	Palomeras (2007)	Yes	Willingness to license	Large	Technology	+	+	0.2801	3,405
	Kim & Vonortas (2006)	Yes	Actual licensing	Large	Firm	+	+	0.0042	9,298
	Ceccagnoli & Hicks (2009)	No	Actual licensing	Small & large	Firm	+	+	0.1222	1,036
	Ceccagnoli & Hicks (2009)	No	Actual licensing	Small & large	Firm	+	+	0.0971	1,036
	Ceccagnoli & Hicks (2009)	No	Actual licensing	Small	Firm	+	+	0.3295	412
	Ceccagnoli & Hicks (2009)	No	Actual licensing	Large	Firm	+	+	0.0991	612
Competition in the product market	Kim (2005)	Yes	Actual licensing	Large	Firm	+	+	0.0035	4,044
	Kim (2005)	Yes	Actual licensing	Large	Firm	+	+	0.4361	2,931
	Kim (2005)	Yes	Actual licensing	Large	Firm	+	+	0.2095	1,299
	Kim (2004)	Yes	Actual licensing	Large	Firm	+	+	0.0002	12,184
	Kim & Vonortas (2006)	Yes	Actual licensing	Large	Firm	+	-	0.9008	9,298
Technological competition	Arora & Ceccagnoli (2006)	Yes	Willingness to license	Large	Firm	+	+	0.2744	747
	Gambardella, Giuri & Luzzi (2007)	Yes	Actual licensing	Small & large	Technology	+	+	0.0579	7,087
	Gambardella, Giuri & Luzzi (2007)	Yes	Willingness to license	Small & large	Technology	+	+	0.0475	6,137
	Fosfuri (2006)	Yes	Actual licensing	Large	Technology	+	+	0.0050	2,009
Market growth	Fosfuri (2006)	Yes	Actual licensing	Large	Technology	+	+	0.0077	2,009
	Kim (2005)	Yes	Actual licensing	Large	Firm	+	+	0.0009	4,044
	Kim (2005)	Yes	Actual licensing	Large	Firm	+	-	0.8108	2,931
	Kim (2005)	Yes	Actual licensing	Large	Firm	+	-	0.7474	1,299
	Kim (2004)	Yes	Actual licensing	Large	Firm	+	+	0.6203	12,184
	Kim & Vonortas (2006)	Yes	Actual licensing	Large	Firm	+	+	0.0001	9,298

Determinants of technology licensing	Study Reviewed	Published Study	Dependent Construct	Size of firms in the sample	Level of measurement	Expected Direction	Observed Direction	p-value one tailed	df
Firm level determinants									
Presence of complementary assets	Arora & Ceccagnoli (2006)	Yes	Willingness to license	Large	Firm	-	-	0.0035	747
	Ceccagnoli & Hicks (2009)	No	Actual licensing	Small & large	Firm	-	+	0.6712	1,036
	Ceccagnoli & Hicks (2009)	No	Actual licensing	Small & large	Firm	-	-	0.3116	1,036
	Ceccagnoli & Hicks (2009)	No	Actual licensing	Small	Firm	-	+	0.9635	412
	Ceccagnoli & Hicks (2009)	No	Actual licensing	Large	Firm	-	-	0.0305	612
	Novelli, Padula, & Rao (2007)	No	Actual licensing	Small	Firm	-	-	0.0001	1,260
	Gambadella & Giarratana (2006)	Yes	Actual licensing	Small & large	Firm	-	+	0.7748	691
Firm's product market share	Fosfuri (2006)	Yes	Actual licensing	Large	Technology	-	-	0.0117	2,009
	Kim (2004)	Yes	Actual licensing	Large	Firm	-	+	0.9996	12,184
R&D intensity	Fosfuri (2006)	Yes	Actual licensing	Large	Technology	+	-	0.9883	2,009
	Kim (2005)	Yes	Actual licensing	Large	Firm	+	+	0.0139	4,044
	Kim (2005)	Yes	Actual licensing	Large	Firm	+	-	0.9064	2,931
	Kim (2005)	Yes	Actual licensing	Large	Firm	+	-	0.7103	1,299
	Gambadella & Giarratana (2006)	No	Actual licensing	Small & large	Firm	+	+	0.0153	691
Firm size	Arora & Ceccagnoli (2006)	Yes	Willingness to license	Large	Firm	-	-	0.0914	747
	Gambardella, Giuri & Luzzi (2007)	Yes	Actual licensing	Small & large	Technology	-	-	0.0001	7,087
	Gambardella, Giuri & Luzzi (2007)	Yes	Willingness to license	Small & large	Technology	-	-	0.0001	6,137
	Kim (2005)	Yes	Actual licensing	Large	Firm	-	+	0.9999	4,044
	Kim (2005)	Yes	Actual licensing	Large	Firm	-	+	0.9175	2,931
	Kim (2005)	Yes	Actual licensing	Large	Firm	-	+	0.9990	1,299
	Kim & Vonortas (2006)	Yes	Actual licensing	Large	Firm	-	+	0.7138	9,298
	Ceccagnoli & Hicks (2009)	No	Actual licensing	Small & large	Firm	-	+	0.5420	1,036
	Ceccagnoli & Hicks (2009)	No	Actual licensing	Small & large	Firm	-	+	0.9771	1,036
	Ceccagnoli & Hicks (2009)	No	Actual licensing	Small	Firm	-	-	0.2341	412
	Ceccagnoli & Hicks (2009)	No	Actual licensing	Large	Firm	-	+	0.8412	612
	Novelli, Padula, & Rao (2007)	No	Actual licensing	Small	Firm	-	-	0.0672	1,260
	Motohashi (2008)	Yes	Actual licensing	Small & large	Firm	-	-	0.0008	1,598
	Gambadella & Giarratana (2006)	No	Actual licensing	Small & large	Firm	-	+	0.2929	691
Patent stock	Kim (2005)	Yes	Actual licensing	Large	Firm	+	-	0.7392	4,044
	Kim (2005)	Yes	Actual licensing	Large	Firm	+	+	0.0062	2,931
	Kim (2005)	Yes	Actual licensing	Large	Firm	+	+	0.0001	1,299
	Kim (2004)	Yes	Actual licensing	Large	Firm	+	+	0.0716	12,184
	Palomeras (2007)	Yes	Willingness to license	Small & large	Technology	+	-	0.9999	8,551

Determinants of technology licensing	Study Reviewed	Published Study	Dependent Construct	Size of firms in the sample	Level of measurement	Expected Direction	Observed Direction	p-value one tailed	df
Patent stock	Palomeras (2007)	Yes	Willingness to license	Large	Technology	+	-	0.9941	3,405
	Kim & Vonortas (2006a)	Yes	Actual licensing	Large	Firm	+	+	0.0040	9,298
	Ceccagnoli & Hicks (2009)	No	Actual licensing	Small & large	Firm	+	+	0.0001	1,036
	Ceccagnoli & Hicks (2009)	No	Actual licensing	Small & large	Firm	+	+	0.0055	1,036
	Ceccagnoli & Hicks (2009)	No	Actual licensing	Small	Firm	+	+	0.0010	412
	Ceccagnoli & Hicks (2009)	No	Actual licensing	Large	Firm	+	+	0.0001	612
	Novelli, Padula, & Rao (2007)	No	Actual licensing	Small	Firm	+	+	0.0001	1,260
	Gambadella & Giarratana (2006)	No	Actual licensing	Small & large	Firm	+	+	0.0273	691
Previous licensing experience	Fosfuri (2006)	Yes	Actual licensing	Large	Technology	+	+	0.0050	2,009
	Kim (2005)	Yes	Actual licensing	Large	Firm	+	+	0.0001	4,044
	Kim (2005)	Yes	Actual licensing	Large	Firm	+	+	0.0001	2,931
	Kim (2005)	Yes	Actual licensing	Large	Firm	+	+	0.0001	1,299
	Kim (2004)	Yes	Actual licensing	Large	Firm	+	+	0.0001	12,184
	Kim & Vonortas (2006)	Yes	Actual licensing	Large	Firm	+	+	0.0003	9,298
Technology level determinants									
Value of technology	Gambardella, Giuri & Luzzi (2007)	Yes	Actual licensing	Small & large	Technology	+	+	0.0054	7,085
	Gambardella, Giuri & Luzzi (2007)	Yes	Willingness to license	Small & large	Technology	+	+	0.0113	6,137
	Palomeras (2007)	Yes	Willingness to license	Small & large	Technology	+	+	0.1836	8,551
	Palomeras (2007)	Yes	Willingness to license	Large	Technology	+	-	0.8499	3,405
	Ceccagnoli & Hicks (2009)	No	Actual licensing	Small & large	Firm	+	+	0.0618	1,036
	Ceccagnoli & Hicks (2009)	No	Actual licensing	Small & large	Firm	+	+	0.4698	1,036
	Ceccagnoli & Hicks (2009)	No	Actual licensing	Small	Firm	+	-	0.9685	412
	Ceccagnoli & Hicks (2009)	No	Actual licensing	Large	Firm	+	+	0.0001	612
Technological fit	Gambardella, Giuri & Luzzi (2007)	Yes	Actual licensing	Small & large	Technology	-	-	0.0576	7,087
	Gambardella, Giuri & Luzzi (2007)	Yes	Willingness to license	Small & large	Technology	-	-	0.0473	6,137
	Palomeras (2007)	Yes	Willingness to license	Small & large	Technology	-	-	0.0331	8,551
	Palomeras (2007)	Yes	Willingness to license	Large	Technology	-	-	0.1440	3,405
Scientific nature of technology	Arora & Ceccagnoli (2006)	Yes	Willingness to license	Large	Firm	+	+	0.0042	747
	Gambardella, Giuri & Luzzi (2007)	Yes	Actual licensing	Small & large	Technology	+	+	0.1374	7,087
	Gambardella, Giuri & Luzzi (2007)	Yes	Willingness to license	Small & large	Technology	+	+	0.0200	6,137
	Ceccagnoli & Hicks (2009)	No	Actual licensing	Small & large	Firm	+	+	0.0460	1,036
	Ceccagnoli & Hicks (2009)	No	Actual licensing	Small & large	Firm	+	+	0.0419	1,036
	Ceccagnoli & Hicks (2009)	No	Actual licensing	Small	Firm	+	+	0.0035	412
	Ceccagnoli & Hicks (2009)	No	Actual licensing	Large	Firm	+	+	0.2716	612

Our analysis does not confirm the relationship between technology licensing and competition in the product market (χ^2=14.95, df=4, p=<0.01). Inconsistency in the empirical findings is more surprising considering the fact that all five studies in our analysis use the same measure to assess the competition in the product market, namely, the cumulative market share of four leading firms in the primary operating industry of the firm. For instance, three studies coming from the same paper by Kim (2005) use three independent samples of firms from three high-tech industry clusters: information and communication technology (ICT), biotechnology, and advanced materials. The positive relationship between technology licensing and competition in the product market is statistically significant only for the sample of firms in the ICT sector. These findings suggest that theoretical predictions regarding the effect of product market competition cannot be generalized across industries.

For the third relationship between licensing and the technological competition, we find that all results are in the predicted direction and relatively homogeneous (χ^2=1.96, df=3, p=0.58). Combining tests confirmed the generalizability of the positive relationship between the technological competition and the likelihood of technology licensing (see Table 2.3).

Despite the similar measurement of the independent construct by most studies, the positive relationship between licensing and the market growth is not supported by the empirical findings. As it can be seen in Table 2.2, the results are not only heterogeneous in terms of significance levels but, most importantly, the studies find opposite relationships between the variables (χ^2=19.97, df=4, p<0.001).

TABLE 2.3 Comparison and combination of significance levels

Determinants of technology licensing	Comparing		Combining						File drawer
	Test	Result	Test					Result	Test
			Adding p's	Adding t's	Adding Z's	Mean p	Mean Z		
1. Effectiveness of patent protection (All)	$\chi^2_{13}=22.26$, $p=0.051$	The studies may not be combined	-	-	-	-	-	Relation not confirmed	-
Effectiveness of patent protection (Technology)	$\chi^2_{3}=1.86$, $p=0.603$	The studies can be combined	p<0.001	3.40 p<0.001	3.40 p<0.001	2.87 p<0.005	-	Relation confirmed	13
2. Competition in the product market	$\chi^2_{4}=14.95$, $p=0.005$	The studies may not be combined	-	-	-	-	-	Relation not confirmed	-
3. Technological competition	$\chi^2_{3}=1.96$, $p=0.581$	The studies can be combined	p<0.001	3.21 p<0.001	3.21 p<0.001	2.80 p<0.005	-	Relation confirmed	11
4. Market growth	$\chi^2_{5}=19.97$, $p=0.001$	The studies may not be combined	-	-	-	-	-	Relation not confirmed	-
5. Presence of complementary assets (All)	$\chi^2_{6}=24.03$, $p=0.001$	The studies may not be combined	-	-	-	-	-	Relation not confirmed	-
Presence of complementary assets (Small & large)	$\chi^2_{2}=0.84$, $p=0.657$	The studies can be combined	p=0.905	- 0.41 p=0.658	- 0.41 p=0.658	- 0.52 p=0.697	-	Relation not confirmed	-
Presence of complementary assets (Large)	$\chi^2_{1}=0.34$, $p=0.563$	The studies can be combined	p<0.001	0.323 p<0.001	0.323 p<0.001	0.237 p<0.01	-	Relation confirmed	6
6. Firm's product market share	$\chi^2_{1}=15.66$, $p<0.001$	The studies may not be combined	-	-	-	-	-	Relation not confirmed	-

Determinants of technology licensing	Comparing		Combining						File drawer
	Test	Result	Test					Result	Test
			Adding p's	Adding t's	Adding Z's	Mean p	Mean Z		
7. R&D intensity	χ^2_4=16.69, p<0.005	The studies may not be combined	-	-	-	-	-	Relation not confirmed	-
8. Firm size (All)	χ^2_{13}=72.88, p<0.001	The studies may not be combined	-	-	-	-	-	Relation not confirmed	-
Firm size (Small)	χ^2_1=0.30, p=0.585	The studies can be combined	p=0.045	1.57 p=0.058	1.57 p=0.058	1.71 p=0.044	-	Relation confirmed	-
9. Patent stock (All)	χ^2_{12}=73.70, p<0.001	The studies may not be combined	-	-	-	-	-	Relation not confirmed	-
Patent stock (without Palomeras (2007))	χ^2_{10}=29.17, p<0.001	The studies may not be combined	p<0.001	8.63 p<0.001	8.61 p<0.001	4.85 p<0.001	6..46 p<0.001	Relation confirmed	>100
10. Previous licensing experience	χ^2_5=1.05, p=0.958	The studies can be combined	p<0.001	8.52 p<0.001	8.52 p<0.001	4.24 p<0.001	18.59 p<0.001	Relation confirmed	>100
11. Value of technology	χ^2_7=24.92, p<0.001	The studies may not be combined	-	-	-	-	-	Relation not confirmed	-
12. Technological fit	χ^2_3=0.33, p=0.953	The studies can be combined	p<0.001	3.07 p<0.005	3.07 p<0.005	2.98 p<0.005	-	Relation confirmed	10
13. Scientific nature of technology	χ^2_6=3.51, p=0.742	The studies can be combined	p<0.001	4.73 p<0.001	4.73 p<0.001	3.90 p<0.001	6.18 p<0.001	Relation confirmed	51

Considering the firm level determinants of technology licensing, we start our analysis with the presence of complementary assets. Overall homogeneity test reports that the empirical findings are very different both in terms of direction of the relation and in their level of significance (χ^2=24.03, df=6, p<0.001), which means these studies may not be combined. However, more detailed analysis reveals some compelling findings suggesting that the empirical results depend on the size of firms in the samples used for the analysis. Separate homogeneity tests for two subgroups, first that consist of both small and large firms (χ^2= 0.84, df=2, p=0.657) and second that consist of only large firms (χ^2= 0.34, df=1, p=0.563), suggest that they can be combined. First combination tests for the subgroup consisting of both small and large firms reject the theoretical proposition of the negative relationship between the presence of complementary assets and licensing because the relationship found to be insignificant for all studies. Whereas combination tests for the second subgroup of large firms confirm the relationship (see Table 2.3). Hence, the results suggest that theoretical prediction of a negative relationship between the presence of complementary assets and the technology licensing cannot be generalized. One possible source of inconsistency in findings can be heterogeneity of proxies used to measure complementary assets. Therefore, there is a need to come up with better measures of complementary assets and maybe to account for the presence of different types of complementary assets.

The negative relationship between technology licensing and the firm's product market share is not supported by our analysis (χ^2= 15.66, df=1, p<0.001). Although both studies report quite significant results, the directions of these relationships are opposite. Again, one reason for such an outcome can be the fact that the studies use very different measures to operationalize their independent construct. Moreover, two studies are not enough to be able to make a confident inference about the relationship between variables.

The meta-analysis does not provide any support for the positive effect of R&D intensity on technology licensing (χ^2= 16.69, df=4, p<0.005). All five studies that consider this relationship measure the construct in the same way: as a ratio between

R&D expenditures and sales. Thus, our analysis suggests that theoretically predicted positive relationship cannot be generalized across firms and industries.

The next hypothesis examined relationship is between the firm size and licensing propensity. Our meta-analysis includes 14 studies that measure this independent construct. Overall homogeneity test suggests that the directions and the significance levels of these studies vary substantially, and they may not be combined (χ^2= 72.88, df=13, p<0.001). However, taken separately, studies that investigate the relationship using the samples of small firms are quite homogeneous and can be combined (χ^2= 0.30, df=1, p=0.585). Combining tests suggest that the negative relationship between constructs can be confirmed for the subgroup of studies that use the sample of small firms, however, results of the tests are significant at the 0.05 level (see Table 2.3). A possible explanation for such results can be one proposed by Motohashi (2008), who argues that there is a non-linear U-shaped relationship between licensing propensity and firm size. Therefore, studies that use the sample of small firms observe a negative relationship between firm size and licensing, whereas studies that use samples of only large or both large and small firms get contradicting results. Future research on technology licensing should consider and investigate the possibility for non-linear relationship between technology licensing and the firm size.

A visual analysis of heterogeneity of studies examining the relationship between the firm's patent stock and its licensing propensity reveals that 10 out of 13 studies report positive and significant relationship, even though formal homogeneity test reports high dispersion (χ^2= 73,70, df=12, p<0,001). Among three studies that find a negative relationship two are taken from Palomeras (2007), who uses patent stock as a measure of firm size without any other extra control, which may be the main reason that these studies report results very distinct from other studies. Therefore, we can omit these to studies from our calculations. The remaining study that reports negative relationship has non-significant p-value. However, even after excluding two studies by Palomeras (2007) homogeneity tests does not recommend combining the studies (χ^2= 29.17, df=10, p<0.001). More detailed inspection of the reviewed studies shows that the results of homogeneity tests are caused by the magnitude of divergence of their significance levels. Out of 11 studies 4 have p-values of 0.0001, while others have lower but still highly significant p-values. Thus, following Sobrero & Schrader (1998), we argue that the existing heterogeneity does not prevent the combination of studies. All combination procedures support our intuition and confirm the generalizability of a positive relationship between the firm's patent stock and the licensing propensity (see Table 2.3).

Our findings fully support the theoretical prediction that previous licensing experience is positively related to the current licensing propensity. Homogeneity test reports that significance levels are highly similar and can be combined (χ^2= 1.05, df=5, $p<0.001$). Combination tests also report highly significant p-values (see Table 2.3). There can be two main possible explanations for the positive relationship. First, previous licensing experience can lower transaction costs of current licensing. Second, the variable can also detect unobserved effects such as management predisposition toward licensing, which means that firms that have licensed before are likely to license in the future as part of their management strategy (Kim & Vonortas, 2006).

With respect to the effect of the value of the technology, our analysis does not find support for theoretically predicted positive relationship. The results are not only heterogeneous in terms of significance levels (χ^2= 24.92, df=7, $p<0.001$) but also in terms of direction. The ambiguous effect of the value of the technology licensing can stem from following reasons. On the one hand, valuable innovation raises interest by potential licensees to be commercially exploited that has a positive effect on licensing revenues. On the other hand, innovator can also be interested in exploiting valuable innovation in-house or can decide to avoid potential competition caused by licensing out valuable innovation (Palomeras, 2007).

The evidence for the relationship between the technological fit and licensing propensity confirms the theoretical proposition that core technology is less likely to be licensed out. Comparison test reports that studies can be combined (χ^2= 0.33, df=3, p=0.953), whereas combination tests confirm the generalizability of conclusions (see Table 2.3). However, in our analysis we have only four studies coming from two research papers, which can be a reason for the homogeneity of their results.

Therefore, there is a need for more studies to be able to better justify the generalizability of our conclusions.

Finally, the last relationship considered in our meta-analysis is related to the scientific nature of the technology. Theoretical proposition suggests that science based and codifiable technologies, rather than tacit ones, are more likely to be licensed out. According to the homogeneity test, results of all the studies reviewed are similar and can be combined (χ^2= 3.51, df=6, p=0.742). All the performed combination tests also present that conclusions observed in the sample can be generalized (see Table 2.3).

The last column in the Table 2.3 reports the result of the file drawer test. The test calculates the number of studies reporting null or opposite results necessary to lower the overall probability of a type I ("false positive") error in the results of our combination procedures to 0.05. The tests suggest that for the confirmed relationships the number of studies needed to falsify the conclusions varies from 6 for the relationships that are represented by very limited number of studies to more than 100 for the relationships that are addressed by a higher number of studies.

2.5. DISCUSSION

2.5.1. Implications for future research

This paper used meta-analytic approach based on 18 studies retrieved from 11 papers to review, compare, and synthesize the results of prior empirical research addressing the relationships between technology licensing and its various determinants. Out of 13 hypothesized relationships suggested in the literature only 7 found full or partial support in the meta-analysis. Results for remaining 6 studies either disconfirmed the generalizability of theoretical predictions or partly supported alternative hypotheses, e.g. hypotheses suggesting a non-linear relationship between dependent and independent constructs.

The evidence fully supports the hypothesized relationships between technology licensing and the technological competition, the size of patent stock, the previous licensing experience, the technological fit, and the scientific nature of the technology. Two hypothesized relationships for the effectiveness of patent protection and the presence of complementary assets are confirmed only for subsets of available studies. Eventually, other six hypotheses related to the product market competition, the market growth, the firm's product market share, the R&D intensity, the firm size, and the value of the technology are not supported by our results.

The cumulative evidence provided by the meta-analysis may have several implications for future research in the field of markets for technology in general, and in the field of technology licensing in particular. Overall inconclusiveness of empirical findings in term of direction and significance levels calls for reconsidering and fine-tuning some of the existing theories and their propositions. As a result of our analysis, we can propose several possible directions of such improvements.

First, all theoretical hypotheses reviewed in this paper suggest for linear relationships between technology licensing and various explanatory variables. However, as in the case of such determinant as the firm size a functional form of the relationship can be U-shaped rather than linear. For instance, Motohashi (2008) on the sample of Japanese firms found that compared to their small and large counterparts medium sized firms are less likely to license their technologies.

Therefore, the possibility of a non-linear relationship between the variables can be a key for resolving some of inconsistencies between theoretical propositions and empirical evidence.

Second, although the studies analyze the effect of an independent variable by trying to hold all the other relevant variables constant, they usually ignore the possible interaction and moderating effects between key explanatory variables. For instance, Arora & Ceccagnoli (2006) find that the effectiveness of patent protection positively effects the licensing decision only when necessary complementary assets are absent or unimportant, whereas Palomeras (2007) finds that the core technology is more likely to be licensed if it has a higher value. These interaction and moderating effects are still not fully explained and constitute an area for further research. Thus, an important implication for empirical research is that our review reveals a need for other studies that include many of the discussed determinants of technology licensing and that test various interaction and moderating effects.

Third, the fact that studies based on the samples represented by different combination of industries get different results, despite similar measurement and operationalization of the independent constructs, suggests that some theoretical predictions can only be applied for specific industries or specific categories of firms and may not be generalized. To understand better these differences in technology licensing across industries, technological classes, countries and various categories of firms (e.g. in terms of size) future empirical studies should collect and utilize richer and more comprehensive datasets that cover a wide range of industry, firm, and technology level characteristics.

Finally, the empirical studies on technology licensing used in the analysis utilize many different measures and proxies for the same explanatory variables. Some of these measures have quite ambiguous and unpersuasive relationships with the theoretical constructs. Therefore, there is a need for better proxies and measures that actually capture the intended theoretical constructs.

The implementation of these recommendations in the future research could improve our understanding of the determinants of technology licensing.

2.5.2. Limitations

The main limitation of the current study is related to the scarcity of studies that empirically address the relationship between technology licensing and its determinants. Most of the studies selected for the analysis are relatively recent and fall within the period between 2006 and 2010. This situation is substantially caused by the limited availability of comprehensive data. The problem is especially severe for some independent constructs, the measures for which are not easily available at the public or commercial databases. Hence, the current meta-analysis can be further improved by including additional studies that may appear in the future. The second concern is related to the variance in the operationalization of the theoretical constructs used in the different studies. The detected heterogeneity among studies in terms of significance levels may partly stem from the variety of measures used. Moreover, since the studies in our sample usually include different sets of independent and control variables it becomes problematic to single out the effect size of a particular determinant and compare it across studies. Therefore, we are not able to fully exploit the possibilities offered by meta-analysis and limit our analysis to the directionality and significance levels of the effects rather than focusing on their magnitude.

CHAPTER 3

THE DETERMINANTS OF THE ECONOMIC USE OF PATENTED INVENTIONS: PURE INTERNAL USE, PURE LICENSING, AND MIXED USE†

ABSTRACT

A firm's ability to choose an optimal strategy for the economic exploitation of its patented inventions is critical for creating and appropriating value from its intellectual property. In this study, we contribute to the literature on technology and innovation management in several ways. First, we compare the determinants of alternative uses of inventions such as pure internal use, pure licensing and mixed use (both internal use and licensing). The main explanatory factors are complementary assets, technological competition, technological distance, and technological generality of a patented invention. Second, we adopt a multidimensional view on complementary assets needed to turn an invention into a success (technological, commercial and both) and explore their role in detail, including the interaction between complementary assets and key explanatory factors. The data to test our hypotheses come from a large-scale survey of European Patent inventors resident in 21 European countries, Japan, and US. The results show that various types of complementary assets are differently associated with the economic use of patented inventions. Our findings indicate that the presence of complementary assets has a strong direct and moderating influence on different patent uses. Other key explanatory variables, by and large, have the expected association with patent pure internal use, pure licensing, and mixed use.

† The paper has been developed in collaboration with the main supervisor Prof. Salvatore Torrisi.

3.1. INTRODUCTION

A firm that has created and patented an invention has different alternatives for its exploitation. The recent development of the markets for technology has increased the number of these options available to firms that range from pure internal use to pure licensing (or sale). The main motivation for the current study is the lack of comprehensive understanding of the determinants of the choice between alternative economic uses of patented inventions.

Not all inventions are patented, and, therefore, patent data provide imperfect coverage of inventive activity. However, we choose patented inventions as a unit of our analysis for the following reasons. First, although, in principle, licensing is possible even without patenting (Anton & Yao, 1994; Arora, 1996), available evidence suggests that firms that do not patent rarely license and the empirical importance of the alternative mechanisms remains unknown (Arora & Ceccagnoli, 2006). Second, since the patent data provide relatively extensive information about an invention in a highly standardized way it allows collecting and analyzing data for each invention using automated procedures. Moreover, patent data is easily comparable across inventions, which is particularly important for an empirical analysis with a large number of observations. Rivette & Kline (2000b), for instance, describe patent databases as "a virtual Alexandrian library of information". Collecting the equivalent data for a large number of unpatented inventions is a difficult and impractical task. Third, since previous studies based on patent data have developed a number of generally accepted indicators affecting the economic use of patented inventions, the use of patent data in our study allows using similar indicators and comparing our findings with earlier works. For the sake of simplicity, throughout this paper we will often refer to patented inventions as technologies or innovations.

Although previous empirical studies have examined the determinants of technology licensing, they have not explicitly accounted for alternative exploitation strategies such as direct internal use and mixed use (i.e. combination of internal use and licensing). As noted by Arora et al. (2001b), licensing is an option not mutually exclusive with own production, therefore, a firm can combine them and come up with a mixed use strategy. We review the literature to identify benefits and drawbacks of combining internal use and licensing compared to the alternatives of pursuing pure internal use or pure licensing strategies. Our findings reveal that the frequency of such mixed use is about 2.7 times higher than pure licensing. Empirical results suggest that the mixed use strategy is an important alternative to pure internal or external exploitation of technology, especially for technologically distant or general-purpose technologies with a wide range of potential application. Moreover, we find that determinants of mixed use are not necessarily the same as determinants of pure internal use and pure licensing.

The importance of complementary assets for technology commercialization is not a novel idea. Starting from the seminal work of Teece (1986) complementary assets have received substantial attention in the literature. However, past empirical research on licensing was mainly focusing on downstream manufacturing complementary assets (e.g. Arora & Ceccagnoli, 2006). Here, we emphasize the importance of the multidimensional nature of complementary assets and distinguish complementary assets necessary for economic success of the invention, such as manufacturing and marketing assets, from complementary assets necessary for technical success, such as advanced R&D capabilities. Another dimension that we focus on is the presence of organization-specific complementary assets that are developed within the firm during the invention process. We find that various types of complementary assets are differently associated with the alternative economic uses of patented inventions.

Arora & Ceccagnoli (2006) found that the presence of complementary assets has moderating effect on the relationship between the appropriability regime and technology licensing. Inspired by their findings, we further investigate the moderating effect of complementary assets on other determinants of the economic use of patented inventions. Our results suggest that the presence of complementary assets has strong moderating influence on technological competition, distance, and generality, apparently, the effects are different for the various patent use alternatives.

The data to empirically test our hypotheses come from a large scale inventor survey developed and conducted within the InnoS&T project (Gambardella et al., 2012). The survey collects cross-sectional data on a number of issues related to the invention process, its determinants, the value of the invention, and its economic use. The dataset has been constructed by combining initial invention level survey data with additional firm and industry level information from public and commercial databases.

The purpose of this study is to contribute to a better understanding of the economic use of patented inventions by expanding the limits of previous research in several different dimensions discussed above, whereas the limitations present in our study could be addressed by future research.

The paper is organized as follows. The next section reviews the literature and introduces a set of hypotheses. The third section describes the dataset, variables, and econometric methods. The fourth section reports our empirical results. Finally, the last section discusses the findings and concludes.

3.2. THEORY AND HYPOTHESES

3.2.1. Economic exploitation of patented inventions: internal commercial use, licensing, and mixed use

A firm that has created and patented an invention has different alternatives for its exploitation. The first and most traditional option is to commercialize it directly by embedding it into a final product or a production process. The existence of the markets for technology facilitates the external use of patented inventions through licensing or sale as an alternative or in addition to internal commercial use. In the literature, licensing and internal use of technology are often viewed as alternatives of each other, and the empirical research has investigated the determinants of one or the other in a "either-or" decision setting (Arora & Ceccagnoli, 2006; Teece, 1986). However, as noted by Arora et al. (2001b), licensing is an option not mutually exclusive with own production, therefore, a firm can combine internal use and licensing. Empirical evidence suggests that such mixed use strategy is an alternative to pure internal or pure external exploitation of technology, especially in industries characterized by general-purpose technologies with a wide range of potential application (e.g. Arora et al., 2001b). As emphasized by Teece (1986, p. 289), "decisions to integrate or license involve tradeoffs, compromises, and mixed approaches. It is not surprising therefore that the real world is characterized by mixed modes of organization, involving judicious blends of integration and contracting".

Apparently, there can be different tracks that lead to this mixed use strategy. For instance, the patent holder may first license out its invention in order to acquire more information about its technical or economic value and then decide to start its own production or vice versa. For the purpose of this study, we will use the term *mixed use* to define such combination, as opposed to *pure commercial use* and *pure licensing*.

It is important to emphasize that the determinants of mixed use are not necessarily the sum of the determinants of pure internal use and pure licensing. This argument is supported by recent theoretical works that emphasize possible synergies or diseconomies between internal use and licensing of technology (Teece, 2006). There are a number of theoretical arguments that suggest either positive or negative synergies resulted from the mixed use strategy, but so far there is no conclusive answer to a question as to when these positive synergies overbalance the negative ones.

Below we will briefly outline the possible benefits of combining licensing and internal use of inventions. First, an obvious benefit of pursuing together internal use and licensing is a possibility of having multiple sources of revenue (Arora et al., 2001b). Second, by exploiting the same invention internally and externally a firm may achieve economies of scale in its R&D activities and successfully allocate relatively fixed costs of initial R&D investments across multiple parties represented by the firm itself and multiple licensees (Chesbrough, 2003; Fosfuri, 2006). Third, the combination of internal and external use creates more complex business strategy or business model that makes it more difficult for competitors to identify the source of value and to imitate these strategies by creating an additional layer of competitive advantage (Hamel & Prahalad, 1989).

Additionally, the combination of internal use and licensing can benefit and stimulate the firm's own product business. First, the firm may sell products that are complementary to licensed inventions (Rivette & Kline, 2000a), therefore, by licensing, the firm can stimulate additional sales of own products. Moreover, licensing, in addition to internal use, can be pursued in order to create a dominant design or set a technological standard (Khazam & Mowery, 1994), which will be definitely beneficial for the firm in terms of stimulating its product sales. Second, licensing, in addition to internal use, may actually enhance a demand for the firm's products by securing for its customers a "second source of supply" represented by licensee (Davis & Harrison, 2001; Shephard, 1987). If the firm's customers are part of downstream production chain and use firm's products as an input to their own production process, in the absence of the "second source of supply" they will have to deal with a monopolist supplier and be subject to hold-up and lock-in problem. By licensing to others, the technology owner creates the "second source of supply" and mitigates these problems to its potential customers and, therefore, may actually enhance the demand for its own products.

Considering the benefits of internal use on licensing, first, internal commercial use may have a signaling effect about potential technical and economic value of the invention. For instance, potential licensees often require a proof of the concept by means of prototypes (Jensen & Thursby, 2001) or by other means. The successful application of the invention in the firm's own production may represent the proof of its functionality and technical value (Arora et al., 2001b). Moreover, the internal use of technology may facilitate potential licensees' interest by demonstrating areas of possible application of the technology. Finally, internally used technologies due to learning effect can be constantly improved, and any existing defects and bugs can be efficiently fixed. Therefore, if internally exploited technologies are offered for licensing, they are more likely to have higher licensing prospects due to their higher overall quality.

The main drawback of combining licensing and internal use of inventions is that licensing creates new competitors in the product market (the rent dissipation effect) and, therefore, reduces the price-cost margin and/or market share (Arora & Fosfuri, 2003; Fosfuri, 2006). In an extreme case, licensing, in addition to internal use, could turn a monopoly into a competitive market (Arora et al., 2001b). Thus, although the combination of internal use and licensing may increase revenue opportunities, the size of these revenue flows could be overbalanced by the rent dissipation effect due to increased competition (Arora & Fosfuri, 2003). Teece (2007) has made a similar point by claiming that licensing is likely to yield some cannibalization of profitable product lines for large, diversified firms, which are, therefore, less willing to license their technology. Moreover, internal use may discourage potential licensee to adopt the technology due to the presence of strong and powerful competitor in the product market represented by the licensor. Therefore, in certain cases licensees seek an exclusive license that prevents the patent owner from internally using its invention and competing with the licensee.

It is worth noting that a firm may internally and externally exploit different inventions or the same invention. In the first case, firms may use one invention for developing a new product and license another invention to enable other firms to develop complementary products. In the second case, firms may commercialize internally and license the same invention. Firm level analyses cannot clearly distinguish between these two cases, whereas our invention level analysis clearly focuses on the combination of internal and external uses of a particular patented invention. Considering the discussion above, it is interesting to investigate and compare the determinants of pure internal use, pure licensing and mixed use strategies.

Two main theories that help us to identify and explain the determinants of economic use of patented inventions are the transaction cost theory and the resource-based theory. Drawing on the transaction cost theory (Williamson, 1975; Williamson, 1979), Teece (1988a) explains the use of technology by emphasizing the importance of minimizing transaction costs. He suggests that market-based technology transfer mechanisms like licensing are attractive when the associated transaction costs are lower compared with internal exploitation. On the other hand, the resource-based theory highlights the role of unique combinations of resources in maximizing value creation and imperfections in the market for strategic resources (Dierickx & Cool, 1989), suggesting that a technology is best used by those who possess the bundle of complementary resources that are required to profit from the technology (Teece, 1986).

The main limitation of the transaction costs theory in its examination of market based technology transfers is a too narrow focus on separate transactions (Fosfuri, 2006). The resource-based view, on the other hand, focuses on the resources and capabilities that maximize value creation by overlooking the organization of markets for these resources and capabilities. Therefore, using only one of these two theoretical frameworks does not permit to fully understand the use of strategic assets like patents phenomena. For this reason, we examine licensing and commercial use of patents through an integrated framework which takes into account the transaction cost theory, the resource-based view in order to study the problem by looking at it through multiple theoretical lenses.

Complementary assets. The resource-based view suggests that one of the most significant determinants of the economic use of inventions is the presence and the nature of complementary assets (Teece, 1986). The complementary assets are defined as resources necessary to produce and commercialize an invention. In this study, we identify and investigate two types of complementary assets: complementary assets necessary for economic success and complementary assets necessary for technical success of the invention. The first type of complementary assets comprises manufacturing, marketing and distribution assets that are necessary to turn an invention into an economically successful product or process innovation. The second type of complementary assets is represented by the firm's R&D capabilities such as specialized technical knowledge or sophisticated equipment necessary to improve and refine the invention. For instance, a small R&D intensive biotechnology company that has discovered and patented new therapies for diseases such as diabetes, heart attacks, or cancer may lack technical complementary assets necessary for further research, development, and testing that are required before full scale commercialization of the pharmaceutical product.

Given these two types of complementary assets, firms can be endowed either with the first type, the second type or both types of complementary assets. Therefore, in this study we investigate the effect of these different types of complementary assets on the economic use of patented inventions.

The literature suggests that the effect of complementary assets on the use of inventions is relatively clear. If the owner of the invention does not have complementary assets necessary to commercialize it, the transfer of the invention through market-based arrangements to other parties that possess these complementary assets is a rational strategy. Therefore, the pure internal use of patented inventions is a natural choice for the firm which is endowed with all necessary complementary assets. By the same token, these firms are unlikely to purely license their invention, which would imply that the firm does not utilize already available complementary assets to use the invention internally.

By contrast, when an innovating firm does not possess all necessary complementary assets (e.g. firm has downstream production and marketing assets but misses sufficient technical capabilities), it may access missing complementary assets through collaboration with other firms that already own these resources and capabilities. For instance, during the convergence of computer and communication technology, firms in each industry were discovering that they often lack the necessary technical capabilities in the other industry that induced the collaboration between the two (Teece, 1986). Such collaboration through technology licensing, in addition to internal commercial use, may result in a mixed use strategy. Building on these considerations, we formulate the first hypothesis:

Hypothesis 1: The availability of all complementary assets (i.e. for both economic and technical success) is positively associated with pure internal use, but negatively associated with pure licensing and mixed use.

Organization-specific complementary assets. As mentioned before, complementary assets are important to develop an innovation. However, complementary assets are particularly difficult to imitate and acquire on the strategic factor markets (Barney, 1986) if they are organization-specific and highly rely on tacit knowledge. Clearly, the organizational specificity of complementary assets has important implications for the use of the inventions. Patented inventions, as any other forms of knowledge, have both codifiable and tacit dimensions (Arora, 1995; Nelson & Winter, 1982; Polanyi, 1966). While codified knowledge about the invention is relatively easy to transfer through patent documents, blueprints, and other documents, tacit knowledge is more difficult to communicate and costly to transfer to other parties. Teece (1988a) emphasizes that the production of technology is a cumulative process based on tacit knowledge, which is organizationally embedded and difficult to transfer. Dierickx & Cool (1989) argue that implementation of strategy often requires highly firm specific assets. Because of their idiosyncratic nature, organization-specific assets have to be accumulated over time and cannot be traded in the strategic factor markets.

Kline & Rosenberg (1986) argue that inventive activity and commercialization activities (i.e. production and marketing activities) are intertwined and require frequent information exchange, improvements and modifications in the underlying technology at different commercialization phases. Therefore, tacit knowledge and organizational routines are developed within the organization during the invention stage through frequent communication and knowledge flows. For this reason, inventions are often developed and commercialized internally.

Moreover, Teece (1992) argues that the firm's ownership of unique and difficult to replicate complementary assets represents a second line of defense for the invention against imitators even in the absence of effective patent protection. Thus, tacit knowledge about the invention embedded in the organizational routines makes the imitation of strategic assets difficult and, therefore, can be a source of competitive advantage.

Frequent interactions between employees from different functional departments of the organization can be considered as a mechanism that creates and develops idiosyncratic capabilities, skills, and tacit knowledge about the invention by means of mutual learning, specific organizational routines, interpersonal relationships, and unique communication channels (Nelson & Winter, 1982). The innovating firm may benefit from the presence of such tacit knowledge developed within the organization over time only if the invention is commercialized internally. Drawing on the notion of tacitness and organizational embeddedness, Arora & Ceccagnoli (2006, p. 299) have claimed that the frequency of interactions between R&D and manufacturing personnel is "the quintessence of the notion of specialized complementary assets". We elaborate on this idea and consider frequent interactions between inventors and all other organizational departments during the inventive process as an indicator of the presence and importance of organization-specific complementary assets. On this basis, we posit the following:

Hypothesis 2: Organization-specific complementary assets are positively associated with pure internal use, but negatively associated with pure licensing and mixed use.

Technological competition. The presence of several firms that have similar or substitutable technologies competing with each other could affect the decision about the use of the invention. With regard to internal use, intensive technological competition is likely to discourage firms from commercializing their inventions. First, with several firms competing for the technology there is uncertainty about which technology will outperform others and eventually become a technical standard, therefore, firms will be cautious about making large irreversible investments into commercialization of their technology (Kauffman & Li, 2005). Second, the intensive technological competition is a predictor of highly competitive product market in the future. Therefore, firms may prefer to concentrate their resources into commercialization of inventions for which they possess some technological and competitive advantage, i.e. inventions associated with lower external technological competition.

With regard to pure licensing and mixed use options, we argue that technological competition should encourage both. Arora & Fosfuri (2003) demonstrate analytically that competition in the markets for technology induces licensing of innovations and that even incumbent firms may find it profitable to license, especially in highly competitive markets. This is because the entry of new competitors in a competitive market produces limited rent dissipation effects for incumbents. Even in a monopolistic market, despite the potentially high rent dissipation effects, the presence of competing technologies may lead the incumbent to license out for various reasons such as deterring the entry of strong competitors (Rockett, 1990b) or establishing a market standard (Khazam & Mowery, 1994). The presence of multiple sources for technology creates a strategic incentive to license because a technology holder's refusal to license not only will be unable to keep technology secret and block entry of other firms to the product market but also will reduce the flow of licensing payments (Fosfuri, 2006). Therefore, we posit the following:

Hypothesis 3a: Technological competition is negatively associated with pure internal use, but positively associated with pure licensing and mixed use.

The absence of complementary assets may reinforce the effect of technological competition on the likelihood of licensing. First, without necessary complementary assets the only way for firms to profit from their inventions under conditions of high technological competition is by aggressively licensing to other firms that already posses these assets and, therefore, can exploit the invention. Second, the lack of complementary assets may stem from a strategic choice not to become a downstream producer and focus on upstream technology creation (Gambardella et al., 2007), which implies a business model that is primarily based on technology licensing strategy (Teece, 2010). In this case, technological competition should intensify the licensing behavior by these specialized technology firms in order to disseminate their technology and try to earn more licensing revenues than their competitors. In other words, in their licensing behavior firms without complementary assets should be more sensitive to the technological competition than firms with complementary assets. Therefore, we expect the following:

Hypothesis 3b: The positive association between technological competition and pure licensing is stronger if the firm does not possess necessary complementary.

Technological distance. The technological distance is defined as a degree to which a given invention overlaps the firm's existing patent portfolio, which represents the firm's core knowledge and competencies (Laursen, Leone, & Torrisi, 2010). For instance, when the existing patent portfolio contains high fraction of patents in the same technological class as the focal patent, the technological distance is considered low.

Other things being equal, a low technological distance will favor pure internal use, while a high technological distance will induce external use strategies. Rivette & Kline (2000b) suggest that while core technologies that give the firm competitive advantage should be rigorously protected, non-core technologies should be actively licensed for revenue. Empirical studies on licensing find that marginal technologies are more likely to be licensed out (Gambardella et al., 2007). Thus, firms tend to license out non-core technologies rather than sharing their core technologies, which are usually commercialized internally (Gambardella & Torrisi, 2010a).

Pure licensing and mixed-use strategies are less likely to be adopted with respect to core technologies due to the potentially strong rent dissipation effects that we have discussed earlier. Licensing the core technology that is also used internally may allow new competitors to enter the licensor's core product market, with potential negative consequences for its profits and market shares. Therefore, we expect the following:

Hypothesis 4a: High technological distance is negatively associated with pure internal use, but positively associated with pure licensing and mixed use.

Considering the moderating role of the complementary assets on the effect of technological distance, we argue that the absence of complementary assets will reinforce the positive relationship between the technological distance and licensing. The real option theory suggests that, under uncertainty, an option to wait and preserve the right to make investment choices in the future is valuable to a firm (McDonald & Siegel, 1986; McGrath & Nerkar, 2004). In our context, the choice here is whether to invest in the development of necessary complementary assets for the internal commercial use of an invention or not. We argue that for the technologically distant or non-core inventions the firm is less likely to consider seriously future investments in complementary assets, therefore, these inventions are more likely to be licensed out for revenue. Therefore, we pose the following hypothesis:

Hypothesis 4b: The positive association between technological distance and pure licensing (mixed use) is stronger if the firm does not possess necessary complementary assets.

Technological generality. The generality of technology refers to the variety of applications where the technology can be potentially used. For instance, Bresnahan & Trajtenberg (1995) characterize general-purpose technologies by their potential for pervasive use in a wider range of sectors, their technological dynamism, and the need for complementary investments after adoption. The level of technological generality and associated variety of applications imply the higher number of potential licensors that could exploit the invention and, therefore, higher demand for the technology. As emphasized by Arora et al. (2001b), the technological generality affects the breadth of the markets for technology. Therefore, the more general is the patented invention the higher the likelihood that it can be licensed to a large number of different licensees operating in different industries and product markets, thus providing multiple sources of licensing revenue.

The technological generality may also be positively associated with the mixed use strategy. Since the licensor can structure a licensing agreement in a way that limits the licensee's use of technology as to time, geographical area, or field of use, this allows licensing out more general-purpose technology to parties that operate in different product markets and do not directly compete with each other or with the licensor. Consequently, the technological generality allows for combining internal use and licensing (i.e. mixed use) without creating a significant rent dissipation effect arising from the competition between the licensor and licensee. Therefore, we posit the following:

Hypothesis 5: The level of technological generality of the invention is negatively associated with pure internal use, but positively associated with pure licensing and mixed use.

3.3. DATA AND METHODS

3.3.1. Data

The data to empirically test our hypotheses come from a large scale inventor survey developed and conducted within the InnoS&T project (Gambardella et al., 2012). The survey collects cross-sectional data on a number of issues related to the invention process, its determinants, the value of the invention, and its economic use. The dataset has been constructed by combining initial invention level survey data with additional firm and industry level information from Amadeus, EPOSYS, Orbis, Osiris, PATSTAT databases.

The self-administered survey of inventors is global in scope and covers patented inventions from 21 European countries, Japan, and US. The sample was drawn at the level of patent applications with priority years between 2003 and 2005. The final composition of the sample is the following: Europe – 62,148 observations, U.S. – 45,861, and Japan – 16,125. After sampling the patents, one inventor listed on the patent document was randomly chosen and was sent an invitation letter to participate in the survey. The letter asked the inventors to fill out an online questionnaire on a website that they could access through an identification number and a password, generated for the specific inventor. The number of responses for the survey by the inventors in all surveyed countries is equal to 23,044, which corresponds to a corrected response rate of 20%.

For the analysis, we use a part of the survey that contains only patented inventions owned by private for-profit firms. The patented inventions that belong to individuals and to non-profit organizations are excluded from the further analysis. The exclusion of non-profit organizations such as universities and research institutes is justified by the fact that these organizations have completely different institutional settings and different motivations for the use of their patented inventions. For instance, due to the lack of necessary complementary assets universities tend to specialize in the creation of knowledge assets, the commercialization of which is usually left to other organizations. As a result of this restriction, incomplete responses about the economic use of patented inventions, and missing data for different explanatory and control variables, the final sample comprises 14,006 observations on 6,131 firms.

3.3.2. Variables

Dependent Variables

Based on dichotomous responses about internal commercial use and licensing of the patented inventions we generate 4 dummy variables. *Pure internal use* equals to 1 if the patent owner or affiliated parties only used the patented invention commercially (i.e., in a product, service or manufacturing process) without licensing it. *Pure licensing* takes a value of 1 if the patent has only been licensed by the patent owner to an independent party without using it internally. *Mixed use* accounts for the fact that the patent owner or affiliated parties used the patent in a product, service or manufacturing process and licensed it to an independent party. Finally, *no use* equals to 1 if the patent has neither been used commercially by any of the patent owners nor licensed out to other parties. Sold patents (i.e. when the entire ownership rights for an invention were transferred to another firm) were excluded from the *non use* category and from the sample used in the regressions.

Independent Variables

The independent and control variables used in the study can be classified in the following three categories: characteristics of the patent, characteristics of the organization, and characteristics of the industry or external context (see the Appendix I for a summary of variables and their measures). These measures represent either indicators adapted from existing literature or novel indicators developed within the InnoS&T project.

Complementary assets. The survey asks whether (a) the organization had all the complementary resources to make the invention a technical success and (b) the organization had all the resources to turn the invention into something economically valuable (e.g. new product, process or else). The answers are measured on the 5-

point Likert scale ranging from 1 (completely disagree) to 5 (completely agree). Based on this information we construct the following 4 dummy variables. *No complementary assets* takes a value of 1 if both types of assets for the technical and economic success were absent, whereas *complementary assets both* indicates that both assets were present. Finally, *technical complementary assets* and *economic complementary assets* indicate that only one type of asset was present. The assets are considered to be present if the answer to the question equals to 4 or 5 and absent if the answer is 1, 2 or 3 on the Likert scale.

Organization-specific complementary assets. The variable *organizational-specific complementary assets* measures a particular dimension of complementary assets that is theoretically distinct from the availability of technological and economic complementary assets. The variable captures the importance and scope of tacit and organizationally embedded complementary assets developed within the firm during the invention process. To measure the organizational specificity of complementary assets, we use the communication breadth. The communication breadth measures the number of other functional departments of the organization that are different from the inventor's department with which the inventor communicated frequently for the invention. The variable is constructed based on response of inventors to the question about frequency of communication with various functional departments with answers ranging from 1 (never) to 5 (daily). The communication is considered to be frequent if the interaction with personnel from other departments was at least weekly, i.e. answer to the question equals to 4 or 5.

Technological competition. The survey provides a measure of *technological competition* by asking respondents whether they were aware of one or of several parties competing for the patent. *Technological competition* takes the value of 1 if the inventor was aware of such parties. For about 18% of observations respondents did not know whether there was a competition or not. To maintain the sample size these observations are coded as 0 (i.e. the absence of technological competition), and we include a dummy variable for these observations so that *technological competition* coefficient will not be biased.

Technological distance. The *technological distance* is defined as a degree to which a given invention is distant from the firm's core knowledge and competence. Following Laursen et al. (2010), the distance is measured by the degree of overlapping between the existing patent portfolio and the focal patented invention. Thus, the distance is considered high when the existing patent portfolio contains only a small fraction of patents in the same 3-digit International Patent Classification (IPC) class as the focal patent.

To measure the *technological distance* we first calculate so-called *focus index* proposed by Ziedonis (2007) and then subtract it from 1. The *focus index* is calculated on the basis of two patent stocks. The *patent stock class* represents the number of patents received by the firm in the same 3-digit IPC class as our focal patent, i.e. the patent that was surveyed. The *patent stock total* stock represents the total number of patents received by the firm. The two variables measuring the patent stocks are constructed using a perpetual inventory method. The routine considers year 1985 as an initial period to calculate patent stock for entities that existed before 1985, and includes all patents for firms established after that year. The selection of year 1985 is reasonable because the term of patent lasts 20 years. The last date to calculate the patent stock is the priority year of the focal patent. The routine accounts for a depreciation rate of 15% due to technological obsolescence and the expiration of legal rights (Hall, Thoma, & Torrisi, 2007). Next, since high share of patenting intensity in a particular technological class represents a field of firm's knowledge and expertise, to create a variable *technological distance* we divide the *patent stoke class* by *patent stock total* and subtract it from 1:

$$Technological\ distance = 1 - \frac{Patent\ stock\ class}{Patent\ stock\ total}$$

Technological generality. One commonly used method to measure generality of technology is based on the number of forward citations. Since it follows from the discussion above that the higher level of generality is associated with the wider range of technological areas in which technology can be applied, it implies that more general-purpose patented inventions will have a larger number of citations from within and outside their technological area (Hall & Trajtenberg, 2004). Therefore, as suggested by Trajtenberg et al. (1997) *generality* of technology is measured on the basis of the Herfindahl concentration index by the following formula:

$$Technological\ Generality_i = 1 - \sum_j^{n_i} s_{ij}^2,$$

where s_{ij} denotes the percentage of citations received by patent i that belongs to IPC class j, out of n_i patent classes. Thus, if a patent is cited by other patents that represent a wide range of technological classes then the measure should be higher, whereas if most citations originate in a few classes then it is expected to be low (Hall & Trajtenberg, 2004).

Control Variables

There are several other factors that can impact the economic use of patented inventions. Therefore, we include control variables to capture additional invention-, firm-, and industry-level effects. In order to control for *technological class* of an invention, we use 6 *macro technological classes* (see Appendix II). Since another generally recognized factor affecting the use of a patent is its value, we control for the *economic value* of the invention. The survey asks to rate the economic value of the patented invention relative to the other inventions in the same industry or technological area (top 10%, 10%-25%, 25%-50%, bottom 50%). Based on this information we generate 4 dummy variables for the *economic value*. A small number of observations for which economic value is missing are included into bottom 50% group to maintain the sample size. For these observations, we include a dummy variable so that the *economic value* coefficient will not be biased.

In addition to these invention-level control variables, we include firm-level control variables. As suggested by previous research, we control for the *firm size* measured by the number of employees. The size of firms ranges from very small (less than 10 employees) to very large (more than 5000 employees) firms. For convenience, in the analysis the f*irm size* variable is represented by 3 classes indicating the size of the organization based on the number of employees. The firm is classified as *small* if it has 1-49 employees, *medium* if there are 50-499 employees, and *large* if it employs more than 500 people.

Since patent intensive firms may be more predisposed to licensing out their technologies or may be less effective in managing their large patent portfolios, we control for the firm's overall patent stock using the logarithms of the *patent stock total* variable that was described above.

Another important factor discussed in the literature is the effectiveness of *patent protection*. The effectiveness of *patent protection* or the appropriability regime is a quite complex concept, and its measure is not straightforward in the literature. The survey measures the patent protection by asking respondents how important prevention of imitation as a reason for patenting was. The answers are measured on the 5-point Likert scale ranging from 1 (not important) to 5 (very important). Since the literature suggests that patent protection is an industry level construct, we aggregate individual survey responses at the 3-digit Standard Industrial Classification (SIC) level.

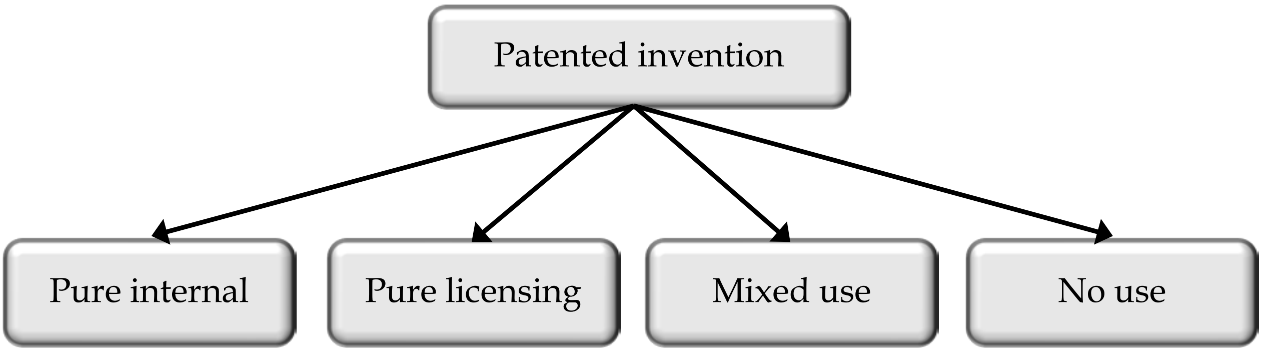
In their study of technology licensing Gambardella et al. (2007) find that the scientific nature of the invention (i.e. the importance of scientific knowledge and literature to create and develop the invention) is positively associated with the probability of licensing. Therefore, we control for it. The PatVal II survey measures the *scientific nature of the invention* by asking respondents to rank the importance of the scientific publications as a source of information. The answers are measured on the 5-point Likert scale ranging from 1 (not important) to 5 (very important). We generate a dummy variable that equals to 1 if scientific publications as a source of information for the invention are important. Scientific publications are considered to be important if the answer to the question equals to 4 or 5 and unimportant if the answer is 1, 2, or 3 on the Likert scale.

Finally, to account for the geographical composition of the dataset we include 3 aggregated region dummies that control for patented inventions from Europe, Japan, and US.

3.3.3. Econometric Model

The current section specifies the econometric model and describes estimation methods. The decisions regarding the economic use of the invention are qualitative choices among a set of alternatives such as pure internal use, pure licensing, and mixed use (see Figure 3.1.). Considering the nature of the dependent variables, in this case conventional linear regression methods are inappropriate, thus, for quantitative analysis there is a need to use econometric models for discrete choices, more precisely, for unordered discrete choices.

FIGURE 3.1 Model specification



Unordered choices can be interpreted as the result of an optimization process described by a random utility model (Greene, 2002). For the *i*th patent owner faced with *j* choices, the utility of choice *j* is:

$$U_{ij} = z'_{ij}\beta + \varepsilon_{ij}. \tag{1}$$

Choosing option j implies maximization of U_{ij}. The probability that a choice j made for patent i is driven by the probability of the latent unobservable utility attached to that choice relative to the utility of alternative choices:

$$Prob(U_{ij} > U_{ik}) \text{ for all other k } \neq \text{j.} \tag{2}$$

The two most popular models for unordered discrete choices are multinomial logit and multivariate probit models. Due to an assumption of independent, identical, normal distributed errors and need to evaluate multiple integrals, multivariate probit model found rather limited use compared to multinomial logit model that has been used in many fields.

The multinomial logit model is very convenient for modeling probabilistic choice; however, multinomial logit model has some limitations. The main important restriction is a requirement of independence from irrelevant alternatives (IIA), which implies that adding another alternative or changing the characteristics of a third alternative does not affect the relative odds between other two alternatives (Wooldridge, 2002). Put differently:

$$\frac{p_j\,(x_j)}{p_h(x_h)} = \frac{e^{x_i\beta}}{e^{x_h\beta}} = e^{(x_i - x_h)\beta} \tag{3}$$

so that relative probabilities for any two alternatives depend only on the attributes of those two alternatives. This implication is not very attractive and not always plausible for applications with similar alternatives. In particular, the presence of mixed use alternative can significantly affects the odds between pure internal use and pure licensing alternatives.

Another possible specifications are bivariate and multivariate probit models. For the purpose of this study, the main advantage of multivariate probit model compared to multinomial logit model is the absence of the assumption of independence from irrelevant alternatives requirement. A bivariate probit model that is a natural extension of probit model allows more than one equation with correlated disturbances (Greene, 2003). The specification for a two-equation model would be:

$$y_1^* = x_1^{'}\beta_1 + \varepsilon_1, \quad y_1 = 1 \quad if\ y_1^* > 0, 0 \text{ otherwise},$$
$$y_2^* = x_2^{'}\beta_2 + \varepsilon_2, \quad y_2 = 1 \quad if\ y_2^* > 0, 0 \text{ otherwise},$$
$$E[\varepsilon_1 | x_{1,} x_2] = E[\varepsilon_2 | x_{1,} x_2] = 0, \qquad (4)$$
$$Var[\varepsilon_1 | x_{1,} x_2] = Var[\varepsilon_2 | x_{1,} x_2] = 1,$$
$$Cov[\varepsilon_1, \varepsilon_2 | x_{1,} x_2] = \rho.$$

Estimation of bivariate probit model is carried out by maximum likelihood. A multivariate probit model would extend (4) to more than two outcome variables just by adding equations (Greene, 2003). The multivariate probit estimations also account for unobservable factors that affect all choices through the correlation between the error terms of the different alternatives. To analyze the determinants of different patent use alternatives we conduct a multivariate probit regression analysis using simulated maximum likelihood (Cappellari & Jenkins, 2003). In all our estimations, we cluster observations by firms to account for unobserved correlation among the patents owned by the same company.

3.4. RESULTS

3.4.1. Descriptive statistics

Table 3.1 shows that on average 47.34% of patented inventions are only used internally for commercial purposes by the patent owner or affiliated parties, i.e. in a product, service or manufacturing process. About 1.48% of patented inventions are purely licensed by the patent owner to an independent party, while 4.05% of patents are both used internally and licensed to an independent party. As described earlier, we refer to this combination of patent uses as a mixed use. Finally, 47.13% of patented inventions are neither used internally nor licensed out to other parties.

An important point that deserves a discussion in itself is that mixed use of patented inventions is more than 2.7 times more frequent than pure licensing. Given the fact that there are numerous studies on licensing in the markets for technology literature, it is striking that such important issue as the combination of licensing and internal use has received a very scant attention in the literature. Therefore, one of the important contributions of this study to highlight the importance and investigate determinants of the mixed use of patented inventions.

TABLE 3.1 Descriptive statistics, economic use of patented inventions

Economic use of patent	*Freq.*	*Percent*
Pure internal use	6,631	47.34
Pure licensing	207	1.48
Both commercial use and licensing	567	4.05
No use	6,607	47.13
Total	14,006	100.00

Table 3.2 reports the differences in the economic use of patented inventions across three regions, namely, Europe, Japan, and US. Although there are some differences within Europe in terms of patent exploitation, for the sake of space we present aggregated data for European firms in order to compare it with Japanese and US firms. Table 3.2 shows that the proportion of pure internal use is relatively higher for European firms. Japanese firms have relatively lower proportion of pure internal

use. With regard to pure licensing and mixed use, patented inventions owned by US firms display about 1.5 higher proportions compared to inventions owned by European firms and about 2.4 times higher compared to inventions owned by Japanese firms. In other words, US firms are most active in pursuing pure licensing and mixed use strategies for their patented inventions, whereas Japanese firms are more reluctant to exploit these two strategies. Finally, the proportion of unused patents is higher for Japanese firms compared to European and US firms. These findings suggest for the presence of some regional differences in the exploitation of patented inventions, which may stem from different organizational cultures or from maturity of technology markets in these regions.

TABLE 3.2 Descriptive statistics, economic use of patented inventions by region (percentages in parentheses)

	Economic use of patent				
Region	*Pure internal use*	*Pure licensing*	*Mixed use*	*No use*	*Total*
Europe	4,116	121	336	3,883	8,456
	(48,68)	(1.43)	(3.97)	(45.92)	(100.00)
Japan	1,339	28	77	1,551	2,995
	(44.71)	(0.93)	(2.57)	(51.79)	(100.00)
US	1,176	58	154	1,167	2,555
	(46.03)	(2.27)	(6.03)	(45.68)	(100.00)
Total	6,631	207	567	6,601	14,006
	(47.34)	(1.48)	(4.05)	(47.13)	(100.00)

Table 3.3 presents the economic use of patented inventions by firm size. The table suggests that pure internal use of patented inventions can be characterized by an inverse U-shaped form with lower proportions for small and large firms and higher proportions for medium firms. We will further consider the relationship between pure internal use and the firm size in our empirical estimations. As expected, small firms with less than 50 employees have relatively high proportion of pure licensing. Moreover, small firms have also the highest proportions of mixed use,

which is more than three times higher than their proportion of pure licensing. Relatively higher proportion of mixed use compared to pure licensing is persistent across different size categories.

TABLE 3.3 Descriptive statistics, economic use of patented inventions by firm size (percentages in parentheses)

	Economic use of patent				
Number of employees	*Pure internal use*	*Pure licensing*	*Mixed use*	*No use*	*Total*
1-49 empl.	743	50	172	532	1,497
	(49.63)	(3.34)	(11.49)	(35.54)	(100.00)
50-99 empl.	342	12	30	196	580
	(58.97)	(2.07)	(5.17)	(33.79)	(100.00)
100-249 empl.	619	11	44	365	1,039
	(59.58)	(1.06)	(4.23)	(35.13)	(100.00)
250-499 empl.	541	13	29	377	960
	(56.35)	(1.35)	(3.02)	(39.27)	(100.00)
500-999 empl.	537	10	47	491	1,085
	(49.49)	(0.92)	(4.33)	(45.25)	(100.00)
1000-4999 empl.	1,327	30	65	1,292	2,714
	(48.89)	(1.11)	(2.39)	(47.61)	(100.00)
5000 and more empl.	2,522	81	180	3,348	6,131
	(41.14)	(1.32)	(2.94)	(54.61)	(100.00)
Total	6,631	207	567	6,601	14,006
	(47.34)	(1.48)	(4.05)	(47.13)	(100.00)

The economic use of patented inventions across macro technological classes is displayed in Table 3.4 (see Appendix II for the concordance between macro technological classes and 30 technological classes). There are marked differences in the use of patented inventions across macro technological classes. Consumption and Process Engineering have the highest proportions of pure internal use, whereas Chemistry/Pharmaceuticals have the lowest proportions. As for pure licensing, Chemistry/Pharmaceuticals are characterized by the highest proportion and Mechanical Engineering is characterized by the lowest. Finally, mixed use strategies are more frequent in Consumption and Process Engineering macro technological classes. As in other tables, the proportion of mixed use is always higher than pure licensing across all macro technological classes.

TABLE 3.4 Descriptive statistics, economic use of patented inventions by macro technological class (percentages in parentheses)

	Economic use of patent				
Macro technological class	*Pure internal use*	*Pure licensing*	*Mixed use*	*No use*	*Total*
Electrical engineering	1,562	42	133	1,682	3,419
	(45.69)	(1.23)	(3.89)	(49.20)	(100.00)
Instruments	1,024	33	89	1,070	2,216
	(46.21)	(1.49)	(4.02)	(48.29)	(100.00)
Chemistry/Pharmaceuticals	1,023	79	113	1,460	2,675
	(38.24)	(2.95)	(4.22)	(54.58)	(100.00)
Process engineering	1,078	25	106	764	1,973
	(54.64)	(1.27)	(5.37)	(38.72)	(100.00)
Mechanical engineering	1,389	18	74	1,345	2,826
	(49.15)	(0.64)	(2.62)	(47.59)	(100.00)
Consumption	555	10	52	280	897
	(61.87)	(1.11)	(5.80)	(31.22)	(100.00)
Total	6,631	207	567	6,601	14,006
	(47.34)	(1.48)	(4.05)	(47.13)	(100.00)

Table 3.5 presents the use of patented inventions by their economic value. The table suggests that the proportion of pure internal use, pure licensing, and mixed use increase with the economic value of patent. Consequently, the non use of a patent is inversely associated with the economic value. These findings are consistent with the patent literature that suggests that a substantial share of patented inventions remains unused due to their low economic value.

TABLE 3.5 Descriptive statistics, economic use of patented inventions by economic value (percentages in parentheses)

	Economic use of patent				
Economic value	*Pure internal use*	*Pure licensing*	*Mixed use*	*No use*	*Total*
Value bottom 50%	2,334	71	131	3,196	5,732
	(40.72)	(1.24)	(2.29)	(55.76)	(100.00)
Value 25%-50%	1,737	45	126	1,618	3,526
	(49.26)	(1.28)	(3.57)	(45.89)	(100.00)
Value 10%-25%	1,548	48	150	1,122	2,868
	(53.97)	(1.67)	(5.23)	(39.12)	(100.00)
Value top 10%	1,012	43	160	665	1,880
	(53.83)	(2.29)	(8.51)	(35.37)	(100.00)
Total	6,631	207	567	6,601	14,006
	(47.34)	(1.48)	(4.05)	(47.13)	(100.00)

Finally, Table 3.6 reports the correlation matrix for all explanatory and control variables used in the analysis.

3.4.2. Regression results

We conduct a multivariate probit regression analysis for the economic use of patented inventions, first entering the controls and then explanatory variables one by one. Table 3.7 presents the results of the regressions. Due to the fact that there is no default marginal effects output after multivariate probit regression, in the table, we report only β coefficients and associated p-values.

Model 1 in Table 3.7 includes only the controls. The model shows that, compared to other firms, medium-sized firms are more likely to commercialize their inventions internally. This inverse U-shaped relationship between the firm size and pure internal use becomes more evident when we further add our explanatory variables. Small firms, instead, are more active in pure licensing and mixed use. Moreover, when we add key explanatory variables in the subsequent models we observe a U-shaped relationship between the firm size and pure licensing. In other words, compared to small and large firms, medium sized firms are less likely to purely license their patented inventions.

TABLE 3.6 Descriptive statistics and correlation matrix

Variables	*Mean*	*s.d.*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*
1. No complementary assets	0.33	0.47	1.00													
2. Technical complementary assets	0.11	0.32	-0.25	1.00												
3. Economic complementary assets	0.10	0.30	-0.24	-0.12	1.00											
4. Complementary assets both	0.45	0.50	-0.64	-0.33	-0.31	1.00										
5. Organization-specific compl. assets	0.76	1.09	-0.08	-0.04	0.03	0.09	1.00									
6. Technological competition	0.33	0.47	0.09	-0.01	-0.02	-0.07	-0.04	1.00								
7. Technological distance (log)	-0.78	1.25	-0.04	0.01	-0.03	0.05	-0.17	0.08	1.00							
8. Technological generality (log)	-3.59	1.74	-0.02	0.01	-0.02	0.02	-0.01	0.04	0.04	1.00						
9. Size small	0.11	0.31	0.09	0.02	0.01	-0.10	0.17	-0.06	-0.45	-0.01	1.00					
10. Size medium	0.18	0.39	-0.02	-0.01	0.02	0.01	0.17	-0.05	-0.16	-0.03	-0.16	1.00				
11. Size large	0.71	0.45	-0.04	-0.00	-0.03	0.06	-0.26	0.09	0.44	0.03	-0.54	-0.74	1.00			
12. Patent stock total (log)	4.95	2.62	-0.06	0.01	-0.05	0.08	-0.26	0.05	0.63	0.03	-0.44	-0.31	0.57	1.00		
13. Patent protection	4.05	0.17	-0.02	-0.04	0.03	0.02	0.11	0.02	-0.06	-0.03	0.01	0.10	-0.09	-0.22	1.00	
14. Scientific nature	0.37	0.48	0.01	0.06	-0.02	-0.03	-0.00	0.16	0.02	0.09	0.03	-0.04	0.01	0.01	-0.07	1.00
15. Value bottom 50%	0.41	0.49	0.03	0.04	-0.01	-0.05	-0.07	-0.07	0.09	-0.04	-0.07	-0.05	0.10	0.13	-0.06	-0.06
16. Value 25%-50%	0.25	0.43	-0.02	-0.01	0.00	0.03	-0.00	0.03	0.02	0.01	-0.02	-0.00	0.02	0.01	-0.01	0.02
17. Value 10%-25%	0.20	0.40	-0.02	-0.02	0.01	0.03	0.04	0.03	-0.04	0.03	0.04	0.03	-0.05	-0.06	0.05	0.05
18. Value top10	0.13	0.34	0.01	-0.02	0.01	-0.00	0.06	0.03	-0.10	0.01	0.09	0.05	-0.10	-0.13	0.04	0.01
19. Electrical engineering	0.24	0.43	0.03	0.01	-0.01	-0.03	-0.07	-0.00	0.03	-0.02	-0.04	-0.07	0.08	0.18	-0.31	-0.02
20. Instruments	0.16	0.36	0.02	0.01	0.01	-0.03	0.03	-0.00	-0.08	0.03	0.07	0.01	-0.06	-0.04	-0.03	0.03
21. Chemistry/Pharmaceuticals	0.19	0.39	-0.04	0.03	-0.02	0.03	-0.06	0.07	0.07	0.13	-0.03	-0.01	0.03	-0.01	0.02	0.27
22. Process engineering	0.14	0.35	-0.01	-0.02	0.01	0.01	0.09	-0.03	-0.03	-0.02	0.02	0.05	-0.06	-0.10	0.17	-0.07
23. Mechanical engineering	0.20	0.40	0.00	-0.02	0.01	0.00	-0.01	-0.02	0.05	-0.08	-0.04	-0.01	0.04	0.03	0.09	-0.14
24. Consumption	0.06	0.24	-0.01	-0.03	0.02	0.02	0.07	-0.05	-0.09	-0.05	0.06	0.05	-0.09	-0.14	0.16	-0.11
25. Europe	0.60	0.49	-0.10	-0.00	0.03	0.08	0.12	-0.29	-0.10	-0.14	0.08	0.11	-0.15	-0.08	0.05	-0.12
26. Japan	0.21	0.41	0.20	0.00	-0.05	-0.16	-0.20	0.44	0.17	0.01	-0.15	-0.13	0.21	0.12	0.02	0.07
27. US	0.18	0.39	-0.08	0.00	0.01	0.07	0.07	-0.10	-0.05	0.17	0.06	-0.01	-0.03	-0.03	-0.08	0.07

Variables	*Mean*	*s.d.*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24*	*25*	*26*	*27*
15. Value bottom 50%	0.41	0.49	1.00												
16. Value 25%-50%	0.25	0.43	-0.48	1.00											
17. Value 10%-25%	0.20	0.40	-0.42	-0.29	1.00										
18. Value top10	0.13	0.34	-0.33	-0.23	-0.20	1.00									
19. Electrical engineering	0.24	0.43	0.04	0.02	-0.04	-0.04	1.00								
20. Instruments	0.16	0.36	0.00	-0.00	0.00	-0.01	-0.25	1.00							
21. Chemistry/Pharmaceuticals	0.19	0.39	-0.02	0.01	0.02	-0.00	-0.28	-0.21	1.00						
22. Process engineering	0.14	0.35	-0.02	-0.03	0.02	0.05	-0.23	-0.18	-0.20	1.00					
23. Mechanical engineering	0.20	0.40	0.01	0.00	-0.01	-0.01	-0.29	-0.22	-0.24	-0.20	1.00				
24. Consumption	0.06	0.24	-0.03	-0.01	0.01	0.04	-0.15	-0.11	-0.13	-0.11	-0.13	1.00			
25. Europe	0.60	0.49	-0.05	-0.03	0.05	0.05	-0.09	-0.07	-0.07	0.06	0.12	0.10	1.00		
26. Japan	0.21	0.41	0.03	0.02	-0.03	-0.02	0.06	0.00	0.03	-0.04	-0.02	-0.07	-0.64	1.00	
27. US	0.18	0.39	0.04	0.01	-0.03	-0.04	0.05	0.08	0.05	-0.02	-0.12	-0.05	-0.58	-0.25	1.00

Note: N=14,006

The negative association between the firm's patent stock and all patent uses can be explained by the fact that larger patent portfolios are less effectively managed, and many inventions remain unused. Moreover, the owners of large patent portfolios often stack up a number of patents for purely strategic reasons (e.g., patent blocking, litigation or cross-licensing). These strategic patents are rarely commercially exploited.

The effectiveness of patent protection has a significant positive effect on pure internal use. However, in contrast with the literature and our expectations we find that the effectiveness of patent protection is negatively associated with pure licensing and mixed use. This finding suggests that more effective patent protection actually facilitates the internal use of patented inventions rather than their transfer to other parties through licensing.

Considering the variable scientific nature of the invention, we find a negative association with pure internal use and a positive association with pure licensing. The results can be interpreted that highly science-based inventions are practically less relevant and often do not find an application within the firm. This reason may also lead to a decision to license out the invention to other parties that have a better idea about its application. Moreover, the literature suggests that the scientific nature of the invention is associated with higher level of codifiability of technological knowledge, which makes it easier to transfer from the licensor to the licensee.

The difference in the economic use of patented inventions in various regions also deserves a discussion. Although it is not apparent in the Model 1, in the subsequent models we find that, compared to European and US counterparts, Japanese firms are more likely to internally use their patented inventions. With regard to pure licensing, US firms are more likely, and Japanese firms are less likely compared to European firms to purely license their inventions. Finally, US firms are more likely to combine internal use and licensing. All these relationships are statistically significant and relatively similar across the models. In addition, we also control for the economic value of inventions and six macro technological classes.

Model 2 adds the first set of variables included in our hypotheses. Hypothesis 1 proposed that the presence of complementary assets required for the technical and economic success of the invention will be positively associated with pure internal use, but negatively associated with pure licensing and mixed use. For pure internal use and pure licensing we find a full support for our hypothesis (β = 0.55 and β = -0.26, respectively, $p < 0.01$). Hypothesis also predicted a negative association between complementary assets and mixed use which does not find support in the data. However, the positive and significant coefficient of the economic complementary assets on mixed use suggests that a mixed use strategy requires some level of complementary manufacturing or marketing resources to be implemented. Instead, pure licensing is less likely to be pursued if a firm possesses complementary economic assets, whereas it is more likely to occur in the presence of only technical complementary assets. This comparison suggests that pure licensing firms tend to be small technology specialists with limited manufacturing and commercial capabilities.

Model 3 adds the variable organization-specific complementary assets, which were developed during the invention stage. The first part of the hypothesis 2 proposes that organizational specificity of complementary assets will be positively associated with pure internal use. The results fully support this argument (β = 0.12, $p < 0.01$). Although such organization-specific complementary assets are highly relevant for pure internal use, they are absolutely unimportant for pure licensing and mixed use. This finding suggests that these types of organization-specific complementary assets are valuable and useful only if the patented invention is exploited internally. Asset specificity then hampers the generation of value from the use of the invention outside the inventor's organization.

Model 4 includes the variable technological competition. The estimation results support only positive relationship between the technological competition and pure licensing proposed in hypothesis 3a (β = 0.15, $p < 0.05$). This finding is in line with the technology licensing literature and previous empirical findings. The competition in the markets for technology facilitates the technology licensing.

TABLE 3.7 Hierarchical multivariate probit regression analyses

Variable	*Model 1*	*Model 2*	*Model 3*	*Model 4*	*Model 5*	*Model 6*
Pure internal use						
Controls						
Size medium	0.29***	0.21***	0.21***	0.21***	0.22***	0.21***
Size large	0.12***	0.02	0.07	0.07	0.07	0.07
Patent stock total (log)	-0.05***	-0.06***	-0.05***	-0.05***	-0.05***	-0.05***
Patent protection	0.51***	0.46***	0.41***	0.41***	0.41***	0.41***
Scientific nature	-0.26***	-0.25***	-0.26***	-0.26***	-0.26***	-0.26***
Japan	-0.01	0.15***	0.19***	0.21***	0.21***	0.21***
US	0.03	0.00	-0.01	-0.01	-0.02	-0.01
Economic value	Yes	Yes	Yes	Yes	Yes	Yes
Macro technological class	Yes	Yes	Yes	Yes	Yes	Yes
Explanatory variables						
Technical complementary assets		-0.08**	-0.08**	-0.09**	-0.09**	-0.09**
Economic complementary assets		0.51***	0.50***	0.50***	0.50***	0.49***
Complementary assets both		0.55***	0.53***	0.53***	0.53***	0.53***
Organization-specific compl. assets			0.12***	0.12***	0.12***	0.12***
Technological competition				-0.04	-0.04	-0.04
Technological distance (log)					-0.00	-0.00
Technological generality (log)						-0.01*
Pure licensing						
Controls						
Size medium	-0.25***	-0.21**	-0.21**	-0.22**	-0.24**	-0.24**
Size large	-0.21**	-0.16	-0.14	-0.14	-0.16	-0.16
Patent stock total (log)	-0.03**	-0.03**	-0.03**	-0.03**	-0.04***	-0.04***
Patent protection	-0.61***	-0.56***	-0.59***	-0.59***	-0.59***	-0.59***
Scientific nature	0.17***	0.16***	0.15***	0.14**	0.14**	0.14**
Japan	-0.14	-0.20**	-0.19**	-0.25***	-0.26***	-0.26***
US	0.10	0.12*	0.12*	0.13*	0.13*	0.13*
Economic value	Yes	Yes	Yes	Yes	Yes	Yes
Macro technological class	Yes	Yes	Yes	Yes	Yes	Yes
Explanatory variables						
Technical complementary assets		0.11	0.11	0.12	0.12	0.12
Economic complementary assets		-0.22**	-0.23**	-0.23**	-0.24**	-0.23**
Complementary assets both		-0.26***	-0.28***	-0.27***	-0.27***	-0.27***
Organization-specific compl. assets			0.03	0.03	0.03	0.03
Technological competition				0.15**	0.15**	0.15**
Technological distance (log)					0.03	0.03
Technological generality (log)						0.02
Mixed use						
Controls						
Size medium	-0.43***	-0.44***	-0.44***	-0.44***	-0.47***	-0.47***
Size large	-0.42***	-0.43***	-0.43***	-0.43***	-0.46***	-0.46***
Patent stock total (log)	-0.03***	-0.03***	-0.04***	-0.04***	-0.05***	-0.05***
Patent protection	-0.24**	-0.28**	-0.27**	-0.28**	-0.29**	-0.28**
Scientific nature	0.03	0.04	0.04	0.03	0.03	0.02
Japan	-0.08	-0.07	-0.07	-0.10	-0.11*	-0.12*
US	0.22***	0.22***	0.22***	0.21***	0.21***	0.18***
Economic value	Yes	Yes	Yes	Yes	Yes	Yes
Macro technological class	Yes	Yes	Yes	Yes	Yes	Yes
Explanatory variables						
Technical complementary assets		0.02	0.02	0.02	0.02	0.02
Economic complementary assets		0.17***	0.17***	0.17**	0.16**	0.17**
Complementary assets both		0.02	0.02	0.02	0.02	0.02
Organization-specific compl. assets			-0.01	-0.02	-0.02	-0.02
Technological competition				0.07	0.07	0.07
Technological distance (log)					0.05***	0.05**
Technological generality (log)						0.02
N	14,006	14,006	14,006	14,006	14,006	14,006
Ll	-12,078.47	-11,743.76	-11,676.75	-11,665.07	-11,660.48	-11,654.09
Chi^2	1,435.67	2,093.26	2,167.24	2,196.32	2,203.33	2,227.70

Note: * p<.1; ** p<.05; *** p<.01

TABLE 3.8 Split-sample multivariate probit regression analyses

Variable	*Pure internal use (Model 6)*			*Pure licensing (Model 6)*			*Mixed use (Model 6)*		
	Both assets	*Partial or no assets*	*Full sample*	*Both assets*	*Partial or no assets*	*Full sample*	*Both assets*	*Partial or no assets*	*Full sample*
Controls									
Size medium	0.25***	0.20***	0.29***	-0.30*	-0.20*	-0.27***	-0.45***	-0.48***	-0.47***
Size large	0.10	0.08	0.17***	-0.14	-0.18	-0.21**	-0.44***	-0.45***	-0.44***
Patent stock total	-0.06***	-0.04***	-0.04***	-0.05*	-0.03*	-0.04***	-0.03	-0.08***	-0.05***
Patent protection	0.29***	0.56***	0.45***	-0.63**	-0.53**	-0.57***	-0.09	-0.17	-0.19
Scientific nature	-0.29***	-0.23***	-0.27***	0.22**	0.13*	0.13**	0.10	0.00	0.01
Japan	0.09*	0.21***	0.09***	-0.04	-0.33***	-0.20**	-0.19	-0.08	-0.12*
US	0.02	-0.04	0.02	0.05	0.17**	0.11	0.16**	0.20***	0.18***
Economic value	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Macro technological class	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Explanatory variables									
Organization-specific assets	0.11***	0.14***	0.14***	0.05	0.01	0.01	-0.03	-0.01	-0.02
Technological competition	-0.06	-0.03	-0.04	-0.19	0.27***	0.14**	0.02	0.08	0.06
Technological distance	0.01	-0.01	-0.00	0.09*	0.02	0.03	0.04	0.07***	0.05***
Technological generality	-0.02	-0.01	-0.01*	0.06*	0.01	0.02	0.05***	-0.00	0.02
N	6,345	7,661	14,006	6,345	7,661	14,006	6,345	7,661	14,006
Ll	-5,133.41	-6,574.62	-11,949.61	-5,133.41	-6,574.62	-11,949.61	-5,133.41	-6,574.62	-11,949.61
Chi^2	853.72	994.96	1,602.93	853.72	994.96	1,602.93	853.72	994.96	1,602.93

Note: * p<.1; ** p<.05; *** p<.01

Model 5 adds the variable technological distance. Hypothesis 4a states that a higher distance from the firm's core technological domain (i.e., the technological area where a large share of patents is taken) will be negatively associated with pure commercial use and positively associated with pure licensing and mixed use. While the relationships for pure internal use and pure licensing have the expected sign, they are not statistically significant. However, we find support for the part of the hypothesis about a positive relationship with mixed use ($\beta = 0.05$, $p < 0.01$). This means that firms tend to combine internal use and licensing only for their non-core inventions, for which they do not posses profound knowledge and competence.

Finally, Model 6 contains the variable technological generality introduced in hypothesis 5. Although all coefficients have the expected sign, the results are statistically significant only for pure internal use ($\beta = -0.01$, $p < 0.1$). Therefore, the findings based on the pooled sample do not support our hypothesis. However, we will further investigate the role of technological generality in the next section devoted to the moderation effect of complementary assets.

3.4.3. Moderation effect of complementary assets

To see the moderating role of complementary assets we conduct additional multivariate probit regressions (Model 6) by splitting the sample into two subsamples according to the presence or absence of complementary assets for both technical and economic success of the invention (Table 3.8).

Hypothesis 3b proposes that the absence of complementary assets for both technical and economic success will strengthen the positive association between the level of technological competition and pure licensing. The data fully support the hypotheses 3b, as the coefficient of competition in the pure licensing equation increases considerably, from $\beta = 0.14$, $p < 0.05$ in the full sample to $\beta = 0.27$, $p < 0.01$ in the subsample without complementary assets. When both types of complementary assets are present, the relationship between technological competition and pure licensing becomes statistically insignificant. This difference between two subsamples is striking. While firms with complementary assets are indifferent to technological competition in their pure licensing decision, firms without complementary assets are highly sensitive and more likely to purely license out their inventions if there is a technological competition in the market.

Hypothesis 4b states that the positive association between the technological distance and pure licensing (mixed use) will be stronger if the firm does not possess complementary assets for both technical and economic success of the invention. Our findings support this hypothesis for mixed use. Technological distance does not have any significant effect on mixed use when complementary assets are present, while the effect remains positive and highly significant when the firm lacks complementary assets ($\beta = 0.07$, $p < 0.01$). The finding suggests that when firms do not possess entire set of complementary assets they may choose to combine internal use and licensing only for their non-core inventions and not for core inventions. The possible interpretation is that for their core inventions firms are concerned that the licensee with better complementary asset position can cannibalize their current or future product market. For non-core inventions, on the other hand, it is less important issue and firms without necessary complementary assets can license out their inventions, in addition to internal use, to get access to licensee's complementary assets.

Finally, we consider the moderation effect of the presence of both complementary assets on the relationship between the technological generality and the economic use of patented inventions. Our findings show that there is a significant positive moderation effect of the presence of complementary assets on the relationship between the generality and the likelihood of mixed use ($\beta = 0.05$, $p < 0.01$). This suggests that only vertically integrated firms with complementary assets can appropriate the benefits of a general-purpose invention by sharing their technology with other parties while they use it internally. Our findings also show that vertically integrated firms with complementary assets are more likely to purely license out their general-purpose inventions compared with firms without complementary assets ($\beta = 0.09$, $p < 0.1$). This finding apparently contradicts the idea that general purpose technologies favor vertical disintegration and the growth of technology specialists. But it also shows that vertically integrated firms participate in the markets for technology by sharing their general-purpose inventions with others.

3.5. DISCUSSION

3.5.1. Implications of the study

This section summarizes and discusses the main findings of our study and their implications for research, management, and policy.

First of all, the descriptive statistics presented in the study provides an overview of the alternative economic uses of patented inventions that by itself may have valuable implications. Our data reveals that only about a half of patented inventions are used internally for commercial purposes by their owners. The proportions of purely licensed and mixed used patents represent about 1.5% and 4.0%, respectively. This suggests that, in general, the share of inventions transacted in the markets for technology is not large. However, most importantly, our data reveals that even licensed patents are often exploited internally; and this mixed use is actually 2.7 times more frequent than pure licensing. Considering the fact that there are numerous studies on licensing in the markets for technology literature, it is striking that such relevant issue as the combination of licensing and internal use has received a very scant attention in the literature. Therefore, an important purpose of this study is to highlight the importance of mixed use of patented inventions and investigate its determinants. Finally, we find that a large share of patents are neither used internally nor licensed out to others. However, the study of unused patents is beyond the scope of this study and represents a fertile area for future research in itself.

In the study, we provide a number of descriptive statistics on the alternative economic uses of patented inventions by region of the patent owner, firm size, macro technological class, and economic value of the patented invention. We find that there are notable differences and regularities across these technology, firm, and industry characteristics. Therefore, we include all these variables to our empirical estimations as controls in order to further investigate them.

With regard to noteworthy findings associated with control variables, we find some evidence for an inverse U-shaped relationship between the firm size and pure internal use, i.e. medium size firms are more likely than small and large counterparts to internally use their patented inventions. In the case of pure licensing, on the contrary, we find some evidence on a U-shaped relationship with the firm size. The research implication of this finding is that the relationship between firm size and economic use of patented inventions is likely to be non-linear with medium sized firms different from their small and large counterparts. However, to better examine the non-linear relationship it is necessary to obtain a continuous measure of firm size.

We also find that firms with large patent portfolio are less likely to use internally or license their inventions. This finding has two main interpretations and, therefore, two different implications for public policy and business practice. The first interpretation is that larger patent portfolios are less effectively managed and, therefore, many inventions remain unused. Moreover, R&D intensive firms with large patent portfolios are unable to overstretch their limited resources to commercially exploit all their inventions. Here, the managerial implication is that firms with large patent portfolios need to implement processes to constantly monitor and manage their patent portfolios to identify patents that can be offered for licensing or sale in order to derive additional value from their inventions. The second interpretation is that owners of large patent portfolios often stack up a number of patents for purely strategic reasons (e.g., patent blocking, litigation or cross-licensing). This interpretation suggests for strategic anticompetitive role of unused patents and, therefore, may have some valuable policy implications.

Next, the effectiveness of patent protection has a significant positive effect on pure internal use. However, in contrast with the licensing literature we find that the effectiveness of patent protection is negatively associated with pure licensing and mixed use. This finding suggests that more effective patent protection actually facilitates the internal use of patented inventions but not their transfer to other parties through licensing. The results support the argument that the effective patent protection increases the opportunity cost of licensing by enhancing the payoff from exclusive internal commercialization of patented inventions. Therefore, our findings contribute to an ongoing discussion whether the patent system promotes or hampers technological development and diffusion of technologies.

Consistent with the literature, we also find that highly science-based inventions are less likely to be used internally and more likely to be purely licensed out. This finding supports the idea that inventions that significantly rely on scientific literature are practically less relevant and often do not find an in-house application. However, such inventions are more likely to find external application outside firm boundaries. Moreover, codified nature of scientific knowledge makes the transfer of technology from licensor to licensee more convenient and less costly. If this interpretation is correct, then the managerial implication of this finding is that in order to successfully license out an invention there is a need to invest additional time and resources to codify technological knowledge about the invention to facilitate its transfer to potential licensees.

We also observe some difference in the economic use of patented inventions in various regions. In particular, compared to European and US counterparts, Japanese firms are more likely to internally use their patented inventions. With regard to pure licensing, US firms are more likely, and Japanese firms are less likely compared to European firms to purely license their inventions. Finally, US firms are more likely to combine internal use and licensing. As discussed earlier, these differences may stem either from organizational cultures or the efficiency of technology markets in these regions. In terms of research implication, this evidence calls for further research that investigates the reasons for differences across countries and regions in their propensity to use and license their technologies.

Although the importance of complementary assets for technology commercialization is not a novel idea, past empirical research has not fully appreciated the multidimensional nature of complementary assets. To address this problem, our study distinguishes between complementary assets necessary for technical and for economic success of an invention and emphasizes the role of organization-specific complementary assets developed during the invention process. Our results show that these various types of complementary assets are differently associated with the economic exploitation of patented inventions.

In particular, we find that firms that have only technical complementary assets (e.g. R&D capabilities) are unlikely to vertically integrate and acquire requisite downstream assets in order to commercialize their inventions in-house. On the contrary, firms that have only economic complementary assets (e.g. manufacturing and marketing assets) are more likely to adopt pure internal use and mixed use strategies and less likely to purely license out their inventions. Moreover, firms that possess both types of complementary assets are extremely likely to internally use their inventions and avoid purely licensing. In addition, we empirically test the role of organization-specific complementary assets that highly rely on the tacit knowledge developed within the organization during the invention process. As shown in our results, these types of complementary assets are only relevant for pure internal use of the invention and absolutely irrelevant for other uses. Summarizing all above-mentioned, an important contribution of this study is that it reveals that firms possess different types of complementary assets, which have different impacts on the economic use of patented inventions.

Next, our study provides additional support to the argument that technological competition is positively associated with technology licensing. Our novel contribution here is that we identify a moderating role of complementary assets on the effect of technological competition on pure licensing. We find that technological competition facilitates technology licensing only if the patent owner does not possess in-house necessary complementary assets. In other words, only firms without downstream complementary resources are sensitive to technological competition in their licensing decision. Our interpretation of this finding is that firms without downstream complementary assets can primarily profit from their inventions by licensing them to other firms that already possess these assets. Moreover, the lack of complementary assets may stem from a strategic choice to become an upstream technology specialist and rely on a business model based on technology licensing strategy. Therefore, technological competition may induce these firms to license more aggressively. On the contrary, firms that own requisite complementary assets have a wider array of options including pure internal use, pure licensing, and mixed use. Moreover, these firms may have a higher real option value for their inventions and may prefer to wait in order to decide whether to pursue internal commercialization option in the future. Thus, these firms can be less subject to the inducement effect to license out their inventions caused by intense technological competition.

Consistent with our hypothesis and the rent dissipation effect suggested in the literature, we find that mixed use of patented inventions is more likely for technologically distant inventions that do not fall in the area of firm’s core activity and competence. While for core technologies combining internal use and licensing is associated with the rent dissipation effect and risk of licensor’s product market cannibalization by the licensee, for non-core technologies this problem is relatively less severe. Our additional contribution is that we find strong moderation effect of complementary assets on the relationship between technological distance and mixed use. More precisely, in our regressions technological distance is statistically significant only when the patent owner does not own all necessary complementary assets. We interpret this finding that for technologically distant inventions licensing, in addition to internal use, is a way for the patent owner to access licensee’s complementary assets and capabilities, which are necessary to successfully commercialize the invention.

Finally, our last key explanatory variable is technological generality. In line with our hypothesis, we find some empirical support to the argument that the level of technological generality of the invention is negatively associated with pure internal use, but positively associated with pure licensing and mixed use. Our findings also reveal that there is a significant positive moderation effect of the presence of both complementary on the relationship between the generality and the likelihood of mixed use. This suggests that only vertically integrated firms with complementary assets can appropriate the benefits of a general-purpose invention by sharing their technology with other parties while using it internally. Our findings also show that vertically integrated firms with complementary assets are more likely to purely license out their general-purpose inventions compared with firms without complementary assets.

Summarizing the discussion above, we conclude that by investigating the determinants of economic uses of patented inventions this study contributes to the innovation and technology management literature and provides multiple implications for research, management and policy.

3.5.2. Robustness checks

To find out whether our main results are robust and stable, we run several robustness checks. For reasons of space, we briefly report the results and do not include tables in the paper. The robustness check tables are available from the author.

First, as a robustness check, we have tried other measures of the effectiveness of patent protection such as appropriability index developed by B. Hall (University of California at Berkeley), G. Thoma (University of Camerino) and S. Torrisi (University of Bologna). Our main findings remain similar and do not change due to the use of alternative control for the effectiveness of patent protection. Moreover, although significance levels are lower, we still find a negative relationship between the effectiveness of patent protection and the likelihood of pure licensing and mixed use. This provides another support to our earlier argument that strong appropriability regime may actually hamper technology transfer and diffusion.

Second, we have tried alternative set of dependent variables. Instead of using *pure licensing* as a dependent variable in the second equation of the multivariate probit regression, we generated variable *pure external use* that took value 1 if patented invention was only licensed or sold to other parties not affiliated with initial patent owner. The use of this dependent variable in the second equation does not change our findings for other two equations. However, we find some differences between pure licensing and pure external use in the effect of some key explanatory variables. In particular, the technological competition that is an important factor affecting pure licensing, but it does not appear to be a significant factor when we use pure external use as a dependent variable. These results suggest that, although pure patent licensing and patent sale have many common determinants, there are still some differences that need to be studied in more detail. Therefore, our next study will address and focus on the issue of patent sale.

3.5.3. Limitations

This study is subject to several limitations. First, the study focuses only on the supply side of technology markets. However, as it has been emphasized in the literature, it is important to look at both supply and demand sides of the market because the likelihood of the transaction is affected by the behavior and characteristics of parties from both sides. Unfortunately, for the dataset of this size it is not feasible to match the corresponding information about the demand side. Furthermore, lack of information about the demand side does not permit to analyze the characteristics of technology licensees such as their size, market share and competitive position vis-à-vis technology supplier.

Second, cross-sectional nature of the data precludes the adaptation of longitudinal perspective and poses certain limitations on the range of applicable econometric methods and estimations. Moreover, cross-sectional data do not allow to fully account for firm-specific unobserved heterogeneity. Thus, obtaining a panel dataset with a longitudinal dimension remains the objective of future research. All these limitations notwithstanding, we believe that this study will contribute to a better understanding of the economic use of patented inventions.

CHAPTER 4

THE SALE OF PATENT RIGHTS:

A STUDY OF EUROPEAN PATENTS

ABSTRACT

The paper studies the sale of patent ownership rights for European patents using a unique large scale inventor survey data. Existing literature on the markets for technology has primarily focused on patent licensing and largely overlooked an aspect of patent sale. Recently, few scholars attempted to fill up this gap by developing theories that could explain factors affecting patent sale. The current paper aims at contributing to this novel stream of research. We provide theoretical reasoning and empirical tests for a number of patent, firm, and industry level factors that may affect the likelihood that a patent is sold in the markets for technology. We believe that empirical findings provided in this study will enhance our knowledge about patent sale and foster future research in this field.

4.1. INTRODUCTION

Within the markets for technology framework there is a substantial empirical work on patent licensing (Arora & Ceccagnoli, 2006; Fosfuri, 2006; Gambardella & Giarratana, 2006; Gambardella et al., 2007; Kim, 2004; Kim, 2005; Kim & Vonortas, 2006; Motohashi, 2008). However, remarkably few studies have empirically analyzed patent sales, i.e. patent ownership transfer or assignment from one party to another. For instance, Serrano (2006, 2010) has studied the transfer and renewal of patent rights by firms and Galasso, Schankerman, & Serrano (2011) have studied patent sales by individual inventors. These recent papers on patent sales open up a new stream of research in the field of technology management that may potentially receive more scholarly attention in the future. This paper aims to contribute to this novel research agenda on patent sale. The objective of this paper is to determine what factors may affect the likelihood that a patent is sold. Given this objective, the study seeks to address the following research questions: *What factors determine the likelihood that a patented invention is sold? What are the characteristics of patent sellers in the markets for patents?*

Although still in their infancy, patent sale is becoming an increasingly important component of the markets for technology. Many large corporations, like AT&T and Hewlett Packard, implement processes to constantly monitor and manage their patent portfolios. As a result of these processes, they identify patents that can be offered for sale in order to derive additional value from their innovations (AT&T, 2013). As described by HP's vice-president, motivations for active patent sales practice include the desire to generate revenue for the company, reduce maintenance fees and other costs associated with holding patents in the firm's portfolio (Chapman & Shah, 2012). According to HP's Intellectual Property website, out of about 37,000 patents in its portfolio, currently more than 4,000 patents are available for license or sale (Hewlett Packard, 2013). Another empirical evidence suggesting for the importance of patent sale is provided by Serrano (2010). Using a pooling of all US patents granted from 1983 to 2001, he shows that 13.5% of all granted patents were sold at least once over their lifetime. Given this evidence, it becomes increasingly difficult to ignore the relevance of patent sale for the markets for technology.

For the purpose of this study, it is important from the beginning to define what we consider patent sale and how it differs from patent licensing. Patent sale represents a transfer of ownership rights for an invention from one party to another and needs to be registered in the form of assignment in a patent register. In order for an assignment to occur, the transfer to another legal entity must include the entirety of the bundle of rights associated with the patent ownership, i.e., all of the bundle of rights inherent in the right, title and interest in the patent or patent application (Serrano, 2010). In the case the bundle of rights transferred is less than the entire ownership interest such transaction is defined as patent license, which is a contractual agreement that the patent owner will not sue the licensee for patent infringement if the licensee makes, uses, offers for sale, sells, or imports the claimed invention, as long as the licensee fulfills its obligations and operates within the limits delineated by the license agreement (USPTO, 2012). Even if the license is an exclusive license that excludes licensor from using a patent it is not considered a patent sale. Therefore, in our study we clearly differentiate between patent sale and patent licensing and investigate the first phenomenon. For the sake of simplicity, throughout the paper the terms "sale", "transfer", and "assignment" of patent rights will be used interchangeably.

The data to empirically test our hypotheses come from a large scale inventor survey developed and conducted within the InnoS&T project (Gambardella et al., 2012). The PatVal II survey collects cross-sectional data on a number of issues related to the invention process, its determinants, the value of the invention, and its economic use. The dataset has been constructed by combining initial invention level survey data with additional firm and industry level information from public and commercial databases.

Our empirical findings suggest that the effectiveness of patent protection, the presence of complementary assets, and the technological fit are negatively associated with the likelihood of patent sale; whereas the scientific nature of the invention (i.e. substantial reliance on scientific publications) is positively associated with the likelihood of patent sale. We also find that, compared to European firms, US firms are more likely to sell their inventions, whereas Japanese firms are less likely to do that.

The remainder of this paper is organized as follows. The next section reviews the literature relevant for understanding and analyzing patent sale. The third section describes the dataset, variables and econometric methods used in the analysis. The fourth section reports descriptive statistics and econometric analysis results. Finally, the last section discusses and concludes the paper.

4.2. THEORY AND HYPOTHESES

4.2.1. Theoretical background

The main objective of this section is to review theories that can help to understand determinants of patent sale. As noted earlier, theoretical and empirical literature addressing directly the issue of patent sale is very scarce and recent. Therefore, we draw on some insights relevant for studying patent sale borrowed from a substantial literature on patent licensing. Although patent sale and licensing are different, they both are part of the markets for technology and represent alternative means of externally using and profiting from internally developed inventions. Therefore, in some (though not all) cases the arguments used for technology licensing can be applied to patent sale. In other cases, however, certain factors relevant for patent licensing may have an opposite or no effect on patent sale decision. Since empirical studies on patent sale are limited, it is sometimes difficult to say upfront which theoretical arguments on patent licensing can be successfully extended to patent sale and which do not apply. Perhaps our further empirical analysis will contribute to filling this gap in the technology management literature.

The managerial and technological literature have long been interested in the role of the patent system in lowering transaction costs associated with technology transfer. The transaction costs theory (Williamson, 1979) suggests that market transactions depend on the related level of uncertainty and opportunism. The research on contracts and transaction costs has studied the effects of moral hazard and asymmetric information on transfer of technologies through arm's-length contracts (Caves, 1996; Hart, 1995; Teece, 1992). Teece (1988) emphasizes four main sources of transaction costs in technology transfer: (a) incomplete contracts due to substantial uncertainty leave both parties open to opportunistic behavior of the partner; (b) the production of technology is a cumulative process based on tacit knowledge, which is organizationally embedded and difficult to transfer; (c) transaction-specific investments from both sides create so-called "lock-in" problem associated with high switching costs; and (d) technology transfer can involve disclosure of innovator's sources of competitive advantage. Other transaction costs of technology transfer can be associated with gathering information and search for potential buyers (Fosfuri, 2006). The transaction cost theory suggests that market-based technology transfer mechanisms can be attractive when the associated transaction costs of using them are relatively low (Teece, 1988a).

The value of a patent to any given firm depends on the extent to which the patented invention can be used to generate economic profits. The resource based theory highlights the role of unique combinations of resources in maximizing the value creation (Barney, 1991; Dierickx & Cool, 1989; Wernerfelt, 1984). Starting with a seminal paper by Teece (1986), a significant body of theoretical literature has considered the role of complementary assets in appropriating returns from commercializing innovations. Complementary assets are defined as resources necessary to produce and commercialize a technology, such as manufacturing, marketing, and other assets (Teece, 1986). Since firms are endowed with different levels of complementary assets, patented inventions are best used by those who already posses necessary bundle of complementary assets or can relatively easy access them (Arora & Ceccagnoli, 2006; Mitchell, 1989; Rothaermel, 2001; Tripsas, 1997).

The real option theory is also useful to understand factors affecting technology transfer. The theory suggests that, under uncertainty, an option to preserve the right to make investment choices in the future is valuable to a firm (McDonald & Siegel, 1986; McGrath & Nerkar, 2004). With respect to inventions, the patent ownership gives the right, but not the obligation, for a firm to use an invention in-house, license or sell it out to others at any time in the future. The sale of patent rights, however, requires giving up the real option, which means that if the patented invention later appears to be a blockbuster the original patent owner will be excluded from future revenues generated by the invention. Therefore, the theory suggests that under conditions of uncertainty patent owners may prefer to leave their inventions unused rather than selling them out in the markets for technology.

4.2.2. Hypotheses

Further in this section we will consider various possible patent, firm, and industry level determinants of patent sale and develop hypotheses about their relationship to the likelihood that a patent is sold.

Appropriability regime/effectiveness of patent protection. Teece (1986) defines an appropriability regime as the efficacy of the legal system to assign and protect intellectual property. The appropriability regime can vary across different industries and geographical regions. The main social function of the patent system is to increase incentives for innovations by giving a temporal monopoly power to inventors and patent owners. By defining property rights for technology or knowledge, patents should provide a way for technology owners to disclose information while preventing its unauthorized use, which should also reduce the challenges of assessing the value of innovation highlighted by Arrow (1962). However, the evidence suggests that patents do not work in practice as they do in theory (Levin et al., 1987). Although patents afford considerable protection for the invention in some industries, in others they do not confer perfect appropriability and can be "invented around" at modest costs (Teece, 1986).

With respect to the effect of appropriability regime on patent sale, on the one hand, more effective patent protection should induce patent sale. First, as suggested in the literature better patent protection should reduce the transaction costs of patent sale by lowering the risk of opportunism on the demand side. The effective patent protection provides a way for patent owners to disclose information while preventing it unauthorized use and "free-riding" by others (Levin, 1986). Second, the effective patent protection increases the value of patent ownership rights. An invention that has an effective patent protection is more attractive to a potential buyer. Moreover, under a real threat of litigation a potential infringer may prefer to buy and pay for the well protected patent rather than trying to "invent around".

On the other hand, the tight appropriability regime may enhance an opportunity cost of patent sale by increasing the attractiveness of alternative methods of commercializing the patent, such as internal commercial use or licensing.

The effective patent protection enhances the payoff from exclusive commercialization of invention and secures larger market for products encompassing the patented invention (Arora & Ceccagnoli, 2006; Gans et al., 2002). Moreover, a long list of studies on licensing suggest that the tight appropriability regime favors technology licensing (Arora & Ceccagnoli, 2006; Arora et al., 2001b; Gambardella et al., 2007; Kim, 2005; Palomeras, 2007).

According to the real option theory, an option to preserve the right to make investment choices in the future is valuable when an uncertainty characterizes the environment (McDonald & Siegel, 1986; McGrath & Nerkar, 2004). The literature suggests that uncertainty about technical success and commercial applicability of an invention is a constituent part of the markets for technology (Arora & Gambardella, 2010). Under uncertainty, the effective patent protection facilitates an ability to exercise this real option by preventing imitation and giving sufficient time to a patent owner to decide what to do with its invention. The ineffective patent protection, on the contrary, makes the real option less effective and requires more immediate decisions whether to use an invention in-house or transfer it to other parties that have access to necessary resources and can use the invention immediately. Since the sale of patent ownership rights means giving up the real option, we argue that it is more likely to occur with patents that do not have the effective patent protection and, therefore, have the lower real option value.

Finally, anecdotal evidence suggests that firms are reluctant to sell out well protected patents because these patents may be later turned against them. For instance, as noted by HP's vice president, companies are concerned about a risk that patents they sell can be used against them in an offensive way by competitors or non-practicing entities (NPE) (Chapman & Shah, 2012).

As it apparent form the discussion above, arguments for a positive association between the effectiveness of patent protection and patent sale are related to demand side incentives and convenience of technology transfer process, whereas arguments for a negative association are related to supply side incentives. Since in order for a patent sale to occur it is first necessary that patent owner offers a patent for sale, we argue that supply side incentives should have some precedence. Put differently, if a patent owner is unwilling to sell its well protected invention the patent sale will not occur despite potential buyer's willingness to acquire the patent. Given the arguments above, we formulate our first testable hypothesis:

Hypothesis 1: Ceteris paribus, there will be a negative association between the effectiveness of patent protection and the likelihood that a patent is sold.

Complementary assets. As noted earlier, starting with the paper by Teece (1986), a significant body of theoretical literature has considered the role of complementary assets for the economic use and transfer of technologies. When a patent owner does not have complementary assets necessary to commercialize an invention, the transfer of the patent through market-based arrangements to other parties that already possess these complementary assets or that can create them at relatively lower costs is a rational strategy. In principle, the patent owner without complementary assets could acquire these assets in strategic factor markets (Barney, 1986). However, often critical complementary assets necessary to develop a particular invention are not easily purchasable in the strategic factor markets, and need to be accumulated over time within the firm (Dierickx & Cool, 1989). Teece (1986, p. 303) argues that the firm that lacks necessary complementary assets and unable to easily access them is "left with the option of selling its intangible assets in the market for know how", which is better than no remuneration at all.

The lack of complementary assets can also be a result of strategic choice not to become a downstream producer and focus on upstream technology creation (Gambardella et al., 2007). Such upstream technology specialization implies a business model that is largely based on technology licensing and sale (Teece, 2010).

Therefore, the effect of the presence of complementary assets on patent sale is relatively straightforward:

Hypothesis 2: Ceteris paribus, there will be a negative association between the presence of complementary assets and the likelihood that a patent is sold.

Technological fit. Next, we introduce to our discussion a notion of technological fit defined by Palomeras (2007) as a degree to which a given invention falls within an area firm's core activity and technological competence. This construct is usually operationalized using so called "focus index" suggested by Ziedonis (2007) that measures the weight of a technological class of the patented invention in the firm's overall patent portfolio. Relatively higher patenting activity by the firm in a certain technological class indicates that a substantial part of firm's innovative activity has occurred in that area (Ziedonis, 2007). Therefore, inventions that have high technological fit with the firm's patent portfolio are characterized as core technologies.

As it was emphasized by Prahalad & Hamel (1990), firms should invest in and protect their core technologies, which are key to their sustainable competitive advantage. Rivette & Kline (2000) suggest that while core technologies that provide competitive advantages should be rigorously protected, non-core technologies can be actively traded for revenue. The sale of non-core patents that have no direct use in current or planned products can also help to reduce the amount of patent portfolio maintenance costs (Rivette & Kline, 2000b).

The real option theory suggests another argument for not selling patents that fit with the firm's core technological activity. By selling a patent, firm gives up its waiting-to-invest option (McDonald & Siegel, 1986). Therefore, even if a firm is uncertain about the value of its invention or unable to exploit invention immediately, for core technologies firm is more likely to retain the real option by keeping ownership rights on the invention and use alternative ways to explore the value of technology, for instance, by licensing out the invention. Moreover, unlike patent licensing that permits a licensor to pose restrictions in terms of time, geographical area, or field of use to avoid direct competition with a licensee, patent sale does not provide means to refrain a patent buyer from competing with a patent seller in its core business sector.

As it follows from the discussion, core inventions should have higher value and importance for a patent owner. Therefore, we posit the following hypothesis:

Hypothesis 3: Ceteris paribus, there will be a negative association between the technological fit and the likelihood that a patent is sold.

Scientific nature of the invention. An important factor that affects the transfer of knowledge about an invention is the level of its tacitness and codifiability (Nelson & Winter, 1982; Polanyi, 1966). Technological knowledge, as any other forms of knowledge, has both codifiable and tacit components. While the codified knowledge about an invention is relatively easy to transfer through patent documents, blueprints, and other documents, the tacit knowledge is more difficult to communicate and costly to transfer to other parties (Arora et al., 2001b; Arora & Gambardella, 1994a). As Polanyi (1966, p. 136) puts it in his seminal work, "we can know more than we can tell". Teece (1988b) also points out that the production of technology is a cumulative process based on tacit knowledge, which is organizationally embedded and difficult to transfer across firm boundaries. Generally, science-based inventions that significantly rely on scientific publications are more likely to be codified and not tacit (Arora & Ceccagnoli, 2006; Arora & Gambardella, 1994a; Winter, 1987). Therefore, the scientific nature of the invention should make it easier to transfer technological knowledge from one firm to another and make patent sale a more convenient alternative.

Another reason for a positive association between the scientific nature of the invention and the likelihood that a patented invention is sold is based on the argument that science-based inventions are in general more likely to be offered for sale because they are less practically relevant or too far from the market. Studies on patents by universities and public research organizations suggest that inventions that significantly rely on scientific literature often lack practical relevance (Arundel et al., 2012). Therefore, science-based inventions are more likely to be offered for sale by their owners. If this argument is true, then patents that are actually sold in the markets for technology are more likely to be scientific because they were picked from a subset of more scientific patents preselected for sale. In any case, both sets of arguments suggest the following hypothesis:

Hypothesis 4: Ceteris paribus, there will be a positive association between the scientific nature of the invention (i.e. the reliance on scientific publications) and the likelihood that a patent is sold.

4.3. DATA AND METHODS

4.3.1. Data

The data for our analysis come mainly from a large scale PatVal II inventor survey developed and conducted within the InnoS&T project (Gambardella et al., 2012). The survey collects cross-sectional data on a number of issues related to the invention process, its determinants, the value of the invention, and its economic use. The dataset has been constructed by combining initial invention level survey data with additional firm and industry level information from Amadeus, EPOSYS, Orbis, Osiris, PATSTAT databases.

The self-administered survey of inventors is global in scope and covers patented inventions from 21 European countries, Japan, and US. The sample was drawn at the level of patent applications with priority years between 2003 and 2005. The final composition of the sample is the following: Europe – 62,148 observations, U.S. – 45,861, and Japan – 16,125. After sampling the patents, one inventor listed on the patent document was randomly chosen and was sent an invitation letter to participate in the survey. The letter asked the inventors to fill out an online questionnaire on a website that they can access through an identification number and a password, generated for the specific inventor. The number of responses for the survey by the inventors in all surveyed countries is equal to 23,044, which corresponds to a corrected response rate of 20%.

In the analysis, we use a part of the survey that contains only patented inventions owned by private for-profit firms. The patented inventions that belong to individuals and to non-profit organizations are excluded from the further analysis. The exclusion is justified by the fact that individuals and non-profit organizations have completely different institutional settings and different motivations for the use and transfer of their patented inventions. As a result of this restriction, incomplete responses about the economic use of patented inventions, and missing data for different explanatory and control variables, the final sample comprises 14,151 observations on 6,206 firms.

The PatVal II survey asks respondents whether an ownership right to a patent was sold to another party not related to the original owner or applicant. In the survey, 809 respondents answered that patent or patent application was sold, and 823 answered that the patent was not sold but the owner was willing to sell it. A preliminary analysis of patents and patent applications, characterized by survey respondents as sold patents, has revealed that some of them were not ever actually sold. In other words, we did not find any recorded transfer of ownership rights in the European Patent Register (EPR) or in the National Patent Registers (NPR) of European Patent Convention (EPC) member states (the last applies only if a European patent is granted); and the current patent owner is the same as initial applicant.

The discovered discrepancy between survey responses and actual patent sale transactions necessitated an additional patent ownership check procedure to verify a final list of actually sold patents. Appendix III provides a detailed description of the check procedure.

There are several possible explanations of this discrepancy between responses given by survey respondents and patent right transfer records in the patent registers. A first set of explanations suggests for a possibility of Type I (“False positive”) error, which means that a patent was classified by the survey respondent as sold despite the fact that a patent ownership transfer has never actually occurred. A second set of explanations suggests for a possibility of Type II (“False negative”) error, which means that we could fail to find records of patent sales that have actually occurred. Appendix IV provides a detailed analysis and discussion on the likelihood of both types of errors. The analysis concludes that, although there is a likelihood of the Type II (“False negative”) error and we may underestimate the amount of actual patent sales, this likelihood is relatively small and the use of data resulting from our additional patent transfer check process seems to represent a more accurate and conservative approach.

Therefore, the final list of observations with confirmed patent transfer records includes 496 observations. This is an extended list that includes the following types of transfers: transfers between unaffiliated firms (283), transfers between affiliated firms (116), transfers from individual(s) to a firm (57), transfers from a non-business organization to a firm (20), transfer between non-business organizations (16), and transfers from firms to an individual (4). However, 116 transfers between affiliated firms cannot be regarded as external market transactions, and we exclude them from our further analysis. At the end, we have 380 observations that can be truly regarded as patent sales. In the empirical analysis, for the reasons discussed earlier, we use only 283 observations for patent sales between unaffiliated for-profit firms.

4.3.2. Variables and measurement

Below we describe dependent, explanatory, and control variables used in the empirical analysis section. The measures that we used represent either indicators adapted from existing literature or novel indicators developed within the InnoS&T project. For a short summary of the variables and their measures see an Appendix V.

Dependent variables

Patent sale. Based on the survey responses and the subsequent patent ownership transfer check procedure results (see Appendix III), we generate a dependent variable called *patent sale.* The *patent sale* equals to 1 if the ownership right to the patent is sold to another firm not related to the original patent owner. The variable patent sale is used in the outcome equation of the Heckman selection model (the econometric model will be described further in the section).

Commercial use. A dependent variable used in the selection equation is *commercial use*, which is generated using dichotomous responses about internal commercial use (i.e. exploitation in a product, service or manufacturing process), licensing, or sale of a patented invention. *Commercial use* equals to 1 if the invention is commercialized internally, licensed, or sold by a patent owner to an independent party not related to the original patent owner.

Explanatory variables

Patent protection. The effectiveness of patent protection or the appropriability regime is a quite complex concept, and its measure in the literature is not straightforward. The survey measures the *patent protection* variable by asking respondents how important was the prevention of imitation as a reason for patenting. The answers are measured on the 5-point Likert scale ranging from 1 (not important) to 5 (very important). Since the literature suggests that patent protection is an industry level construct, we aggregate individual survey responses at the 3-digit Standard Industrial Classification (SIC) level.

Complementary assets. The survey asks respondents whether the organization had all the resources to turn the invention into something economically valuable (e.g. new product, process or else). The answers are measured on the 5-point Likert scale ranging from 1 (completely disagree) to 5 (completely agree).

Technological fit. The *technological fit* is operationalized as a fraction of patents in the same 3-digit International Patent Classification (IPC) class as the focal patent in a firm's overall patent portfolio. Therefore, analogous to the "focus index" proposed by Ziedonis (2007), the *technological fit* is calculated based on two patent stocks: *patent stock class* and *patent stock total*. The *patent stock class* represents the number of patents received by a firm in the same 3-digit IPC class as the focal patent, i.e. the patent that was surveyed. The *patent stock total* represents the total number of patents received by a firm. The two variables measuring the patent stocks are constructed using a perpetual inventory method. The routine considers year 1985 as an initial period to calculate patent stock for entities that existed before 1985, and includes all patents for firms established after that year. The selection of year 1985 is reasonable because the term of patent lasts 20 years. The last date to calculate the patent stock is the priority year of the focal patent. The routine accounts for a depreciation rate of 15% due to technological obsolescence and the expiration of legal rights (Hall et al., 2007). Finally, to generate the variable *technological fit* we divide the *patent stock class* by *patent stock total*:

$$Technological\ fit = \frac{Patent\ stock\ class}{Patent\ stock\ total}$$

Scientific nature of the invention. The literature suggests that science-based inventions that significantly rely on scientific publications are more likely to be codified and not tacit (Gambardella et al., 2007). They may also have a more general purpose nature and, therefore, find a wider array of potential applications. The PatVal II survey measures the *scientific nature of the invention* by asking respondents to rank the importance of the scientific publications as a source of information. The answers are measured on the 5-point Likert scale ranging from 1 (not important) to 5 (very important). We generate a dummy variable that equals to 1 if scientific publications as a source of information for the invention were important. Scientific publications are considered to be important if the answer to the question equals to 3, 4 or 5 and unimportant if the answer is 1 or 2 on the Likert scale.

Control variables

Further in the section, we describe variables that we use in our econometric analysis as controls.

Firm size. The literature suggests that the *firm size* is an important factor affecting the economic use of patented inventions (Arora et al., 2001b), therefore, we control for it. Following many other studies, we measure the *firm size* by the number of employees collected via survey. The size of the firms ranges from very small (less than 10 employees) to very large (more than 5000 employees) firms. For convenience, in our empirical analysis the *firm size* variable is represented by 3 classes indicating the size of the organization based on the number of employees. The firm is classified as small if it has 1-49 employees, medium if there are 50-499 employees, and large if it employs more than 500 people.

Patent stock total. Size of firm's patent portfolio or patent stock may also affect the probability of firm's participation in the markets for technology. For instance, patent intensive firms with large patent portfolio may have more technologies available than they can commercialize internally (Kim, 2005; Kim & Vonortas, 2006). Hence, they may resort to the markets for technology in order to extract additional revenues by licensing out or selling their patents (Rivette & Kline, 2000b). However, by the same token, large patent stock may result in a large number of unused or "sleeping" patents due to firm's inability to efficiently manage and profitably deploy their large intellectual property portfolio (Palomeras, 2003). We control for the firm's overall patent stock using the logarithm of the *patent stock total*. The *patent stock total* represents the total number of patents received by a firm. The variable is constructed using the perpetual inventory method that was described above.

Technological competition. The survey provides a measure of *technological competition* by asking respondents whether they were aware of one or several parties competing for the patent. The *technological competition* takes the value of 1 if the inventor was aware of such parties. For about 18% of observations respondents did not know whether there was a competition or not. To maintain the sample size these observations are coded as 0 (i.e. the absence of technological competition), and we include an additional dummy variable for these missing observations so that the *technological competition* coefficient will not be biased.

Technological generality. The *technological generality* refers to a variety of areas where an invention can be potentially used. Bresnahan and Trajtenberg (1995) characterize general-purpose technologies by their potential for pervasive use in a wider range of sectors, their technological dynamism, and the need for complementary investments after adoption. The *technological generality* characterizes a breath of the markets for technology (Arora et al., 2001b), i.e. the number of different areas for application and, therefore, the number of potential buyers of the invention. A commonly used method to measure the *technological generality* is based on the number of forward citations. Since the level of generality is associated with the wider range of technological areas in which technology can be applied, more general-purpose inventions will have a larger number of patent citations from within and outside their technological area (Hall & Trajtenberg, 2004). Therefore, as suggested by Trajtenberg et al. (1997) the *technological generality* is measured on the basis of the Herfindahl concentration index by the following formula:

$$Technological\ Generality_i = 1 - \sum_j^{n_i} s_{ij}^2,$$

where s_{ij} denotes the percentage of citations received by patent i that belongs to 3-digit IPC class j, out of n_i patent classes. Thus, if a patent is cited by other patents that represent a wide range of technological classes the measure should be higher, whereas if most citations originate in a few classes it is expected to be low (Hall & Trajtenberg, 2004). In the analysis we use the logarithm of the *technological generality* variable.

Economic value. Since another generally recognized factor affecting the economic use of a patent is its value, we control for the *economic value* of the patented invention. The survey asks to rate the *economic value* of the patent relative to the other patents in the same industry or technological area (top 10%, 10%-25%, 25%-50%, bottom 50%). Based on this information we generate 4 dummy variables for the *economic value*. A small number of observations for which economic value is missing are included into bottom 50% group to maintain the sample size. For these missing observations, we include a dummy variable so that the *economic value* coefficient will not be biased.

Technological class. We use 30 dummies to control for the *technological class* of a patent. Following (Gambardella et al., 2007), we use ISI-INPI-OST classification developed by the German Fraunhofer Institute of Systems and Innovation Research (ISI), the French Patent Office (INPI) and the Observatoire des Science and des Techniques (OST). Based on the International Patent Classification, the classification distinguishes among 30 different technological fields (see an Appendix II for a list of technological classes).

Macro technological class. In addition, we use 6 dummies for *macro technological classes* that are also based on the ISI-INPI-OST classification. These *macro technological classes* include Electrical Engineering, General Instruments, Chemistry, Process

Engineering, Mechanical Engineering, and Consumption (see the Appendix II for a concordance between technological classes and macro technological classes).

Region. Finally, to account for the geographical composition of the dataset we include 3 aggregated region dummies that control for patented inventions from Europe, Japan, and US.

4.3.3. Estimated model specification

In the empirical analysis section we will estimate a model in which patent owners first decide whether to commercially use their patent (i.e. to commercialize internally, license out, or sell), and if so whether to sell the patent. We use a Heckman selection probit model because it permits to estimate the selection model with dichotomous dependent variables with a similar set of factors affecting the selection and outcome equations. This is a maximum likelihood model in which both the selection equation and the outcome equation are probit models. In all our estimations we cluster observations by firms to account for unobserved correlation among the patents owned by the same company.

We have two latent variable models $\mathbf{y_1 = X'_1\, \beta_1 + u_1}$ and $\mathbf{y_2 = X'_2\, \beta_2 + u_2}$. The latent variables $\mathbf{y_1}$ and $\mathbf{y_2}$ represent the commercial use of patent and the sale of patent, respectively. The $\mathbf{X'}$ are n×k_i vectors of n observations and the k_i (i=1,2) covariates. The $\boldsymbol{\beta_1}$ and $\boldsymbol{\beta_2}$ are the k×1 vectors of parameters to be estimated. Finally, $\mathbf{u_1}$ and $\mathbf{u_2}$ are the n×1 vectors of i.i.d. normally distributed errors, with $\boldsymbol{\sigma}_{u1,u2} = \boldsymbol{\rho}$. Since the latent variables in the equations are not observed, we estimate a probability model whose log-likelihood function is the following:

$$Log\ L = \sum\nolimits_{y_1=1,\ y_2=1} \log \phi\ (\varepsilon_1 > -x'_1\beta_1, \varepsilon_2 > -x'_2\beta_2)$$

$$+ \sum\nolimits_{y_1=0,\ y_2=1} \log \phi\ (\varepsilon_1 < -x'_1\beta_1, \varepsilon_2 > -x'_2\beta_2) + \sum\nolimits_{y_2=0} \log \phi_2\ (\varepsilon_2 < -x'_2\beta_2)$$

where $\boldsymbol{\varepsilon_1}$ and $\boldsymbol{\varepsilon_2}$ are two generic elements of $\mathbf{u_1}$ and $\mathbf{u_2}$, $\mathbf{x'_1}$ and $\mathbf{x'_2}$ the corresponding row vectors of the $\mathbf{k_i}$ covariates of the two equations. The $\boldsymbol{\Phi(\cdot)}$ is a cumulative bivariate standard normal function, and $\boldsymbol{\Phi_2(\cdot)}$ is a standard marginal normal function of $\boldsymbol{\varepsilon_2}$. The three sums correspond to the following three probabilities: (1) Prob (Sale = 1, Commercial use = 1), (2) Prob (Sale = 0, Commercial use = 1), and (3) Prob (Commercial use = 0). The last one is a marginal probability because when Commercial use = 0, Sale = 0 with probability equal to 1.

The Heckman selection model requires identifying the selection and outcome equations. The Heckman selection model is appropriate only when at least one extra explanatory variable influences selection but not subsequent outcome equation (Sartori, 2003). However, as highlighted in the literature, it is often difficult to think of a theoretically justified variable that affects selection but not the outcome. In this particular case we also cannot rationally exclude any explanatory or control variable from the outcome equation. The variables discussed above can possibly affect both the selection and outcome equations.

Therefore, drawing on argumentation by Gambardella et al. (2007), we decided to exclude 30 technological class dummies from the outcome equation but not from the selection equation. The exclusion of technological class dummies seems to be reasonably safe because we have other variables that account for differences across technological sectors. Moreover, following the Gambardella et al. (2007) paper, we use 6 macro technological class dummies in our outcome equation to account for technological field effect.

In addition, we have performed several robustness checks that are reported in the last section. We tried running the Heckman probit selection model using other variables as exclusion factors. The use of particular variables as exclusion factors was motivated by the fact that they appeared to be insignificant in the outcome equation our initial model with 30 technological dummies as the exclusion factor. In the robustness checks, the results for our explanatory variables remain stable and significant.

4.4. RESULTS

4.4.1. Descriptive statistics

Table 4.1 shows that, on average, 2.00% of patented inventions in our sample were sold to another firm not related to the original owner. With regard to the share of sold patents in the subset of commercially used patents (i.e. patents that were either used internally, licensed out or sold), it constitutes 3.75%. The relatively low share of sold patents in our data can be explained by the fact that most of these patents are in the early stage of their life cycle. The PatVal II survey sample was drawn at the level of patent applications with priority dates between 2003 and 2005.

TABLE 4.1 Descriptive statistics, commercial use and sale of patented inventions (percentages in parentheses)

Commercial use of patent	*Sale of patent* Not sold	Sold	*Total*
Not commercially used	6,614	0	6,614
	(100.00)	(0.00)	(100.00)
Commercially used	7,254	283	7,537
	(96.25)	(3.75)	(100.00)
Total	13,868	283	14,151
	(98.00)	(2.00)	(100.00)

As shown in the Table 4.2, there are notable differences in the sale of patented inventions by patent owners from three regions represented in our study, namely, Europe, Japan, and US. The most active participants in the markets for technologies through patent sales are US firms. Their share of sold patents is about 3.55% which is almost two times more frequent compared to European and five times more frequent compared to Japanese firms with 1.99% and 0.70%, respectively. These findings suggest that there are significant differences across European, Japanese, and US firms in their propensity to sell their patents. These differences may stem from different organizational cultures or maturity of technology markets in various regions.

TABLE 4.2 Descriptive statistics, sale of patented inventions by region (percentages in parentheses)

Region	*Sale of patent*		*Total*
	Not sold	*Sold*	
Europe	8,383	170	8,553
	(98.01)	(1.99)	(100.00)
Japan	2,983	21	3,004
	(99.30)	(0.70)	(100.00)
US	2,502	92	2,594
	(96.45)	(3.55)	(100.00)
Total	13,868	283	14,151
	(98.00)	(2.00)	(100.00)

Table 4.3 presents the sale of patented inventions by firm size. As expected, small firms with less than 50 employees have the highest share of sold patents, about 7.52%. Large firms with more than 500 employees have lower than average proportion of patent sales. Therefore, it is necessary to take into account and control for the size of the patent owner in the empirical estimations.

TABLE 4.3 Descriptive statistics, sale of patented inventions by firm size (percentages in parentheses)

Number of employees	*Sale of patent*		*Total*
	Not sold	*Sold*	
1-49 empl.	1,438	117	1,555
	(92.48)	(7.52)	(100.00)
50-99 empl.	569	25	594
	(95.79)	(4.21)	(100.00)
100-249 empl.	1,029	22	1,051
	(97.91)	(2.09)	(100.00)
250-499 empl.	954	10	964
	(98.96)	(1.04)	(100.00)
500-999 empl.	1,079	11	1,090
	(98.99)	(1.01)	(100.00)
1000-4999 empl.	2,702	22	2,724
	(99.19)	(0.81)	(100.00)
5000 and more empl.	6,097	76	6,173
	(98.77)	(1.23)	(100.00)
Total	13,868	283	14,151
	(98.00)	(2.00)	(100.00)

The proportion of sold patents across macro technological is reported in Table 4.4. The patent sale is more frequent in Instruments and Chemicals/Pharmaceuticals with 2.59% and 2.47%, respectively. Patent sale is least frequent in Mechanical Engineering class with proportion equal to 1.06%. This finding is fully consistent with data reported by Serrano (2010) using a pooling of all U.S. patents granted from 1983 to 2001. He also finds that the proportion of traded patents is highest in Chemical and Drugs/Medical technology fields and lowest in Mechanical field. He argues that this can be due to varying benefits from specialization across technology fields.

TABLE 4.4 Descriptive statistics, sale of patented inventions by macro technological class (percentages in parentheses)

Macro technological class	*Sale of patent*		*Total*
	Not sold	*Sold*	
Electrical engineering	3,387	70	3,457
	(97.98)	(2.02)	(100.00)
Instruments	2,183	58	2,241
	(97.41)	(2.59)	(100.00)
Chemistry/Pharmaceuticals	2,650	67	2,717
	(97.53)	(2.47)	(100.00)
Process engineering	1,955	37	1,992
	(98.14)	(1.86)	(100.00)
Mechanical engineering	2,809	30	2,839
	(98.94)	(1.06)	(100.00)
Consumption	884	21	905
	(97.68)	(2.32)	(100.00)
Total	13,868	283	14,151
	(98.00)	(2.00)	(100.00)

Table 4.5 displays the share of sold patents by their economic value. The table suggests that the proportion of sold patents is higher for economically more valuable inventions. Thus, the proportion of sold patent in the lowest value group is about 1.59% and in the highest value group is about 2.83%. This finding is consistent with an argument by Serrano (2006) that more valuable patents are more likely to be sold.

Therefore, we include the economic value of the patented invention as a control variable in the empirical estimations.

TABLE 4.5 Descriptive statistics, sale of patented inventions by economic value (percentages in parentheses)

Economic value	*Sale of patent*		*Total*
	Not sold	*Sold*	
Value bottom 50%	5,694	92	5,786
	(98.41)	(1.59)	(100.00)
Value 25%-50%	3,490	77	3,567
	(97.84)	(2.16)	(100.00)
Value 10%-25%	2,832	60	2,892
	(97.93)	(2.07)	(100.00)
Value top 10%	1,852	54	1,906
	(97.17)	(2.83)	(100.00)
Total	13,868	283	14,151
	(98.00)	(2.00)	(100.00)

Finally, Table 4.6 presents the correlation matrix for explanatory and control variables used in the analysis.

4.4.2. Empirical analysis results

In this section, we empirically test hypotheses about the likelihood of patent sale developed in the second section.

We present our empirical estimation results in Table 4.7. In the table, we report marginal effects because they have more direct interpretation. For instance, the marginal effect implies a change in probability of patent sale as a result of transition from 0 to 1 in the dummy explanatory variable. For continuous variables, the marginal effect present change in probability of patent sale due to one unit change in the explanatory variable. Since our continuous variables are in logarithms, by multiplying the marginal effects by any percentage change in an explanatory variable one can obtain the respective effect on the probability of patent sale.

TABLE 4.6 Descriptive statistics and correlation matrix

Variables	*Mean*	*s.d.*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*
1. Patent protection	4.05	0.17	1.00													
2. Complementary assets	3.45	1.48	0.06	1.00												
3. Technological fit (log)	-1.78	1.50	0.05	0.01	1.00											
4. Scientific nature	0.52	0.50	-0.06	-0.02	-0.02	1.00										
5. Size small	0.11	0.31	0.01	-0.12	0.24	0.03	1.00									
6. Size medium	0.18	0.39	0.10	0.02	0.14	-0.04	-0.17	1.00								
7. Size large	0.71	0.46	-0.09	0.06	-0.29	0.01	-0.54	-0.74	1.00							
8. Patent stock total (log)	4.93	2.63	-0.21	0.06	-0.51	0.02	-0.45	-0.31	0.57	1.00						
9. Technological competition	0.32	0.47	0.02	-0.04	-0.06	0.16	-0.06	-0.05	0.09	0.05	1.00					
10. Technological generality (log)	-3.58	1.74	-0.03	0.02	-0.02	0.10	-0.00	-0.03	0.03	0.02	0.04	1.00				
11. Value bottom 50%	0.41	0.49	-0.06	-0.07	-0.05	-0.08	-0.07	-0.05	0.10	0.13	-0.07	-0.04	1.00			
12. Value 25%-50%	0.25	0.43	-0.01	0.04	0.01	0.04	-0.02	-0.00	0.02	0.01	0.02	0.01	-0.48	1.00		
13. Value 10%-25%	0.20	0.40	0.05	0.04	0.02	0.06	0.03	0.03	-0.05	-0.06	0.03	0.03	-0.42	-0.29	1.00	
14. Value top 10%	0.13	0.34	0.04	0.00	0.04	-0.01	0.09	0.05	-0.10	-0.13	0.03	0.01	-0.33	-0.23	-0.20	1.00
15. Electrical engineering	0.24	0.43	-0.31	-0.03	0.02	-0.03	-0.04	-0.06	0.08	0.18	-0.00	-0.02	0.04	0.02	-0.04	-0.04
16. Instruments	0.16	0.37	-0.03	-0.03	0.02	0.04	0.07	0.01	-0.06	-0.04	-0.00	0.03	0.00	-0.00	0.00	-0.01
17. Chemistry/Pharmaceuticals	0.19	0.39	0.02	0.02	0.01	0.25	-0.03	-0.01	0.03	-0.01	0.07	0.13	-0.02	0.01	0.02	-0.00
18. Process engineering	0.14	0.35	0.17	0.03	-0.01	-0.06	0.02	0.05	-0.06	-0.10	-0.03	-0.02	-0.03	-0.03	0.02	0.05
19. Mechanical engineering	0.20	0.40	0.09	0.00	-0.06	-0.13	-0.05	-0.01	0.04	0.03	-0.01	-0.08	0.01	0.00	-0.01	-0.01
20. Consumption	0.06	0.24	0.16	0.03	0.05	-0.12	0.06	0.06	-0.09	-0.14	-0.05	-0.05	-0.03	-0.01	0.01	0.04
21. Europe	0.60	0.49	0.05	0.05	0.10	-0.12	0.08	0.11	-0.15	-0.08	-0.29	-0.14	-0.05	-0.03	0.05	0.05
22. Japan	0.21	0.41	0.02	-0.14	-0.15	0.08	-0.15	-0.13	0.21	0.13	0.44	0.01	0.03	0.02	-0.03	-0.02
23. US	0.18	0.39	-0.08	0.08	0.02	0.06	0.06	-0.00	-0.03	-0.03	-0.10	0.18	0.04	0.01	-0.03	-0.04

Variables	*Mean*	*s.d.*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*
15. Electrical engineering	0.24	0.43	1.00								
16. Instruments	0.16	0.37	-0.25	1.00							
17. Chemistry/Pharmaceuticals	0.19	0.39	-0.28	-0.21	1.00						
18. Process engineering	0.14	0.35	-0.23	-0.18	-0.20	1.00					
19. Mechanical engineering	0.20	0.40	-0.28	-0.22	-0.24	-0.20	1.00				
20. Consumption	0.06	0.24	-0.15	-0.11	-0.13	-0.11	-0.13	1.00			
21. Europe	0.60	0.49	-0.09	-0.07	-0.07	0.06	0.12	0.10	1.00		
22. Japan	0.21	0.41	0.06	0.00	0.03	-0.04	-0.02	-0.07	-0.64	1.00	
23. US	0.18	0.39	0.05	0.08	0.05	-0.02	-0.12	-0.05	-0.59	-0.25	1.00

Note: N=14,151

TABLE 4.7 Heckman probit estimations of sale and commercial use of patented inventions, marginal effects (p-values in parentheses)

Variable	*P - selection* *Pr(commercial use)*	*P – outcome* *Pr(sale=1 | commercial use=1)*	*P - bivariate 11* *Pr(sale=1, commercial use=1)*
Patent protection	0.086 (0.002)***	-0.044 (0.002)***	-0.017 (0.011)**
Complementary assets	0.074 (0.000)***	-0.012 (0.000)***	-0.002 (0.003)***
Technological fit (log)	-0.005 (0.143)	-0.004 (0.066)*	-0.002 (0.038)**
Scientific nature	-0.072 (0.000)***	0.019 (0.000)***	0.006 (0.018)**
Size medium	-0.027 (0.093)*	-0.033 (0.000)***	-0.017 (0.000)***
Size large	-0.090 (0.000)***	-0.038 (0.000)***	-0.023 (0.000)***
Patent stock total (log)	-0.026 (0.000)***	-0.004 (0.021)**	-0.003 (0.000)***
Technological competition	0.004 (0.724)	0.001 (0.808)	0.001 (0.763)
Technological generality	-0.001 (0.736)	0.002 (0.339)	0.001 (0.368)
Value 25%-50%	0.082 (0.000)***	-0.002 (0.741)	0.003 (0.355)
Value 10%-25%	0.130 (0.000)***	-0.011 (0.092)*	0.001 (0.808)
Value to 10%	0.151 (0.000)***	-0.009 (0.205)	0.003 (0.443)
Technological class[1]	Yes		
Macro technological class[1]	Yes		
Japan	0.031 (0.010)***	-0.029 (0.002)***	-0.012 (0.007)***
US	0.013 (0.258)	0.019 (0.005)***	0.0.10 (0.002)***
N	14,151		
Ll	-9,847.46		
Chi^2	288.62		
Athrho	1.716 (0.331)		
Predicted probability	0.533	0.041	0.020

Note: p-values in parenthesis are based on robust standard errors adjusted for clusters by firms' identifier.

[1] For the identification reasons Technological class dummies are included only in the selection equation and Macro technological class dummies are included only in the outcome equation.

* p<.1; ** p<.05; *** p<.01

Table 4.7 presents the impact of our explanatory and control variables on the following three probabilities. The first column reports the impact of the variables on the probability of selection into commercial use, i.e. Pr (Commercial use = 1). The second column presents the impact of the variables on the probability of patent sale conditional on selection, i.e. Pr (Sale = 1|Commercial use = 1). The third column reports the marginal probability of patent sale, i.e. Pr (Sale =1, Commercial use = 1). The third probability is the product of the first two probabilities[3]. Therefore, we will primarily focus our further discussion on the differences in the effect of our explanatory variables on the first two probabilities.

Our *patent protection* variable is statistically and practically significant in both selection and outcome equations. However, the effect of patent protection is opposite in the two equations. We find that tighter appropriability regime favors commercial use of patented inventions in general but discourages patent sale in particular. This is fully rational from the patent owner's perspective and supports the real option reasoning in our first hypothesis. Thus, with respect to patent sale, our findings contradict the wide spread opinion that more effective patent protection encourages patent transfer by lowering transaction costs. On the contrary, the patent protection increases the option value and, therefore, hampers or leads to delay the decision to sell the patented invention. Moreover, the effective patent protection may actually increase the opportunity costs of selling the patent by making other commercial use alternatives such as internal use and licensing more attractive.

Similarly, the *complementary assets* are positively and significantly associated with the commercial use but negatively and significantly associated with the patent sale. In other words, the ownership of complementary assets is one of the key reasons for not selling the invention. This finding is in line with the literature and our second hypothesis. As noted by Teece (1986), the firm that lacks necessary complementary assets and unable to easily access them is left with the option of selling or licensing out its intangible assets in the markets for technology, which is better than no remuneration at all. Although numerous empirical studies have

[3] Pr (Sale=1, Commercial use=1) = (Sale=1|Commercial use=1) × Pr (Commercial use=1). Moreover, Pr(Sale=1) = Pr (Sale=1, Commercial use=1) because Pr (Sale=1| Commercial use=0) = 0

provided support for this argument with respect to patent licensing, here we provide an additional empirical support with respect to patent sale.

The *technological fit* variable is statistically insignificant in the selection equation. In the outcome equation, the relationship between the technological fit and probability of patent sale is statistically significant at the 0.1 level. The relationship is statistically more significant for the marginal probability of patent sale (i.e. third column in Table 4.7). These findings provide some support for the third hypothesis and suggest that core technologies are less likely to be sold in the markets for technology. In other words, firms are more likely to sell out non-core or marginal technologies to other firms.

Finally, the *scientific nature* variable is statistically and practically significant in the both selection and outcome equations. We find that the variable is negatively associated with the commercial use and positively associated with the sale. The negative relationship in the selection equation suggests that highly science-based inventions that significantly rely on scientific publications are less likely to be commercially used. More scientific patents are also likely to be more basic with fewer opportunities for economic use or to be far from the market with higher level of required investments and associated risks.

The positive relationship in the outcome equation supports our last hypothesis. However, there are two alternative interpretations for this positive relationship. The first interpretation is based on the argument that highly science-based inventions that rely on scientific publications are more likely to be codified and not tacit. Since codified knowledge is easier to transfer across firm boundaries science-based inventions are more likely to be sold in the markets for technology. An alternative interpretation is that the positive relationship in the outcome equation is not because science-based inventions are easier to transfer but because such inventions are more likely to be offered for sale due to the patent owner's inability to exploit them internally. This, in turn, may explain the positive relationship between scientific nature of the invention and likelihood of actual patent sale. In other words, patented inventions that are actually sold in the markets for technology are more likely to be scientific because they were picked from a subset of more scientific patents preselected for sale. Further, in our robustness checks section we test the consistency of this alternative interpretation.

Findings associated with the control variables used in our empirical analysis also deserve some attention. First, we find that the *firm size* is negatively associated with both commercial use and patent sale. This finding is consistent with arguments in the literature that large firms may patent their inventions for strategic motives and use them for defensive (e.g. freedom to operate), offensive (e.g. patent blocking and litigation) or cross-licensing reasons without using them commercially, licensing or selling them to others (Hall & Ziedonis, 2001). Another possible explanation is that smaller firms with limited financial resources are more scrupulous and efficient at the patent application phase in weeding out inventions that are unlikely to be commercially valuable.

Second, we find that the size of *patent stocks* is also negatively associated with both commercial use and patent sale. This suggests that patent intensive firms with large patent portfolio may have more technologies available than they can commercially exploit. Moreover, the large number of unused or "sleeping" patents may stem from firms' inability to efficiently manage and profitably deploy their large patent portfolios. Finally, since the firm size and the size of patent stock are correlated, we can also use the above mentioned argument about the strategic role of unexploited patents.

Third, we find that the *economic value* of the patent is important in our selection equation and insignificant in the outcome equation. This suggests that patent value is important for the commercial use but not for sale conditional on commercial use. With regard to commercial use, it is fully rational that firms are more likely to commercially exploit more valuable patents. In the case of patent sale, statistical insignificance of the economic value may have several interpretations. First, there can be high uncertainty about the economic value of the invention that were sold. Therefore, respondents give dispersed answers about the economic value of inventions. Second, in order for a patent sale to occur it is necessary to balance the interests of patent sellers and patent buyers. Since patent sellers would like to sell less valuable patents but patent buyers would like to buy more valuable ones, these two tendencies may neutralize each other resulting in a relatively even distribution of values across inventions that are actually sold in the markets for technology. Our findings suggest that, although patented inventions that were sold are more valuable compared to unused inventions, they are neither superior nor inferior in terms of value compared to other commercially exploited inventions.

Finally, it is worthwhile to note the differences across regions in terms of the sale of patented inventions. The estimation results confirm our findings in the descriptive statistics section that compared to European firms, Japanese firms are less likely to sell their patents and US firms are more likely to do that. The difference may be interpreted either by different organizational cultures or by the efficiency of functioning of the markets for technology in different regions.

4.5. DISCUSSION

4.5.1. Implications of the study

We have used a unique dataset constructed on the basis of the large scale inventor survey to study the determinants of patent sale. In this section, we will try to discuss our findings and draw some implications for research, management, and policy.

Our empirical findings suggest that the effective patent protection restrains and hampers patent sale. This finding is in contrast with a wide spread opinion that the effective patent protection (or tight appropriability regime) facilitates technology transfer by lowering transaction costs. In the case of patent sale, we find the real option reasoning to be more helpful to understand the behavior of patent owners. By preventing imitation, the effective patent protection provides sufficient time to a patent owner to wait and learn more about the potential value of an invention before deciding whether to invest in the technology, license or sell it out. Moreover, as noted by HP's vice president, companies are seriously concerned that patents that they sell can be used against them in an offensive way by non-practicing entities (NPE) (Chapman & Shah, 2012). Therefore, firms can be reluctant to sell well protected inventions and be better of using them for defensive purposes. The policy implication suggested by our finding is that policies that reinforce patent protection do not seem to facilitate surplus-enhancing transfers of patent rights, where the alternative owner has greater valuation for a patent than the current owner. Instead, such policies may facilitate defensive behavior by firms and decrease the share of patented inventions traded in the markets for technology.

In line with the literature on patent licensing, we find that the presence of complementary assets necessary to turn the invention into something economically valuable is negatively associated with the likelihood of patent sale. Thus, the ownership of complementary assets is one of the key reasons for not selling the invention. On the contrary, firm that lacks necessary complementary assets and unable to easily access them is more likely to sell its patented invention in the markets for technology. Although numerous empirical studies have provided support for this argument with respect to patent licensing, in this study we provide an additional empirical support and confirmation with respect to patent sale. Considering managerial implications, firms should deliberately evaluate their position in terms of availability of respective downstream complementary resources to turn their inventions into economically valuable innovations in deciding whether to keep or sell out their patented inventions.

Our findings suggest that core technologies are less likely to be sold in the markets for technology. This implies that, as suggested by Prahalad & Hamel (1990), firms understand that they need to protect their core technologies, which are key to their sustainable competitive advantage. It also in line with the prescriptions given by Rivette & Kline (2000b), which suggest that while core technologies should be rigorously protected, non-core technologies can be actively traded for revenue. The managerial implication of this finding is that firms should implement processes to constantly monitor and manage their patent portfolios to identify non-core patents that can be offered for sale. These processes can help firms not only to generate additional revenues but also to reduce maintenance fees and other costs associated with holding non-core patents in their patent portfolio.

Another research implication is related to the relationship between the economic value of patented inventions and the likelihood of patent sale. Serrano (2006) finds that traded patents, on average, are more valuable than their non-traded counterparts, and argues that better and more valuable patents are more likely to be traded. In our study, we refine Serrano's argument and provide strong empirical evidence that sold patents are neither superior nor inferior in terms of value compared to other commercially exploited patents. Our empirical results suggest that, after controlling for other variables, the economic value is highly significant for the probability of commercial use, but it is not statistically significant for probability of patent sale.

Finally, we find notable differences across regions in their propensity to sell their patented inventions and these differences are statistically significant. We find that compared to European firms, Japanese firms are less likely to sell their patents and US firms are more likely to do that. This finding suggests that US firms are more likely to adopt the "Open Innovation" approach emphasized by Chesbrough (2003) and profit from their inventions by selling them in the markets for technologies. Japanese firms, on the contrary, prefer to keep patented inventions in their portfolio instead of sharing them with others. As noted earlier, these differences in the propensity to sell patents may be interpreted either by different organizational cultures or by the efficiency of functioning of the markets for technology in various regions. This finding, therefore, may have implications and be useful for developing policies that foster technology transfer and commercialization or support the development of efficient technology markets in different countries.

4.5.2. Robustness checks

We run several robustness checks to find out whether our results are stable. We also run additional regressions with different specification of variables in order to check some alternative interpretations. For reasons of space, we provide a brief overview of the robustness checks and do not include tables in the paper. The robustness check tables are available from the author.

First, we exploited our empirical finding that the economic value influences the commercial use of patent and does not influence the patent sale to try an alternative exclusion strategy in our robustness checks. When we run Heckman probit selection regression using economic value as the exclusion factor instead of 30 technological class dummies, the results for our explanatory and control variables remained similar and statistically significant. The results suggest that our initial identification strategy did not introduce any biases to the empirical estimations.

Second, we tried the Heckman probit selection model with different selection criteria. Instead of the variable commercial use we generated a variable *external use* that took value 1 if the invention was licensed or sold by a patent owner to an independent party not related to the original owner. The results for the relationship between the key explanatory and control variables and the probability of patent sale in the outcome equation remained very similar even after using the external use as a dependent variable in the selection equation.

Third, in one of our interpretation of the positive relationship between the scientific nature of the invention and the probability of patent sale we argued that sold patents are more likely to be scientific because they were picked from a subset of more scientific patents preselected for sale. Our dataset allows us to check this alternative interpretation by measuring not only actual patent sale but also patent owner's willingness to sell the patent. In particular, the PatVal II survey asks respondents whether the patent owner was willing to sell a patent when it was not actually sold. Using this information, we generated an alternative dependent variable *willingness to sell* that took value 1 if the invention was sold or patent owner was willing to sell it. The variable was used as dependent variable in the outcome equation of the Heckman probit model. The findings support our interpretation and suggest that inventions that significantly rely on scientific publications are more like to be offered for sale and, therefore, more likely to be actually sold. However, our data do not allow us to find out why more scientific patents are more likely to be offered for sale, whether it is due to due to the patent owner's inability to exploit them internally or for other reasons.

Finally, since the correlation between commercial use (selection) and patent sale (outcome) equations is not statistically different from zero, as a robustness check we run independent probit estimation of the commercial use equation and of the patent sale equation for the selected sample of commercially used patents. These independent probit estimations provide relatively similar results and confirm the robustness of our findings reported in the paper.

4.5.3. Limitations and Future Research

This study is subject to several limitations that need to be briefly discussed. First, as it has been emphasized in the literature it is important to look at both supply and demand sides of the market because the likelihood of the transaction is affected by the behavior and characteristics of parties from both sides. Our data contains information only on the supply side of the markets for technology. In our future research, we plan to deal this limitation by collecting additional data on the demand side, i.e. information on patent buyers. To accomplish this task, we have already identified the names of patent buyers by tracing the flow of patent rights and by looking at patent assignment records in the patent registers. The next step is to collect comprehensive firm and industry level data on patent buyers from various company and industry databases.

Second, cross-sectional nature of the data precludes the adaptation of longitudinal perspective and poses certain limitations on the range of applicable econometric methods and estimations. Moreover, cross-sectional data do not allow to fully account for firm-specific unobserved heterogeneity. Thus, obtaining a panel dataset with a longitudinal dimension could significantly improve the quality of empirical estimations.

Third, since patents and patent applications used in our study are at an early stage of their life cycle and only about 42% of them were granted a European patent, we admit that many of these inventions are likely to be sold in the future. However, the use of more early patents would significantly compromise the ability of survey respondents to recall accurate information about their patents.

Finally, we do not have information on the price paid for the patents. Such information often remains confidential and is difficult to obtain. Nevertheless, in the analysis we use some measures that may allow us to assess the economic value of a patent.

All these limitations notwithstanding, we believe that this study will contribute to a better understanding of patent sales, which have important consequences for the diffusion of technology and the functioning of the markets for technology in general.

APPENDIXES

APPENDIX I. SHORT DESCRIPTION OF VARIABLES

Dependent variables	
Pure commercial use	Variable equal to 1 if the applicant(s) or affiliated parties only used this patented invention commercially, i.e., in a product, service or in a manufacturing process, 0 otherwise
Pure licensing	Variable equal to 1 if the patent has only been licensed by the patent owner to an independent party, 0 otherwise
Mixed use	Variable equal to 1 if the applicant(s) or affiliated parties both used the patent in a product, service or manufacturing process and licensed patent to an independent party, 0 otherwise
No use	Variable equal to 1 if the patent has neither been used internally by any of the applicants nor licensed out to other parties, 0 otherwise
Independent variables	
Complementary assets	4 dummy variables based on the presence of complementary assets in the organization for the technical or economic success of the patent
Organization-specific complementary assets	The number of other functional departments of the organization different from the inventor's department with which the inventor communicated frequently for the invention
Scientific nature	Variable equal to 1 if scientific publications as a source of information for the invention were important, 0 otherwise
Technological competition	Variable equal to 1 if during the invention process the inventor's was aware of one or of several other parties competing for the patent
Technological distance (log)	Variable indicating the distance of the invention from the firm's core activity ranging in the interval between 0 and 1
Technological generality (log)	Variable indicating the range of technological areas in which technology can be applied measured on the basis of the number of forward citations and the Herfindahl concentration index
Control variables	
Technological class	30 technological classes based on the OST classification (Appendix II)
Macro technological class	6 macro technological classes based on the OST classification: Electrical Engineering, General Instruments, Chemistry, Process Engineering, Mechanical Engineering
Economic value	4 dummy variables based on the patent value that is rated as being either bottom 50%, 25% - 50%, 10% - 25%, or top 10% in comparison with other patents in the industry or technological area
Firm size	3 classes indicating the firm size based on the number of employees in the organization
Patent stock total (log)	Variable measuring the total number of patents in the firm's patent portfolio
Patent protection	Variable indicating patent protection in the 3-digit IPC class
Region	3 dummies indicating the geographical regions: Europe, Japan, and US

APPENDIX II. TECHNOLOGICAL CLASSES ACCORDING TO THE ISI-INPI-OST CLASSIFICATION (Source: Schmoch, 2008)

	Technological classes
I.	**Electrical engineering**
1.	Electrical machinery and apparatus, electrical energy
2.	Audio-visual technology
3.	Telecommunications
4.	Information technology
5.	Semiconductors
II.	**Instruments**
6.	Optics
7.	Analysis, measurement, control technology
8.	Medical technology
9.	Nuclear engineering
III.	**Chemistry/Pharmaceuticals**
10.	Organic fine chemistry
11.	Macromolecular chemistry, polymers
12.	Pharmaceuticals, cosmetics
13.	Biotechnology
14.	Agriculture, food chemistry
15.	Chemical and petrol industry, basic materials chemistry
16.	Surface technology, coating
17.	Materials, metallurgy
IV.	**Process engineering/Special equipment**
18.	Chemical engineering
19.	Materials processing, textiles, paper
20.	Handling, printing
21.	Agricultural and food processing, machinery and apparatus
22.	Environmental technology
V.	**Mechanical engineering/Machinery**
23.	Machine tools
24.	Engines, pumps, turbines
25.	Thermal processes and apparatus
26.	Mechanical elements
27.	Transport
28.	Space technology, weapons
VI.	**Consumption**
29.	Consumer goods and equipment
30.	Civil engineering, building, mining

APPENDIX III. PATENT OWNERSHIP TRANSFER CHECK PROCEDURE

In this appendix, we describe the patent ownership check procedure used to verify the list of patents that were actually sold.

Following Serrano (2010), we use patent assignment records in the patent registers to verify PatVal II survey responses and check the actual transfers of patent rights across owners. When a patent or patent application is transferred, an assignment of rights is recorded at the European Patent Register (EPR) or National Patent Registers (NPR) acknowledging the change of patent ownership. A conventional assignment entry records the patent involved, the name of the buyer (assignee), the name of the seller (assignor), the date at which the assignment was registered at the patent office (Galasso et al., 2011). The European Patent Office (EPO) also provides scanned copies of applicant's "request for transfer of rights" and EPO's "communication of the registration of a transfer".

We have conducted several rounds of checks using different information sources and databases such as the European Patent Register (EPR), National Patent Registers (NPR) of European Patent Convention (EPC) member states, Espacenet (INPADOC Legal Status), PATSTAT, and Orbit databases.

We have manually checked 809 observations reporting that patent or patent application was sold and 823 observations reporting that the invention was not sold, but the owner was willing to sell it. At the first round of check, we used Espacenet and PATSTAT online databases to find out whether the EPR contained any record of the patent transfer.

In the second round, we used the legal status section of the Orbit database to check whether any equivalent patents (i.e. patents protecting the same invention) were ever sold. The Orbit database provides legal status information on all patents in the patent family around the world. The Orbit database also keeps track of patent assignment by the EPR and NPRs. NPRs need to be checked only if a European patent was granted. Therefore, in the third round of the procedure we check online NPRs of EPC member countries for a subset of inventions that were granted a

European patent. At this stage, we check only those NPRs in which the patent is alive and active.

Galasso et al. (2011) note that there is a challenge to distinguish changes in the patent ownership from other events recorded in the register. To tackle this challenge, we used manual check procedure, in addition to semi-automated search tools. Following Serrano (2010), we conservatively dropped all assignments that are likely not to be associated with an actual transfer of patent rights. For instance, we dropped assignments to financial institutions in which a patent was used as collateral because such assignments do not represent a real ownership transfer. As noted by Serrano (2010), main concern related to US patents is that the first assignment of an unassigned patent that occurs very close to an application date may not be a patent sale but rather be a transfer of ownership from an inventor to an employer firm. Therefore, we ignore such assignments for the US patents only, while for European patents such problem was not observed. Finally, there are patent right transfer records associated with the change of company's name or patent transfers between affiliated companies that belong to a same business group, e.g. from subsidiary to a parent company. Since such patent transfers cannot be regarded as external market transactions in a true sense, we keep track of such transfers separately.

During the check procedure, we have also collected additional information on patent transfer and characteristics of patent seller and patent buyer. For instance, we have collected information on patent application, patent publication, patent grant, and patent transfer dates, which enrich our data by providing some dynamic perspective. Moreover, we obtained information on organization type, country origins, and patent stock for both patent sellers and buyers. Although this information for patent sellers was largely available from the PatVal II survey, equivalent information for patent buyers was lacking. Since we still need to collect more comprehensive data for patent buyers from various company and industry databases in order to conduct the analysis, we do not report this information in this study and reserve it for future research. This additional information on patent buyers and patent sellers will allow us to open up a black box and look at both supply and demand sides in the markets for technology.

APPENDIX IV. DISCUSSION ON TYPE I AND TYPE II ERRORS

The Appendix IV provides a detailed discussion on reasons that could cause the discrepancy between responses about patent sale given by survey respondents and patent right transfer records in the patent registers.

A first set of explanations suggests for a Type I ("False positive") error, which means that a patent was classified by the survey respondent as sold despite the fact that a patent ownership transfer has never actually occurred.

The first argument here is that in the management literature the term "patent sale" has an ambiguous meaning and often used in relation to patent licensing (exclusive or non-exclusive) (e.g. Cohen et al., 2000, p. 4). Therefore, some inventors could understand the term extensively and misclassify licensed patents as sold patents. Our data shows that 31% of observations that didn't have a recorded confirmation of patent right transfer were also classified by respondents as licensed patents. As discussed in the introduction section, in this study we clearly differentiate between "patent sale" and "patent licensing".

Second, as shown by some psychological and social cognitive studies, questionnaire and survey respondents may indulge in a "wishful thinking" defined as interpretation of facts and events according to what one desires rather than according to the actual evidence (Babad, 1997; Gordon, Franklin, & Beck, 2005). Moreover, people are more likely to recall accurate information when it is consistent with their wishes and less likely when it is not (Woike & Polo, 2001). Thus, the discrepancy between survey responses and actual patent right transfer records may stem from the "wishful-thinking bias" and tendency to present desirable event as real.

The presence of such "wishful-thinking bias" can be supported by another observation from the PatVal II survey. For the subsample of 401 observations in which respondent's positive answer about patent sale didn't find support in the patent registers we have compared the respondents' answers to the question "Has the patent been granted already?" with the data from the PATSTAT database on 10/2012 (for EPO patents) and the Orbit database (for other patents in the world).

Interestingly, 194 out of 401 (48.4%) have reported that their invention has been granted a patent, whereas the PATSTAT data were telling that these patents have never received a European patent. Since the survey question did not explicitly specify whether respondents were asked about a grant of European patent or any other equivalent patent (i.e. patent protecting the same invention) in the patent family, we have used the Orbit database to check if any of these 194 inventions has been granted a patent anywhere in the world. We have found that 121 out of 194 inventions were granted patents in other countries. Nevertheless, at the end we still got 73 inventions out of 401 (18.2%) that have never been granted a patent in any country in the world, while survey respondents were reporting that they have been. Hence, we can argue that there happen to be some "wishful-thinking biases" and survey responses should always receive a certain amount of caution and discretion.

A second set of explanations suggests for a possibility of Type II ("False negative") error, which means that we could fail to find records of patent sales that have actually occurred.

The first explanation is that either European Patent office (EPR) or National Patent Registers (NPR) could fail to record and publish the patent right transfer in their online databases. As stated in the European Patent Convention (EPC) and in the European Patent Office Guidelines for Examination, during the examination period a European patent application may be transferred for one or more of the designated contracting states. The transfer of a European patent application is recorded in the EPR, usually within few weeks after a request is received by the EPO. Once granted, a European patent separates into a bundle of national patent rights for member states of the EPC, and each national patent can be assigned independently of the others. Therefore, the transfer registration should be undertaken in each individual member country separately. After a grant of a European patent, the registration of a transfer at the EPR is not sufficient because it is to the individual NPRs that the public are required to look when seeking to determine patent ownership[4].

[4] On this issue see the UK Patents Court decision related to patent dispute between Lundbeck AS and Infosint SA: http://www.bailii.org/ew/cases/EWHC/Patents/2011/907.html

Most of the NPRs in the EPC member counties have online databases that frequently update information about patent owner, patent transfer, and payment of renewal fees on active patents. However, there is a chance that some NPRs are not that well organized and efficient as the EPR in recording and publishing online all patent right transfers. Therefore, it may occur that few patents within a bundle of national patent rights were sold in certain countries, but respective NPRs have failed to timely and accurately record these transfers. However, the last argument is only valid if an invention has been granted a European patent because otherwise patent application does not reach a national phase any patent application right transfer need to be recorded at the EPR only.

Out of 809 observations for which survey respondents reported a sale of patent rights 401 observations did not have any record of patent transfer. Only 123 patents out of 401 (31%) were granted a European patent, while remaining 278 (69%) patents were under examination, withdrawn, or refused[5].

The efficiency of NPRs in recording and publishing patent legal status data decreases the likelihood of committing the "false negative" error in our checking procedure. As it is apparent from their online registers, France, Germany and UK are efficient in providing sufficient information about patents' legal status at a national phase. Other countries either less efficiently update legal status information (e.g. Estonia and Finland) or do not have online patent registers at all (e.g. Italy and Sweden). Therefore, we classify 123 patent discussed above into three groups of patents: (a) active only in efficient NPR countries (31), (b) active in efficient and inefficient NPR countries (90), (c) active only in inefficient NPR countries (2). Therefore, only 92 patents in the last two groups can be a subject to the "false negative" error due to inefficiency of some NPRs to report patent assignments.

Another explanation suggests that patent buyers may fail to report or to request a record of their acquisition at the EPR or NPRs. However, evidence and legal practice suggests that in many countries in Europe the recording of the transfer of patent rights is important for various reasons. The most important reason is that in

[5] Patent grant information is collected from the PATSTAT database on 10/2012

most countries, if a transfer of patent rights is not registered within six months of the transaction date, then damages and costs related to any infringement of the right may be reduced. In the UK, for example, Section 68 of the UK Patents Act states that if there is a failure to record the transfer of a patent right at the United Kingdom Intellectual Property Office within six months of the transaction, the party will not be awarded costs or expenses in proceedings relating to infringement, if the infringement took place before registration of the transfer. Another reason is that in case if patent rights were fraudulently sold by their owner to different "bona fide" purchasers, the rights will be finally owned by the purchaser who is the first to proceed with the registration of the transfer agreement at the relevant NPRs. Considering similar regulations in other non-European countries, in the US, under Section 261 of the US Patent Act, registering the assignment protects the patent owner against previous unrecorded interests and subsequent assignments. However, if the patentee fails to record the transfer, subsequent recorded assignments will have priority (Dykeman & Kopko, 2004).

For these reasons, although recording of a patent transfer is usually not mandatory patent owners have strong incentives to register transfers and European and US patent attorneys strongly recommend doing that as soon as possible in order to fully protect patent owner's intellectual property rights (Dykeman & Kopko, 2004; Oliver, 2007). The registration of a patent right transfer usually requires a few page request letter with support documents and relatively small amount of fee (e.g. transfer registration fee for EPO is 95 EUR). Therefore, after spending a substantial amount of effort and money to patent an invention, deal with oppositions, and transfer it, it seems unlikely that a patent buyer may fail to accomplish this simple registration procedure that legally asserts the ownership rights on an invention.

Summarizing the discussion above, although there is a likelihood of the Type II ("False negative") error and we may underestimate the amount of actual patent sales, the use of data resulting from our additional patent transfer check process seems to represent a more accurate and conservative approach.

APPENDIX V. SHORT DESCRIPTION OF VARIABLES

Dependent variables	
Patent sale	Variable equal to 1 if the ownership right to the patent was sold to another party not related to the original owner or applicant, 0 otherwise
Commercial use	Variable equal to 1 if the invention was commercialized internally, licensed, or sold by a patent owner to an independent party not related to the original owner, 0 otherwise
Independent variables	
Patent protection	Variable indicating patent protection in the 3-digit SIC sector
Complementary assets	Variable measuring whether the organization had the resources to turn the invention into something economically valuable (e.g. new product, process or else)
Technological fit (log)	Variable indicating the fit of the invention with firm's core technological activity
Scientific nature	Variable equal to 1 if scientific publications as a source of information for the invention were important, 0 otherwise
Control variables	
Firm size	3 classes indicating the firm size based on the number of employees in the organization
Patent stock total (log)	Variable measuring the total number of patents in the firm's patent portfolio
Technological competition	Variable equal to 1 if during the invention process the inventor's was aware of one or of several other parties competing for the patent
Technological generality (log)	Variable indicating the range of technological areas in which technology can be applied
Economic value	4 dummy variables based on the patent value that is rated as being either bottom 50%, 25% - 50%, 10% - 25%, or top 10% in comparison with other patents in the industry or technological area
Technological class	30 dummies for the technological classes of the patent (ISI-INPI-OST classification)
Macro technological class	6 macro technological classes based on the ISI-INPI-OST classification: Electrical Engineering, General Instruments, Chemistry, Process Engineering, Mechanical Engineering
Region	3 dummies indicating the geographical regions: Europe, Japan, and US

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