VALUE CREATION THROUGH THE EXPLOITATION OF KNOWLEDGE ASSETS: ECONOMIC IMPLICATIONS FOR FIRM STRATEGY

by

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à Delphine

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Contents

1 Introduction **3**

2 From the lab to the market: The commercialization strategy of patented inventions **9**

2.1 Introduction 10

2.2 A simple model 17

2.2.1 The patent value 22

2.2.2 Innovator's problem 23

2.2.3 Licensee's problem 27

2.3 Benchmark case (no uncertainty) 29

2.4 Commercialization strategy under uncertainty 32

2.5 Conclusions 44

2.6 Appendix 46

2.6.1 The option value of patents 46

3 Does uncertainty affect the licensing of disembodied knowledge? Evidence from Spanish patents **50**

3.1 Introduction 51

3.2 Background theory and hypothesis 54

3.2.1 Methodology 63

3.2.2 Empirical results 72
3.2.3 Econometric issues and robustness checks 75
3.3 Conclusions 78

4 Spillovers at the research unit level 86

4.1 Introduction 87
4.2 The basic framework 90
4.2.1 The research unit's problem 92
4.3 Data 97
4.3.1 Unit of analysis 98
4.4 Empirical implementation 98
4.4.1 Dependent variable: 100
4.4.2 Explanatory variables 100
4.5 The valuation equation 106
4.6 Conclusions 107
4.7 Appendix 109

Chapter 1

Introduction

The essays in this thesis are concerned to study the potential linkages between firms' business strategies and how the exploitation of intellectual assets determines the way innovation can help in building competitive advantages and increasing firm value. In particular, I focus on the different strategies employed by firms to exploit the value created by innovation, examining how market uncertainty and complementary assets affect commercialization decisions.

The existing empirical evidence on patenting shows that even though firms have increased their innovative output, they profit from a relatively small portion of the knowledge produced by their R&D labs. Therefore much of the value created by knowledge assets (e.g. patents) is held unexploited by firms; reducing opportunities to increase profitability and exploiting competitive dynamics. Pointing in this direction, my research seeks to shed light on the following question: How and through which mechanisms does the uncertainty on the future value of the innovation and the amount of irreversible investments needed to embody ideas into products affect the firm's strategic response to exploit new knowledge created?

The second chapter develops a theoretical model that explores the optimal commercialization strategy for disembodied knowledge. In this model, firms seek the option with higher payoff between making an irreversible investment to create more productive capacity and commercialize the patent in-house, transfer production rights to other firms or keep the patent unexploited. Patents have no economic value if they are not embodied in goods or services that can be commercialized. Moreover since the future market value of the invention is uncertain, there is an option value of deferring the acquisition of complementary assets to exploit the patent in-house. Yet, in the case of licensing, transferring production rights to another firm allows the innovator to exploit the patent without committing to any irreversible investment, but at the risk of not appropriating the full value created by the invention. The solution to this problem is found determining the value of the option to invest for the innovator and the potential licensee, expressed in terms of the minimum expected value that the patent must have to be embodied in new products. Driven by the heterogeneity in firms' complementary assets, I examine the process of market exchange of technologies considering a simple setup where the inventor offers a take-it-or-leave-it offer to the potential licensee. In contrast with the existing literature on bilateral partnerships, where higher levels of uncertainty leads to stronger incentives to contract with another partner reducing this way the potential risk of commercialization. I find that the higher the level of market uncertainty, the less likely it is that an innovator will engage in technology partnerships with other firms. Another important result from the theory developed in this paper is related with the linkages between commercialization uncertainty and complementary assets. I find that even in the case that a firm has a commercialization advantage derived from the ownership of complementary assets to exploit the innovation, if the level of uncertainty associated with the innovation is high, the competitive advantages to exploit the patent are significatively reduced.

In chapter three, I develop an empirical framework to study the licensing of disembodied patents. While most of the literature has focused on the licensing of mature technologies for which firms have already created some productive capacity needed to exploit these ideas, I focus on inventions that have never been commercialized before. Following the theoretical framework derived in chapter two, I test the effect of market uncertainty, complementary assets and patent value on the likelihood that a disembodied patent will be licensed, controlling for key alternative effects. I run this test, using a novel dataset of Spanish inventors, constructed from questionnaires sent directly to the group of inventors involved on the patent creation and complemented with other patent and firm level data. I partially solve the problem of finding a proxy for market uncertainty using a measure that accounts for the novelty of the knowledge upon which the invention has been built. I argue that knowledge "recency" can explain the uncertainty on market demand, by the uncertain response in consumer's adoption to new knowledge. Patents relying over most contemporary areas of research and with a high degree of novel knowledge are new to consumers. Therefore the uncertainty on future demand faced by the innovator is stronger than if the technology to be introduced was already well known. The empirical results obtained support the initial hypothesis that higher levels of uncertainty, lead to decrease the likelihood of licensing a disembodied technology.

The last chapter of this dissertation, written jointly with Walter Garcia-Fontes, takes a different perspective and looks at the effect of knowledge spillovers on the value of the innovations produced by a research unit. Building upon the literature that studies how the market value of the firm can be affected by its stock of knowledge assets, we assess empirically the importance of knowledge spillovers on the innovation value. We estimate the effect of knowledge spillovers on the present discounted value of the research unit, adjusted by the replacement cost of intellectual capital. After correcting potential endogeneity problems, we obtain significant estimators based on different spillover pools supporting the idea that knowledge spillovers positively affect the value created by the research unit.

From a policy perspective, this work contributes to shed light on the commercialization process of new technologies. In the last decades, most of the attention on innovation policy has been focused on promoting the creation of new knowledge. Nowadays, the problem does not seem to be on the knowledge supply side, but making those ideas to turn into new jobs, greater productivity and higher levels of welfare. Therefore, it is also important to promote the exploitation and commercial applicability of existing knowledge assets. Moreover, given the ever increasing role of universities and research centers on the innovation process, new policies should be directed to foster the creation of new ventures and leverage the process of commercialization for those innovators lacking the complementary assets needed to profit from the innovation.

One of the main goals of the European innovation policy, reflected on the Lisbon agenda, is to increase up to 3% of the GPD the investments on research and development. The possibility of sustaining this policy in the long term depends not only on the effort of local governments, but also in increasing the private share of R&D investments. However, this is only possible if the private returns from R&D are higher than the opportunity cost of investing in other projects with similar risks. Increasing the returns on research and development activities depend mostly on how much value can be captured from the innovation and this goes certainly associated to the commercialization process of technologies associated with high market uncertainty. For example, the technological sectors contributing the most on Europe's knowledge creation are associated to new technological fields, such as biotechnology and information & communication technologies. These technologies are associated with greater levels of market uncertainty that will ultimately affect their introduction and mass commercialization. This will affect the speed of technological introduction through in-house commercialization or technology transfer. However, an important factor mitigating this situation is the competition in the development of substitute technologies. When two or more firms compete to develop a technology with similar applications, then the option value of waiting is reduced creating an incentive to enter the market first. Therefore, it is important to promote competition on the supply of knowledge, which will ultimately foster technological progress.

Chapter 2

From the lab to the market: The commercialization strategy of patented inventions

2.1 Introduction

In today's knowledge based economy, innovation is the fundamental source of value creation for corporations. In pursuit of profits, firms introduce new goods and services seeking to increase firm value and build competitive advantages. The largest part of this value rests on intangible assets, from which patents are one of the most important given its role to secure temporary monopolistic rights for the commercial use of an invention. Although, in the last two decades, we have seen an important increase in patenting activity and firms are increasingly profiting from their patent portfolios through technology trading; the existing empirical evidence shows that firms only profit from a small share of their patented inventions.[1] Hence, even though firms are patenting more, this does not seems to lead to the creation of more wealth. For instance, according to a survey conducted by British Technology Group (1998) on 133 firms and 20 universities from Western Europe, North America and Japan more than 67% of surveyed firms have a large share of unexploited patents.[2]

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[1] See Kortum and Lerner (1999) for evidence in the surge of patenting activity in the US. Even though technology exchanges are not new (see in particular Lamoreaux and Sokoloff 1998, for evidence in technology transfer deals in the US glass industry during the early 20th century), the active use of technology licensing as a new source of income is relatively recent (Rivette and Kline 1999, Anand and Khanna 2000). For example, a recent study by Elton et al. (2002), shows that a firm with a patent portfolio of at least 450 patents can generate up to 10 percent of operating income through technology licensing.

[2] Unexploited patents are those patents for which the firm has never invested in creating the capacity needed to profit from them and have neither been commercialized through market exchanges (e.g. Licensing, joint ventures, partnerships, etc.).

Moreover, many corporations obtain the largest part of their profits from an even smaller group of active patents.[3] It is clear that the increase in the size of patent portfolios during the last decades not necessarily obeys a strategy to protect innovation returns; since firms not only fill-in patent applications to this end.[4] However, there are many technologies that could be commercialized and still unexploited by some firms (Grindley and Teece 1997 , Rivette and Kline 1999).[5]

The goal of this article is to explore the forces driving the commercialization capacity of innovative firms. To this end, I develop a model where the presence of uncertainty on the expected patent value, generates new insights on the question of how firms can profit from patented inventions. This paper contributes to the existing literature showing that complementary assets are

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[3] In 2002, just 12 of Procter & Gamble's 250 branded products generated half of its sales.

[4] A firm may also patent to signal technical superiority to investors (Long 2002), as a measure to prevent potential hold-up problems in markets for technology (Hall and Ziedonis 2001, Ziedonis 2004) or to strategically block a competitor's entry (Gilbert and Newbery 1982). Moreover, there exists evidence based on surveys from US firms showing that an important fraction of patentable inventions were not patented (Mansfield 1986) and that patents are not considered as the most effective method to protect innovation returns (Cohen, Nelson and Walsh 2000). In this paper I depart from the fact that firms have a large stock of patents that have not been commercialized, rather than explaining why firms prefer to use secrecy instead of patenting.

[5] For example, recently Motorola has engaged in an aggressive process of technology licensing, but according to the Semiconductor Products Sector's director of intellectual property licensing, Paul Reidy some technologies are not licensed because it is too early to commercialize them (Clarke 2003) .

relevant for the firm only if the level of market uncertainty is low. Moreover, in contrast with the existing literature on licensing, I show that more uncertainty instead of motivating technology transfer deals, makes it even more difficult to transfer patented knowledge.

An innovative firm can profit from new patented knowledge in two ways: one is to create the necessary capabilities to exploit the patent in-house. The other is to profit from the patent transferring the idea through licensing, join-ventures, or partnerships. Inventions that have never been commercialized before usually rely on new knowledge that it is most of the time a proprietary asset for the innovator.[6] This situation allows the firm controlling knowledge to act as a monopolist in the product market.[7] Furthermore, depending on the degree of new knowledge content of the patented invention, commercialization uncertainty will differ. For example, patents with an important degree of new features (radical inventions) face higher commercialization uncertainty than patents more derivative from existing knowledge (cumulative inventions).[8] The decision to exploit the patent in-house involves making an irreversible in-

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[6] The knowledge associated to an invention has traditionally been treated in the economic literature as public good that can be used by multiple agents at zero marginal cost (Romer 1986). However, another fast growing literature argues that the transmission of information takes time and effort to be transmitted and therefore there are no costless spillovers (Cohen and Levinthal 1989, Boldrin and Levine 1997, Zuker et al. 1998).

[7] Even though this monopolistic power is not maintained forever, the slow speed at which ideas spread and the possibility of using property rights to control leakages allow the firm to protect its competitive position.

[8] In this article uncertainty is driven by a continuous time stochastic process followed by the revenues generated by the commercialization of the patent.

vestment in productive capacity that together with the uncertain future value of the invention, and the possibility of deferring the investment timing, creates a real option to wait. The real options approach builds over the financial options literature (Black and Scholes 1973) suggesting that the opportunity to invest in a given project is similar to an American call option.[9] For the case of real options, instead of having a financial asset, previous R&D expenditures have allowed the firm to create a legal asset (patent) entitling the owner with the right, but not the obligation, to invest further resources to commercially exploit the idea. If the real option is exercised today, then the firm is killing the option to invest any time in the future; where the levels of uncertainty may have been reduced and the true payoff of the investment decision can be more precisely accessed. By waiting, the firm can avoid making a large irreversible commitment, while making sequential expenditures to reduce the level of uncertainty. The value of the option to commercially exploit the patent is associated to commercialization uncertainty and to the size of investments

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[9] A financial call option is the right to buy an underlying asset (e.g. shares) at a given price and in a given point in time. This right has a value called the option price and when the option is used the owner is exercising the option. Depending on the timing of exercising the option, they can be classified in American or European Calls. The former specifies that the option can be exercised at any moment. The latter implies that it exists a fixed date to exercise the option. For example, an American call option on IBM shares may specify that the owner can buy a fixed amount of IBM shares if the price gets some threshold value (strike price). If the current price of IBM shares is higher than the strike price, the option is in the money and it is worth for the owner to exercise it, if not the option is not exercised and the owner only loses the option price.

needed to embody the patent in new goods or services. However, since the size of irreversible investments depend on how close are the capabilities already developed by the firm and the ones needed to exploit the patent; it may be better for one firm to wait while for others may be optimal to go ahead and invest. This situation opens the possibility to exchange those technologies in which one firm may be in disadvantage to produce but others may be willing to. For example, Digital Corp. decided to wait before commercializing the Alpha chip, given the market uncertainty faced by the invention. Some time after, the chip was not directly commercialized by Digital, but was licensed to a closer competitor.[10] How should an innovator manage the commercialization of new knowledge? Exchanging those technologies for which they face high uncertainty, keep them unexploited or investing in the productive capacity needed to profit from them? Developing a simple framework, this article provides a foundation to understand these tradeoffs.

I consider a model where there are two risk neutral firms, endowed with the complementary assets required to exploit current inventions. The analysis is restricted to the arrival of a single invention and uncertainty is represented in continuous time. Once a firm innovates, it has to find the optimal commercialization strategy for the new patent. This requires selecting the option with higher payoff between making an irreversible investment or transferring production rights to another firm. The solution to this problem is found determining the value of the option to invest for the inventor and the potential

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[10] In May 1997, Digital filed a lawsuit against Intel for violating the Alpha technology developed by Digital. Later, the dispute was settled and Intel licensed most of the components of the Alpha chip. (Kanellos 2002)

licensee, expressed in terms of the minimum expected value that the patent must have to be embodied in new goods. Later, I examine the process of market exchange of technologies considering simple setup where the inventor offers a take-it-or-leave-it offer to the potential licensee. The model predicts that in the case of incremental inventions with low uncertainty, having complementary assets for the commercial exploitation of the patent reduces the option value of waiting. Therefore, if the value of the invention is high enough, firms enjoying complementarities in production may find optimal to introduce inventions without delay, increasing the speed of technological progress. Furthermore, my model shows that the presence of uncertainty increases the reservation value of the licensor, making it more difficult to engage in technology transfer deals. This can help to explain why so many patents that can be profitable through licensing are held unexploited. Given the uncertainty in the commercial value of the invention, the firm prefers to wait and see, instead of licensing a technology that can be a winning lottery ticket in the future.

Literature review: The existing economics and management literature on innovation argues that the decision to exploit in-house or license relies on two main factors: On the one hand, we have the ownership and control of complementary assets (Teece 1986). Firms specialize in some range of activities developing critical assets that can be physical, human or organizational, allowing the firm to successfully create and appropriate the value from innovations. When an invention arrives, it may not fit completely into the existing firm's assets and therefore it's more difficult to commercialize the innovation in-house. On the other hand, there are contracting problems generated by transaction costs (Coase 1974, Williamsom 1975). When the transaction costs involved in the acquisition of the complementary assets needed to develop the invention are higher than those incurred to license the technology then the patent will be licensed, otherwise the patent will be exploited in-house (Arora et al. 2001). Most of the literature on licensing has focused on the licensing of mature technologies for which the firm has already created an installed capacity and the knowledge is relatively spread across the industry (Arora and Fosfuri 2001, Fosfuri 2004). By contrast, I study the possibility that an innovative firm licenses an invention never commercialized before. The role of uncertainty on licensing have been less explored in the literature. An exception is the paper by Bousquet et al. (1998) that studies the design of linear license contracts under demand or cost uncertainty. In general, the idea is that more uncertainty can be seen as a reason that facilitates the technology exchange, because the parties involved might share the risk. In my model, uncertainty decreases the likelihood of licensing.

This article is also closely related to the literature on real options (McDonald and Siegel 1986, Dixit and Pindyck 1994). These papers examine the optimal investment timing in an irreversible project whose value follows a continuous time stochastic process. By analogy with a financial call option, it becomes optimal to delay exercising the option to invest, even when it will be profitable to do so because at that point we are killing the option to invest any time in the future. This article builds on their methodology, introducing asymmetries in the sunk investments associated to the investment project together with the possibility of securing part of the project's profits without investing.

Within this strand, another related paper is Cassiman and Ueda (2002). They study how the optimal project allocation, by an incumbent firm, can make it reject projects that may be commercialized later on by their inventors through a new start-up. While in their model they focus on the interaction between the firm and the creator of the idea, in this paper I examine how the option value of waiting can affect the innovator's optimal commercialization decision.

The rest of the article is organized as follows. Section 2.2 outlines the model setup, and the problems for both the innovator and the licensee. Section 2.3 shows a benchmark case without uncertainty. Section 2.4 analyzes the optimal commercialization strategy under uncertainty. Finally, section 2.5 concludes.

2.2 A simple model

In this section, I set up a general formulation of the model and study the process of commercialization of patented knowledge. There are two risk neutral firms: an innovator (I) and a potential licensee (L). Both firms are endowed with a set of specific assets needed to commercialize existing inventions. Let A_i denote the assets of firm i, for all $i = I, L$. These assets include not only plant capacity but also other organizational assets such as customer's relationships or marketing and managerial capabilities. The innovator has the mutually exclusive right to keep the patent in-house or transfer production rights to another firm. If the patent is not transferred, the innovator can keep it unexploited or embody it into new goods at the cost $F\left(\theta_I\right)$. The innovator will transfer production rights to another firm, if the payoff from technology transfer is higher than its reservation value. If licensing takes place, both parties commit to a contract that specifies the payment of a fixed license fee $\lambda \in (0,1)$ over the licensee's investment value ($X = \lambda\Pi_L$).[11] Information is symmetric for both players, but there is uncertainty on the value of the innovation (for either party) at the time the contract is created. The model has three different stages: First, the innovator observes the payoff from keeping the patent in-house and makes a take-it-or-leave-it offer λ to the potential licensee. Next, the licensee either accepts or rejects the offer. If it accepts, production rights are transferred and a payment is made. In case of refusing the offer gets his outside option L_0. Finally, the firm with production rights becomes a monopolist in the goods market if the patent is embodied, otherwise it keeps the option to invest any time in the future.

The invention[12] can be an improvement of an existing technology or a radical breakthrough, protected by a perfect patent system and where the innovator is the sole owner of the idea.[13] The idea is ready to be commercial-

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[11] In practice, licensing contracts are usually a combination of royalties plus fixed fee schemes (See Rostoker 1983, Bessy and Brousseau 1999). However, given the model's setup where there is no asymmetric information and the licensee does not faces downstream competition, it becomes more appropriate using only a fixed fee licensing scheme.

[12] Along this paper the terms patent and invention will be used with the same meaning. However, it can be the case that some inventions are protected by a group of patents.

[13] When a new discovery is made, the knowledge needed to reproduce the invention is usually not spread across other potential competitors. For the implications of technology licensing in markets with substitute technologies see Arora and Fosfuri (2003). In the real options literature Weeds (2002) develops a model with competing technologies, where the

ized, thus the firm needs to invest only in creating new productive capacity to exploit it and consequently any previous R&D expenditure is considered sunk. The patent is defined over three different dimensions $\{P, A_P, \sigma\}$. The first patent characteristic P, denotes the initial private value of the patent regarding the potential of the innovation as a technological breakthrough. I assume that the initial value of the patent is drawn from a known distribution. The second characteristic (A_P), denotes the specific type of assets needed to exploit the patented idea. Since ideas have economic value only if they are embodied in goods, the firm needs to develop new specific assets each time a new patent arrives. Moreover, given the randomness associated to the innovation process, the innovator can come up with a patent that needs specific assets very different from the ones the firm has already developed. Finally, σ represents the level of commercialization or market uncertainty associated with the new patent. Patents that build over previous knowledge and represent only a small improvement of an existing idea have lower market uncertainty. By contrast, patents that open a new technological field or market have implicit a higher degree of commercialization uncertainty. However, most of the patented inventions tend to be more cumulative than radical.[14]

Demand uncertainty affecting the market value of the patent is modeled

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option to delay is combined with strategic interactions.

[14] As noted by A. Huijser, executive vice president of Royal Phillips Electronics, "In established businesses, innovation is mostly shaped through small, incremental steps of additional features to augment basic functionalities... Success is relatively predictable through the execution of well-defined innovation processes and in-depth knowledge of their markets in the respective business units" Quoted in Baumol (2004)

letting the demand function to be driven by a stochastic process. In particular, I consider that demand is affected by uncertainty in the following way $p = p\left(q, \xi_t\right)$, where p is the price at which the final good is sold, q is output and ξ_t represents the stochastic shift affecting demand faced by all firms in the market. The structure of ξ_t is common knowledge. Following the assumption of no technological substitutes, the innovator controls industry capacity and can choose the level of output that maximizes profits. This allow us to assume without loss of generality that $q = 1$ and changes in p became proportional to ξ_t, making the revenue flow P, be itself a stochastic variable that obeys a geometric Brownian motion

$$dP = \alpha P dt + \sigma P dz \tag{2.1}$$

where α and σ are constant terms representing the drift parameter and the volatility respectively. dt is a time increment and $dz \sim N(0, dt)$ is a standard Wiener process.[15] The intuition for the stochastic structure that rules uncertainty is as follows. At this stage of the innovation process, when the invention is already patented, technical uncertainty has disappeared. Thus, the firm only faces uncertainty relative to future market conditions (future prices, technologies, consumer tastes, wages, etc.)

The only way a firm can profit from the patent is by embodying the new idea into goods it can sell in the market. This requires that the producer acquires the specific assets needed to exploit the patent (A_P) and obtain the rights to

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[15] The assumption that revenues follow a geometric Brownian Motion can be too strong for some particular industries, however simplifies considerably the calculations.

produce in case of not being the innovator. The production process involves no variable costs and the only cost faced by the producer is the fixed cost $K > 0$ of acquiring the specific assets needed to exploit the patent. These are assumed available to all firms in the economy and can be installed instantaneously. The final embodiment cost paid by the producer depends on the degree of cost complementarity between the assets needed to exploit the patent A_P and the assets the firm has already in place A_i, according to the following relationship

$$F(\theta_i) = K - \theta_i \left(A_i, A_P\right) K_C \tag{2.2}$$

where $\theta_i \left(A_i, A_P\right) \in [0, 1]$ represents the degree of cost complementarity between assets and K_C is the size of savings incurred by those firms having cost complementarities.[16]

I will examine only two extreme cases of cost complementarities. On the one hand, if assets are very similar, that is $A_i = A_P$, cost complementarities are perfect implying $\theta_i = 1$ and the producer will obtain the maximum cost advantage. On the other hand, if the producer's existing assets are very different from the ones needed to exploit the patent $A_i \neq A_P$, cost complementarities are $\theta_i = 0$ and the producer will pay the full cost K. This is likely to happen when the patent doesn't fit in the overall's company strategy.

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[16] The "complementarities" examined in this paper are different from the complementarities studied by Milgrom and Roberts 1990. They argue that adding an activity while already performing others has a higher incremental effect on marginal returns (or reducing marginal costs) than when doing the activity in isolation. The concept of complementarities used in this article is related to the cost reduction associated to an irreversible investment if the assets already developed by the firm are complements with the innovation to be exploited.

Assumption 1 *Cost savings are never greater than fixed costs,* $K \geq K_c$.

2.2.1 The patent value

The profits obtained by the producer if the new idea is embodied are given by the expected present value of the invention net of embodiment costs $\Omega_i = V_t\left(P_t\right) - F(\theta_i)$. The expected present value of the invention $V_t\left(P_t\right)$ is determined by the evolution of the revenue stream P_t, the initial value of the invention P and the discount rate ρ.[17]

$$\Omega_i = \int_0^{+\infty} E\left[P_t\right] e^{-\rho t} dt - F(\theta_i) \tag{2.3}$$

Solving expression (3), it can be easily shown that the expected present value profits for the producer, if the patent is embodied today, are $\Omega_i = \frac{P}{\mu} - F(\theta_i)$ where $\mu = \rho - \alpha$ and $\rho > \alpha$. However, if the inventor postpones the embodiment of the invention some T in the future, expected present value profits may be different. The expected present value of the invention $V_0\left(P\right) = \frac{P}{\mu}$ is similar for all firms willing to commercialize the new patent. This is very common in the case of new technologies where the patent has never been

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[17] In this paper it is assumed that patents are infinitely lived, however if we consider the more realistic case of patents having a finite date of expiration the expected present value becomes $V\left(P\right) = \frac{P}{\mu}\left[1 - e^{-\mu T}\right]$. This assumption considerably simplifies the analysis and does not change the qualitative implications of the results.

introduced in the market. The only difference in producer's profits relies on the embodiment costs.[18]

2.2.2 Innovator's problem

The innovator's problem is to determine the optimal commercialization strategy for the new patent. This requires selecting the option with higher payoff between making an irreversible investment to embody an idea with uncertain future value or transferring the exploitation rights to another firm. Formally this problem can be stated as follows:

$$C^I = \max\left\{\max_T E_t\left[(V_T(P_t) - F(\theta_I))e^{-\rho T}\right], \lambda \Pi_L\right\} \tag{2.4}$$

The first argument $\Pi_I(P) = \max E_t\left[(V_T(P_t) - F(\theta_I))e^{-\rho T}\right]$ represents the value of the option to invest. Maximizing this value the innovator determines whether it is optimal to embody or maintain the patent unexploited. $V_T(P)$ represents the value of the invention at the unknown date T at which the investment is made at cost $F(\theta_I) = K - \theta_I K_C$, ρ represents the discount rate and E_t is the expectations operator conditional on information available at

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[18] The value of patents is not only affected by factors determining the changes in the revenues obtained by the invention. Other factors such as the "quality" of patent protection and the life of the patent can also affect the value of the patent today (See Sherry and Teece, 2004). However, given the assumption of perfect patent protection this is not relevant for this model.

time t. The second component $\lambda\Pi_L$ represents the payoff from transferring production rights to another firm (i.e. licensing). In this case, the innovator makes no investment, but the value appropriated depends on the licensing contract created by the two parties.

To solve this problem I first start determining the value of the option to invest. Since inventions are usually unique, in the sense that demand or risks associated to the invention are not correlated with any other assets, I cannot assume that stochastic changes in demand are spanned by existing assets. Therefore contingent claims valuation can not be used to solve this problem (McGrath 1997). Instead dynamic programming with an exogenously given discount rate ρ can be applied.[19] The basic intuition is that we need to find the *embodiment value* P_I^E for which it is worth investing to embody the idea into new goods.[20] This value is determined by the profit flow and it is contingent on the initial value of the patent P. There are two possible states of the world (i) For the case in which $P \geq P_I^E$ (High value patents), the expected value of the invention is high enough to be commercialized in-house. Given the exclusive rights of production granted by the patent, the producer will hold a monopoly in the goods market. The payoff of producing in-house is simply the net present value of the patent net of embodiment costs $\Omega_I = V(P) - [K - \theta_I K_C]$ (ii) For innovations with value less than the barrier $P < P_I^E$ (Low value patents) the

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[19] See in particular Harrison (1985), McDonald and Siegel (1986) and Dixit and Pindyck (1994) for details on solving this type of problems.

[20] Since P evolves stochastically, instead of finding T, I search for the level of P for which it is worth investing to embody the patent. The term "embodiment value" was first used in a similar context by Bloom and Van Reenen (2002)

firm will prefer not to exercise the option to produce in-house and continue holding the option until some unknown date T where the process may reach P_I^E. The payoff of keeping the invention unexploited is[21]

$$\begin{aligned}\Pi\left(P\right) &= \frac{E\left(d\Pi\left(P\right)\right)}{\rho dt} \\ &= \left[\alpha P\Pi'(P)+\frac{1}{2}\sigma^2P^2\Pi''(P)\right]\diagup\rho\end{aligned} \tag{2.5}$$

The expression above can be interpreted as the relationship between future and present investment value. Thus along the interval dt the discounted expected rate of capital appreciation has to be equal to the value of the patent today. Rearranging equation (5) we obtain a second order differential equation that must be satisfied by $\Pi(P)$.

$$\frac{1}{2}\sigma^2P^2\Pi''(P)+\alpha P\Pi'(P)-\rho\Pi\left(P\right)=0 \tag{2.6}$$

The solution for the differential equation can be obtained guessing a functional form. In this particular case the general solution to equation (6) is given by $\Pi(P)=\omega_IP^{\beta}+\omega_I'P^{\beta'}$ and since the stochastic process followed by profits implies that $\Pi(0)=0$, the solution must take the form of $\Pi_I\left(P\right)=\omega_IP^{\beta}$ for any $P\in\left(0,P_I^E\right)$, where ω_I is a constant term to be determined and $\beta>1$ is the positive root that solves the characteristic equation from the second

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[21] See the appendix for a more detailed derivation. The subscript I has been eliminated to facilitate the exposition.

order differential equation. This equation must also satisfy two conditions at the optimal embodiment value P_I^E. The first is the *value-matching* condition which requires that the option value of the invention must equal the value once capacity is installed.

$$\begin{aligned} \Pi\left(P_I^E\right) &= \Omega\left(P_I^E\right) \\ \omega_I\left(P_I^E\right)^{\beta} &= \frac{P_I^E}{\mu} - \left[K - \theta_I K_C\right] \end{aligned} \tag{2.7}$$

The second optimality condition is known as *smooth-pasting* condition and guarantees that the slopes of the two functions match at the boundary.

$$\begin{aligned} \frac{\partial \Pi\left(P_I^E\right)}{\partial P} &= \frac{\partial \Omega\left(P_I^E\right)}{\partial P} \\ \beta\omega_I\left(P_I^E\right)^{\beta-1} &= \mu^{-1} \end{aligned} \tag{2.8}$$

From the two optimality conditions we can find respectively, the embodiment value P_I^E and the constant term ω_I.

$$\begin{aligned} P_I^E(\sigma, \theta_I) &= \frac{\beta}{\beta-1}F(\theta_I)\mu \\ &= \tilde{\beta}\left[K - \theta_I K_C\right]\mu \end{aligned} \tag{2.9}$$

$$\omega_I = \frac{\Omega_I\left(P_I^E\right)}{\left(P_I^E\right)^{\beta}} \tag{2.10}$$

The embodiment value depends on the level of uncertainty (σ) and the degree of cost complementarities (θ). In the case of high uncertainty, the parameter β is closer to one and, all other things equal, P_I^E is higher.[22] The effect of cost complementarities on the embodiment value works through the size of the embodiment costs that a producer must made to embody the patent into new goods (see proposition 3).

2.2.3 Licensee's problem

The decision for the licensee is similar than the innovator's problem. However, in this case the potential licensee has only the option to acquire the patent and keep it unused waiting to develop it later or immediately embody it into new goods. Once the innovator observes the value of keeping the patent in-house, then evaluates the payoff from transferring exploitation rights contingent on the valuation of the potential licensee. The inventor always makes a take-it-or-leave-it offer λ higher than his reservation value λ_I and the potential licensee accepts or refuses based on his own reservation value λ_L

The licensee's problem is as follows:

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[22] From equation (5) we have that $\frac{1}{2}\sigma^2 P^2 \Pi''(P) + \alpha P \Pi'(P) - \rho \Pi(P) = 0$. Letting $\Pi(P) = \omega_I P^\beta$ and substituting back in (5) we obtain $Q(\beta) = \frac{1}{2}\sigma^2 \beta(\beta - 1) + \alpha\beta - \rho = 0$. Differentiating the quadratic equation totally we obtain $\frac{\partial Q}{\partial \beta}\frac{\partial \beta}{\partial \sigma} + \frac{\partial Q}{\partial \sigma} = 0$. Since $\partial Q/\partial \beta > 0$ at $\beta \geq 1$ and $\partial Q/\partial \sigma > 0$ for $\beta > 1$, then $\frac{\partial \beta}{\partial \sigma} < 0$. Thus, $\tilde{\beta} = \beta/(\beta - 1)$ increases as σ is higher. (See page 144 Dixit and Pindyck 1994)

$$C^L = \max\left\{(1-\lambda)\max_T E_t\left[\left(V_T(P_t) - F\left(\theta_L\right)\right)e^{-\rho T}\right], L_0\right\} \tag{2.11}$$

The solution to this problem is similar to the one for the innovator. However, in this case the embodiment value for the licensee is given by

$$P_L^E = \tilde{\beta}\left[K - \theta_L K_C\right]\mu \tag{2.12}$$

and

$$\omega_L = \frac{\Omega_L\left(P_L^E\right)}{\left(P_L^E\right)^\beta} \tag{2.13}$$

As for the innovator, the possible states of the world depend on the initial value of the invention. For the case in which $P \geq P_L^E$ (High value patents), the profit flow from the invention is high enough to be commercialized in-house by the licensee. Since exclusive production rights are transferred to the licensee he will be a monopolist in the goods market. The net payoff from acquiring the license and producing in-house is $(1-\lambda)\,\Omega_L\left(P\right)$ (ii). For innovations with a profit flow less than the barrier $P < P_L^E$ (Low value patents) the licensee may acquire the patent but will prefer not to exercise the option to produce in-house (see proposition 5).

2.3 Benchmark case (no uncertainty)

First suppose that there is no uncertainty affecting the evolution of innovation value, implying that $\sigma = 0$ in equation (1). This turns the problem to a simple net present value rule of investment decisions, where the producer's investment opportunity is similar to a perpetual call option. Therefore, the innovator has the right but not the obligation to invest in embodying the patented idea or transferring these rights to another firm. For the innovator the decision problem becomes

$$C^I = \max\left\{\max\left\{V\left(P\right) - F\left(\theta_I\right), 0\right\}, \lambda\Pi_L\right\}$$

As before he chooses the highest payoff between keeping the patent in-house or transfer production rights. However, under no uncertainty the option value is zero and unexploited patents have no intrinsic value if $V\left(P\right) - F\left(\theta_I\right) < 0$ for all $i = I, L$. In the case of the licensee the new problem is

$$C^L = \left\{\left(1-\lambda\right)\max\left\{V\left(P\right) - F_L, 0\right\}, L_0\right\}$$

The embodiment value also changes when there is no uncertainty in the future market value of the patent. In this particular case of no uncertainty, the embodiment value becomes $\tilde{P}_i^E = \left(K - \theta_i K_C\right)\mu$ (recall equation 8). I proceed examining the different commercialization regimes that can arise according to the degree of complementarities and uncertainty.

Proposition 1 illustrates the situation in which the inventor owns a patent that is closely associated with the existing line of business of the firm. Thus, the innovative firm has all the advantages to exploit the invention directly embodying it into new goods. This is the traditional argument to point out that a firm will prefer to develop in-house rather than transfer production rights (i.e. Caves 1983, Teece 1988, Arora et al. 2001). However, even in this case of no uncertainty, those patents with initial low value will be kept unexploited by the firm simply because they will not be worth investing by anyone in the industry.

Proposition 1 *If* $\theta_I = 1$*, it will be always optimal for the innovator to keep the patent in-house: (i) Low value inventions will be held unexploited and (ii) high value inventions will be always embodied.*

Proof. See appendix ■

In proposition 2, I examine the optimal commercialization strategy for patents in which the innovator does not enjoy complementarities in production. Nowadays R&D intensive firms obtain many patents in fields that are not the core domain of the firm. For this reason the innovator may be in the situation of having a valuable invention that may be more efficiently exploited by another firm.

Proposition 2 *If* $\theta_I = 0$*, the reservation value of the innovator is*

(2.1) $\lambda_I = \frac{\Omega_I}{\Omega_I + \theta_L K_C}$ *for all* $P \geq \tilde{P}_I^E$*. The patent is always embodied and licensed only if* $\theta_L = 1$*.*

(2.2) $\lambda_I = 0$ *for all* $P < \tilde{P}_I^E$*. For all* $P \in [\tilde{P}_L^E, \tilde{P}_I^E)$ *the patent is always embodied and licensed and for values lower than* $\tilde{P}_L^E$ *the patent is not embodied, neither licensed.*

Proof. See appendix ■

Without uncertainty and not having cost complementarities, if the patent value is sufficiently high, the decision to keep in-house or license will depend on the degree of value appropriation.[23] When the licensee has cost complementarities, his valuation is higher than the innovator's and therefore the former can extract more value licensing the patent.[24] Otherwise it becomes optimal

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[23] Recall that value appropriation depends on the λ parameter set in the licensing contract.

[24] The case of the licensing deal between Genentech and Eli Lilly can help to illustrate this point. Genentech, Inc. is a venture-based firm founded in 1976 to exploit the recombinant's DNA technology. Short after its foundation, Genentech scientists synthesized human insulin. The potential of the innovation was clear, a synthetic substitute to animal insulin for a market with an estimated value of US$3.5 billion (Value estimated for 2001, for more details see http://www.bioportfolio.com). However, Genentech being a small start-up firm didn't had the cost complementarities to exploit the new patent. For Genentech, the value of the innovation was high enough to justify the investment in the new productive capacity needed to exploit the patent. However, they decided to sign an exclusive licensing deal with the dominant supplier of pig and beef insulin in that moment (Eli Lilly) for the commer-

to acquire the specific assets needed to exploit the patent in-house (proposition 2 section 2.1). When the expected value of the patent is low, it is always optimal for the innovator to license. In this case, the reservation value of the innovator is zero and given that another firm has a positive valuation for the patent, licensing takes place (proposition 2 sections 2.2).

2.4 Commercialization strategy under uncertainty

In this section I present different results regarding the optimal commercialization strategy of patented inventions when the producer faces uncertainty regarding the future value of the invention. The results obtained are mainly driven by the interaction between the degree of complementarities and market uncertainty. Patents with more uncertainty (radical inventions) can not only be difficult to commercialize given the lack of potential applications but also may negatively affect current profitability and strategic assets that sustain the

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cialization of synthetic insulin. The innovator (Genentech) had the opportunity to produce in-house even not having cost complementarities, but decided to license instead. My model predicts that in this case, the innovator will claim at least the revenues it would had made if commercialization in-house would have been done. In the case of Genentech, according to Hall (1998), Eli Lilly first tried to make Genentech think that the patent market value V was lower than they expected, making λ_I decrease. After some time, Genentech and Lilly engaged in a long and costly litigation battle over the appropriation share from the innovation.

competitive position of the firm. On the other side less uncertain patents (cumulative inventions) are less risky in terms of commercialization outcome, but they usually have a lower expected value. First of all I will look at the relationship between uncertainty and complementarities and how this affects the embodiment value. Then I will determine how uncertainty affects the process of licensing unexploited technologies given different scenarios.

The embodiment value $V_i^E = \tilde{\beta}(\sigma) \times F(\theta_i)$ determines the threshold that sets the decision rule of wether it is optimal or not to commercialize a patented invention. This value is driven by two different effects that move in opposite directions. On the one hand, market uncertainty is captured through the $\tilde{\beta}(\sigma)$ parameter, and as the volatility on market demand increases, the embodiment value grows $\left(\partial V_i^E / \partial \sigma > 0\right)$. On the other hand, the presence of complementarities makes the embodiment cost of the patent lower $(F(1) < F(0))$, reducing the embodiment value. However, complementary assets are a source of considerable advantage as long as the level of market uncertainty remains low. The higher the level of market uncertainty, the commercialization advantage from having complementary assets declines up to the point in which it will be better not to embody the patent. This is summarized in the following proposition,

Proposition 3 *Let* $\Delta = V_0 - V_i^E$ *be the commercialization advantage of firm i, if embodies a patent with an expected value* $V_0 > V_i^E$. *For any level of embodiment cost* $F(\theta_i)$, *there exist an uncertainty threshold* $\sigma^* > 0$ *such that* $\Delta = 0$.

Proof. See appendix ■

The intuition for Proposition 3 can be explained as follows. Under no uncertainty, the commercialization advantage it is exactly the difference between the expected patent value and the embodiment cost. (Point A in Figure 1). However, as market uncertainty grows, the embodiment value increases steadily up to a point where the commercialization advantage disappears (Point B in Figure 1). The level of uncertainty σ^*, determines the point where both effects completely cancel each other out, and becomes optimal for the firm to wait until uncertainty decreases or embodiment costs can be reduced even more. We can have a better understanding from this result considering it from the perspective of technological discontinuities. When the invention is incremental, the new patent represents a small step built on the basis of an existing practice. Patents with this characteristic are very likely to fit with the assets already developed by the innovator, making the embodiment cost lower. Moreover, the level of market uncertainty associated with incremental innovations it is expected to be low, since consumers know well the applications of the technology and they have experience with earlier versions. Therefore the commercialization advantages for the inventor are likely to be high. Patents with high uncertainty (radical inventions) depart from existing practices creating a new technological path, that can be either a substitute for an existing technology or open a completely new field. In the latter case when the technology creates a new field or application, the pressure over the existing assets and revenues is minimum, since all firms willing to produce will have to build specific capabilities to exploit the invention that may not exist anywhere else. In the former case, where the new technology can be a substitute of an existing technology. If any firm having asset complementarities with the radical invention decides to commercialize it, can either suffer from the cannibalization of its own profits or may not be able to fully exploit its current assets. In my framework this means an embodiment value so high that none of the firms in the market will be willing to produce. In first place, given the uncertainty associated to the invention value, the producer can not estimate the full impact on current profits, situation that ultimately is reflected in the inflated option value that creates more uncertainty. Secondly, acquiring capabilities needed to exploit new and uncertain technologies can result very costly making K, in the fixed cost function, to increase respect to the potential savings of having close complementarities in production (K_C). The joint result of these two effects is that most of the time it becomes optimal to wait and try to reduce the market uncertainty before commercializing a radical invention.[25] This is for example what happened with Digital in the nineties. Given the strong market uncertainty they decided to wait before commercializing the Alpha chip, that was known as the fastest and more efficient processor in the market by that time. In the case of patents with less uncertainty (cumulative innovations) the commercialization threshold may be very close to the case of no uncertainty and therefore the firm may be able to profit more easily from the invention. Moreover, if the firm already has the complementarities, a cumulative invention may not have a negative impact on current profits.

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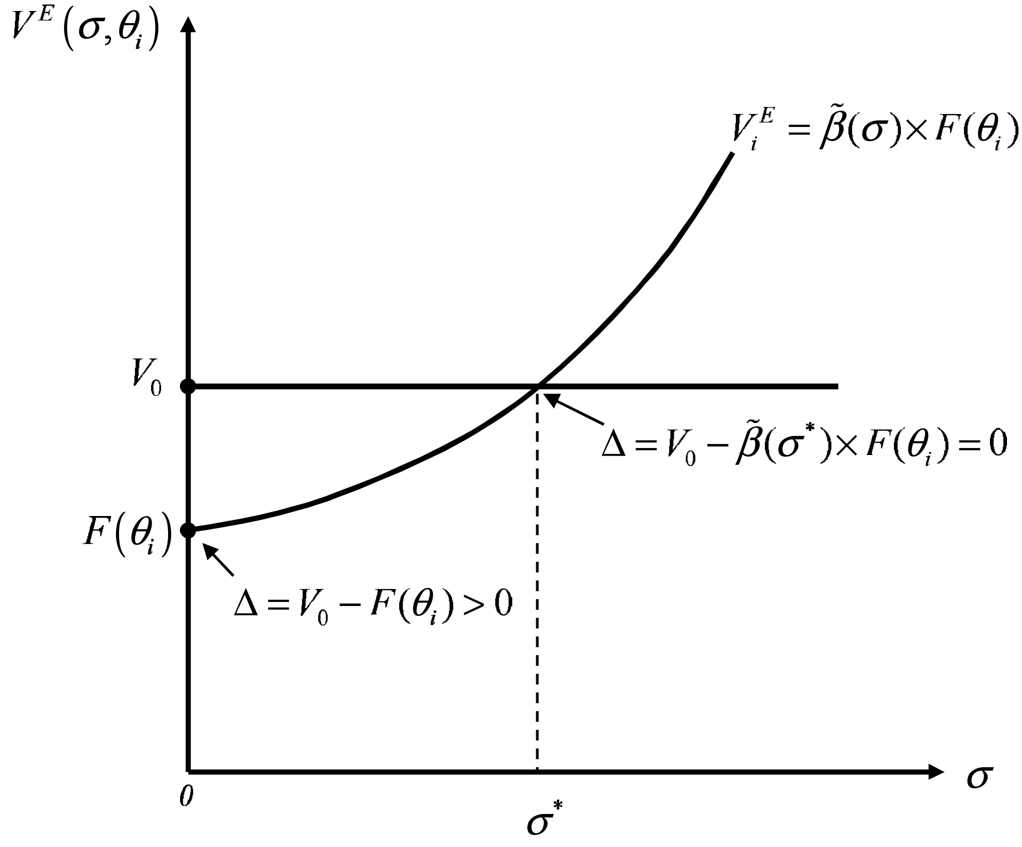
[25] In the existing literature this has been seen from the side of an incumbent firm that will not invest in developing a new radical technology that may cannibalize profits generated by existing products (Arrow, 1962). However since in this paper we start from the invention already patented we look at radical inventions that may have arrived unexpectedly, not necessarily based on a premeditated investment decision of the firm.

Figure 1

Embodiment value, Complementarities and Uncertainty



Now let's turn to the licensing decision under uncertainty. If the inventor has perfect complementarities in production it will be always optimal to keep the patent in-house for any level of uncertainty. However, in the case of radical inventions, the innovator will optimally choose to keep the patent unexploited, waiting to dissipate the uncertainty. Also if the radical invention opens a new technological field licensing is not very likely since all firms in the economy will have the same cost advantages than the inventor and there are no possible gains from trade.

Proposition 4 *If* $\theta_I = 1$*, for any level of uncertainty* $\sigma > 0$*, it is always optimal for the innovator to keep the patent in-house. The innovator's reservation value is* $\lambda_I = 1$ *and: (i) For all* $P \geq P_I^E$*, the patent is embodied in-house and not licensed. (ii) For all* $P < P_I^E$*, the patent is not embodied and not licensed.*

Proof. See appendix ■

Proposition 4 determines the minimum value the innovator with perfect cost complementarities in production is willing to appropriate from the invention, to enter in a licensing deal. However, in this case, the reservation value $\lambda_I = 1$ is so high that even enjoying the same costs complementarities than the innovator $(\theta_L = 1)$, the licensee always rejects the offer. For high value patents $\left(P \geq P_I^E\right)$, the innovator can exploit the patent as efficiently as the potential licensee and therefore no technology transfer deal takes place. In the case of low value patents $\left(P < P_I^E\right)$ for both, the innovator and the licensee the innovation has a similar option value. Thus, the innovator will prefer to wait and keep the patent unexploited until the level of uncertainty decreases.

If the innovator does not have cost complementarities and the uncertainty is low, then it will license the invention to a more efficient firm. However, as uncertainty increases, the option value also does and the inventor values more to keep the invention unexploited. On the one hand, uncertainty may affect the assessment of the true value of the invention, and in case of licensing, the innovator may be losing part of the value created by the invention. On the other hand, if the invention is radical, none of the firms in the market may find profitable to acquire the license and therefore the technology is also keep unexploited. In proposition 5 I formalize this intuition.

Proposition 5 *If $\theta_I = 0$, for any level of uncertainty $\sigma > 0$, the reservation value of the innovator is*

(5.1) $\lambda_I = \frac{\Omega_I}{\Omega_I + \theta_L K_C}$ *for* $P \geq P_I^E$. *The patent is always embodied and licensed only if* $\theta_L = 1$.

(5.2) $\lambda_I = \eta \left(\frac{P}{F(\theta_I)\mu}\right)^{\beta-1} \times \frac{P}{P - F(\theta_L)\mu}$ *for* $P \in [P_L^E, P_I^E)$ *and* $\eta = (\beta-1)^{\beta-1}/\beta^\beta$. *The patent can be licensed or keep unexploited depending on the degree of uncertainty* σ.

(5.3) $\lambda_I = \left(1 - \theta_L \frac{K_C}{K}\right)^{\beta-1}$ *for* $P < P_L^E$ *The patent is not embodied and licensed only if* $\theta_L = 1$.

Proof. See appendix ■

High value inventions (Prop 5, expression 5.1) are feasible to be commercialized by the inventor if the payoff from acquiring the assets needed to exploit the patent and produce in-house are higher than the payoff from licensing. Otherwise, the patent can be licensed to a firm with higher cost complementarities. Even though this result looks similar to proposition 2 (expression 2.1) the embodiment value is much larger since introduces the effect of uncertainty $\left(\tilde{P}_I^E < P_I^E\right)$. Therefore the innovator will be more selective with those projects that may produce in-house, compared with the case of no uncertainty. These patents are always embodied and they can be licensed if the potential licensee has a high level of cost complementarities.

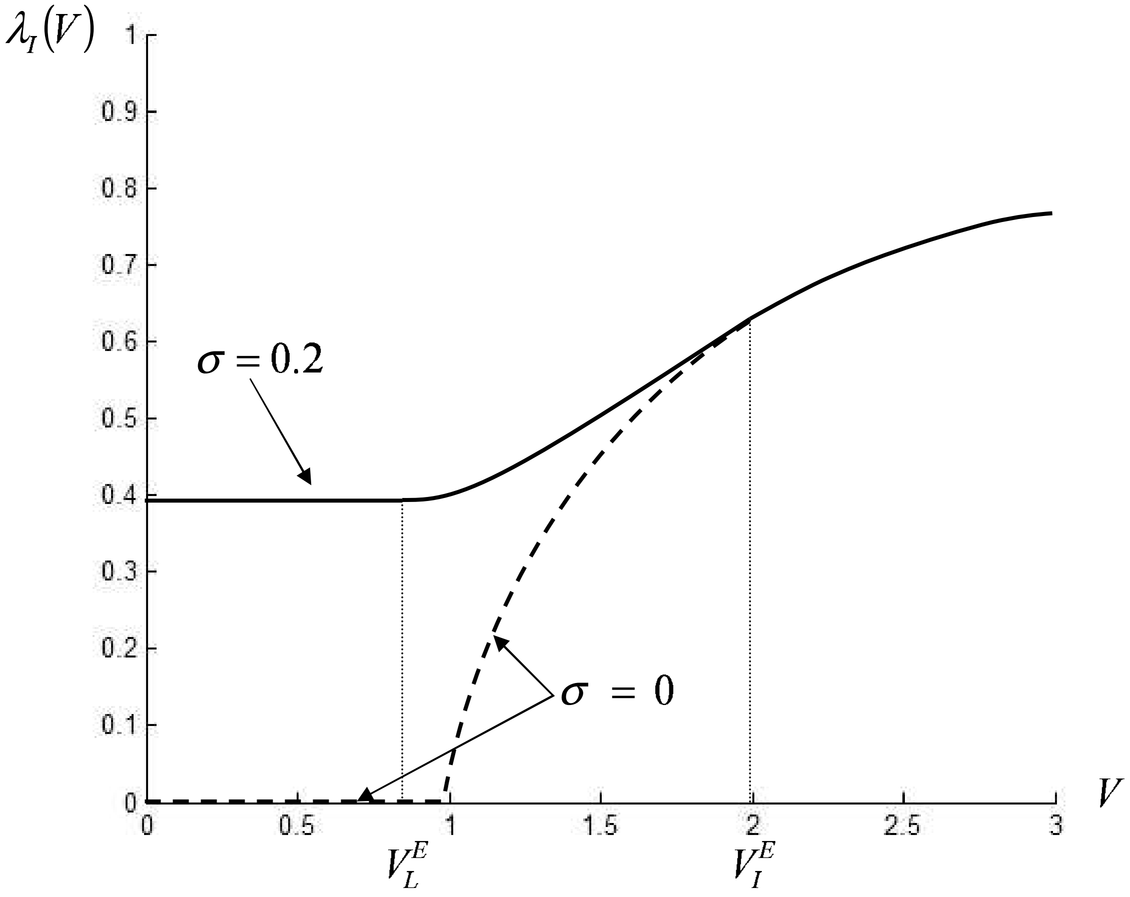
When patents have low expected value, the innovator has to decide if he wants to keep the patent unexploited or transfer production rights. Under this scenario we obtain two possible outcomes. For the case when $P \in [P_L^E, P_I^E)$ (Prop 5, expression 5.2) the reservation value increases if we compare it with the case of no uncertainty, where it was $\lambda_I = 0$ (Prop 2, expression 2.2). To have a more insightful interpretation of expression (5.2) lets divide it in two terms. The first part $\lambda_\sigma = \eta \left(P/F\left(\theta_I\right)\mu\right)^{\beta-1}$ represents the *option value effect* and captures the change in the innovator's valuation for the patent as uncertainty increases. Higher levels of σ make $\beta > 1$ to decrease making λ_σ tend to one, being almost impossible to enter into a licensing deal. The second term $\lambda_C = \frac{P}{P-F(\theta_L)\mu}$ represents the *cost advantage effect* of the potential licensee. For patent values close to $F\left(\theta_L\right)\mu$, the cost advantage effect increases significantly and as the patent value increases λ_C tends to one. The intuition behind this result is that an invention with these characteristics can be of high value for the inventor but given the uncertainty she may not be able to see the potential impact of the patent today. In this case the firm will prefer to keep the lottery ticket and wait if it has a prize. Licensing the patent today may imply losing the possibility of extracting more value in the future.

Finally, expression 5.3 (proposition 5) examines the case of patents with a very low expected value but that a potential licensee may want to acquire to develop in the future. In this case the idea is that even though for the licensee the value of the innovation is not enough to invest in embodying the idea into new goods; it may be optimal to pay a license fee and wait to commercialize in the future.

A numerical example will help to illustrate the model. I will concentrate on the more interesting case where uncertainty is present and the innovator does not have cost complementarities but the licensee does. The set of parameters to be estimated are $\mu = 0.04$, $K = 1$, $K_C = 0.6$, $\sigma = 0.2$, $L_0 = 0.1, \theta_I = 0$ and $\theta_L = 1$. Given these parameters it is easy to show that $\beta = 2, V_I^E = 2, V_L^E = 0.8, \omega_I = 0.25, \omega_L = 0.625$. If the invention arrives with a value higher than V_I^E it will be optimal for the innovator and the licensee to invest and create new goods embodying the idea. For patents with expected value less than V_I^E, the innovator prefers to wait, but the licensor will go ahead and embody the patent until the value of the invention reaches V_L^E. In the case of inventions with value less than V_L^E both, the innovator and the licensee will prefer to wait.

Figure 2

Innovator's reservation value and market uncertainty



The results will be expressed in terms of the present value of the invention $V(P)$. Now consider a patent with high value $V_h = 3 > V_I^E$. Since the embodiment value is reached the patent could be commercialized in-house and the innovator obtains a payoff equal to $V_h - K = 2$. However, since the potential licensor has full cost complementarities, the innovator may obtain even a higher payoff licensing. The innovator will license if $X = \lambda \left(V_h - F\left(\theta_L\right)\right) \geq 2$, and therefore her reservation value is $\lambda_I = 0.77$ and the license will accept any offer that leaves him at least $\lambda_L = 0.96$. The innovator makes a take-it-or-leave-it offer of $\lambda = \lambda_L$, the licensee accepts and the patent is licensed. For the case of patents where $V_m = 1 \in [V_L^E, V_I^E)$ the innovator prefers to wait before making an irreversible investment. Note that in the case of no uncertainty, the option value is zero and the innovator will be always willing to license, but in this case the reservation value has increased by the effect of uncertainty up to $\lambda_I = \lambda_\sigma \times \lambda_C = 0.42$. For any reservation value below $\lambda_L = 0.83$, the patent will be licensed. However, if the uncertainty increases, the reservation value of the innovator will increase as well and the patent will be keep unexploited. Finally in proposition 5.3 we have the case of patents with very low value $V_l = 0.5 < V_L^E$ where both the innovator and the licensee will not embody the patent right away. However, if $\lambda_L > \lambda_I = \left(1 - \frac{K_C}{K}\right)^{\beta - 1} = 0.4$, licensing will take place.

Figure 2 shows how the innovator's reservation value evolves with the value of the patent. In the top of the figure we have a solid line representing the evolution of $\lambda_I\left(V\right)$ when market uncertainty is present $\sigma > 0$. This case is compared with the evolution of the innovator's reservation value under no uncertainty $\sigma = 0$ (dotted line). Keeping the same parameters used in the previous example we can easily find that the embodiment value for the innovator and the licensee under no uncertainty are respectively $\tilde{V}_L^E = (K - K_C) = 0.4$ and $\tilde{V}_I^E = K = 1$. For patent values between any $V \in [0, 1)$ the innovator's reservation value is equal to zero. Therefore, licensing is always feasible for patents belonging to this range. Once V is greater or equal than $\tilde{V}_I^E$, the reservation value of the innovator increases, since now it becomes feasible for him to embody the patent in-house. For higher patent values the cost advantage of the licensee becomes lower in relative terms, making the reservation value of the innovator to increase.[26] When uncertainty is present, the reservation value of the innovator increases significatively especially for patents with low value. Now the embodiment values are shifted to the right given the option value created by the uncertainty. Thus we have $V_I^E = 2$ and $V_L^E = 0.8$ respectively for the innovator and the licensee. For patent values between any $V \in [0, 0.8)$ it is not optimal for any of the two firms to embody the patent and the innovator's reservation increases in 0.4 with respect to the case of no uncertainty. When patents have a value between V_I^E and V_L^E the reservation value initially drops given that now it is optimal for the licensee to embody the patent and it must incur in the irreversible cost $F(\theta_L)$. For patents with higher value the relative advantage of the licensee decreases making the innovator's reservation value to increase steadily. Finally, at $V_I^E = 2$, the innovator can already embody the patent in-house and therefore the path followed by the reservation value is similar than in the no uncertainty case.

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[26] Recall that $\partial\lambda(V)/\partial V > 0$ (proposition 2.1), therefore for higher values of V, $\lambda(V)$ increases.

2.5 Conclusions

Nowadays firms accumulate large stocks unexploited patents that can be transformed into new sources of profits. However, the commercialization of new patented knowledge is a complex process determined by several factors such as uncertainty, production capabilities and the interaction of firms in markets for technology. In this paper I presented a simple model of commercialization strategies of new patented knowledge subject to uncertainty and irreversibilities.

The contributions of this chapter to the existing literature are twofold: First, I analyze the commercialization problem of new technologies as an option to invest. This approach allow us to look at the commercialization process of the innovation as the opportunity to make an irreversible investment on complementary assets in exchange of the uncertain value created by an invention. We found that inventions associated with higher market uncertainty, require a higher investment threshold to be embodied and are less likely to be transferred trough arm's length contracts. Second, this chapter provides the first framework to study the effect of market uncertainty on the commercialization advantage of the firm owing complementary assets.

One potential extension of the model would explore how the commercialization strategies explored in this paper can be affected by the possibility having multiple firms holding substitute technologies. In the latter case, since related options are held by a small number of firms, if there is the possibility of creating value by moving first the option value of delaying will be affected by the fear of preemption.

Also the model leads to hypothesis than could be empirically implemented. For example, my model predicts that more uncertainty affecting the commercialization of the patent, negatively affects the licensing of new technologies. This observation is tested in the third chapter of this dissertation.

Finally, this model also have important implications for business policy shedding some light on the process of commercialization of new patented technologies. Since more radical inventions associated with higher market uncertainty, reduce the commercialization advantage of the innovator, we will expect that disembodied technologies will be commercialized only if they are incremental in the sense that build on an existing technological base.

2.6 Appendix

2.6.1 The option value of patents

. Expression (4) is simply the continuation value of an optimal stopping problem in continuous time $\Pi(P) = \max\left\{(1+\rho\Delta t)^{-1} E\left[\Pi\left(P'\right)\right], \Omega\left(P\right)\right\}$. It can be easily shown that for any $P \in \left(0, P_i^E\right)$ the option value of the patent is

$$\Pi\left(P\right) = \frac{E\left[d\Pi\left(P\right)\right]}{\rho dt}$$

Expanding $E\left[d\Pi\left(P\right)\right]$ using Ito's lemma:

$$E\left[dV\left(P\right)\right] = E\left[\frac{\partial\Pi}{\partial P}dP + \frac{1}{2}\frac{\partial^2\Pi}{\partial P^2}\left(dP\right)^2 + \left(o\right)dt\right] \tag{2.14}$$

where $\left(o\right)dt$ includes higher order terms. Taking expectations and omitting terms that go to zero faster than dt as $dt \rightarrow 0$.

$$E\left[d\Pi\left(P\right)\right] = \alpha P\frac{\partial\Pi}{\partial P} + \frac{1}{2}\sigma^2 P^2\frac{\partial^2\Pi}{\partial P^2} \tag{2.15}$$

Finally substituting (14) into expression (4) and letting $\partial\Pi\left(P\right)/\partial P = \Pi'(P)$, $\partial^2\Pi\left(P\right)/\partial P^2 = \Pi''(P)$ we obtain

$$\frac{1}{2}\sigma^2 P^2\Pi''(P) + \alpha P\Pi'(P) - \rho\Pi(P) = 0 \tag{2.16}$$

■

Proof of proposition 1. For $P \geq \tilde{P}_I^E$ when $(\theta_I, \theta_L) = (1, 1)$ the innovator's payoff from keeping the patent in-house is $V\left(P\right) - \left(K - K_C\right)$ and for the potential licensee the payoff from acquiring the license is $(1-\lambda)\left[V\left(P\right)-\left(K-K_C\right)\right]$. Thus the reservation values for the innovator and the licensee are respectively $\lambda_L < \lambda_I = 1$. The innovator offers $\lambda > \lambda_I$, the licensee rejects and the patent is embodied by the innovator. For the other state of the world $P < \tilde{P}_I^E$ the payoff from keeping the patent in-house is 0 for both players. Thus the reservation values are $\lambda_I = \lambda_L = 0$. The innovator offers $\lambda > \lambda_I$, the licensee rejects and the patent is held unexploited. Finally, the case when $(\theta_I, \theta_L) = (1, 0)$ is strictly dominated by the previous case. ■

Proof of proposition 2.

(A) For $P \geq \tilde{P}_I^E$ when $(\theta_I, \theta_L) = (0, 1)$ the innovator's payoff from keeping the patent in-house is $V(P) - K$ and for the potential licensee the payoff from acquiring the license is $(1-\lambda)\left[V\left(P\right)-\left(K-K_C\right)\right]$. Thus the reservation values for the innovator and the licensee are respectively $\lambda_I = \frac{\Omega_I}{\Omega_I + K_C} < \lambda_L$. The innovator offers $\lambda = \lambda_L$, the licensee accepts and the patent is embodied. When $(\theta_I, \theta_L) = (0, 0)$, the innovator makes an offer where $\lambda > \lambda_I$, the licensee rejects and the patent is embodied by the innovator, (not licensed).

(B) For the other state of the world $P < \tilde{P}_I^E$ and $(\theta_I, \theta_L) = (0, 1)$ we have two different cases: (1) If $P \in [\tilde{P}_L^E, \tilde{P}_I^E)$ the innovator's payoff from keeping the patent in-house is 0 and for the potential licensee the payoff from acquiring the license is $(1-\lambda)\left[V\left(P\right)-\left(K-K_C\right)\right]$. Thus the reservation values are $\lambda_I = 0 < \lambda_L$. The innovator offers $\lambda = \lambda_L$, the licensee accepts and the patent is embodied. (2) When $P \in [0, \tilde{P}_L^E)$ the the reservation values are $\lambda_I = \lambda_L = 0$, the innovator makes an offer where $\lambda > \lambda_I$, the licensee rejects and the patent is not embodied by anyone. Finally when $(\theta_I, \theta_L) = (0, 0)$ the outcome is similar than in case 2. ■

Proof of proposition 3. For this result is enough to show that V_i^E is strictly increasing in the level of uncertainty. Then can be easily shown that for any $V_0 > V_i^E(\sigma_0)$, it will exist a $\sigma^* > \sigma_0$ such that $V_0 = V_i^E(\sigma^*)$.

We have that

$$V_i^E = \tilde{\beta} F(\theta_i)$$

and

$$\beta = \left[\frac{\sigma^2 - 2\alpha}{2\sigma^2}\right] + \sqrt{\left(\frac{\alpha}{\sigma^2} - \frac{1}{2}\right)^2 + \frac{2\rho}{\sigma^2}} > 1$$

Since $\partial\beta/\partial\sigma < 0$, higher levels of uncertainty will make $\tilde{\beta} = \beta/(\beta - 1)$ to increase. Also note that for any given $\theta_i > \theta_i'$ it holds that $V_i^E(\theta|\sigma) < V_i^E(\theta'|\sigma) \Rightarrow \tilde{\beta}[K - \theta K_C] < \tilde{\beta}[K - \theta' K_C]$. However, for values of $\sigma \rightarrow \infty$, $\tilde{\beta} = \beta/(\beta - 1) = \infty$ and $V_i^E(\theta|\sigma) = V_i^E(\theta'|\sigma) \rightarrow \infty$ ■

Proof of proposition 4. For $P \geq P_I^E$ when $(\theta_I, \theta_L) = (1, 1)$ the innovator's payoff from keeping the patent in-house is $V(P) - (K - K_C)$ and for the potential licensee the payoff from acquiring the license is $(1 - \lambda) V(P) - (K - K_C)$. Thus the reservation values for the innovator and the licensee are $\lambda_I = \lambda_L = 1$. The innovator offers $\lambda > \lambda_I$, the licensee rejects and the patent is embodied by the innovator. For the other state of the world when $P < P_I^E$ the innovator's payoff from keeping the patent in-house is $\omega_I P^\beta$ and for the potential licensee the payoff from acquiring the license is $(1 - \lambda)\omega_I P^\beta$. Thus the reservation values are $\lambda_I = \lambda_L = 1$. Since $\lambda_I = \lambda_L$ the innovator offers $\lambda > \lambda_I$, the licensee rejects and the patent is keep disembodied. The case when $(\theta_I, \theta_L) = (1, 0)$ is strictly dominated by the case when $(\theta_I, \theta_L) = (1, 1)$. ■

Proof of proposition 5.

(A) For $P \geq P_I^E$ when $(\theta_I, \theta_L) = (0,1)$ the innovator's payoff from keeping the patent in-house is $V(P) - K$ and for the potential licensee the payoff from acquiring the license is $(1-\lambda)[V(P) - (K - K_C)]$. Thus the reservation values for the innovator and the licensee are respectively $\lambda_I = \frac{\Omega_I}{\Omega_I + K_C} < \lambda_L$ for all $K_C > L_0$. The innovator offers $\lambda = \lambda_L$, the licensee accepts the offer and the patent is embodied. When $(\theta_I, \theta_L) = (0,0)$ the the reservation values are $\lambda_I = 1 > \lambda_L$, the innovator makes an offer where $\lambda > \lambda_I$, the licensee rejects and the patent is embodied by the innovator.

(B) For the other state of the world $P < P_I^E$ there are two possible cases when $(\theta_I, \theta_L) = (0,1)$: (i) If $P \in [P_L^E, P_I^E)$ the innovator's payoff from keeping the patent in-house is $\Pi_I = \omega_I P^\beta$ and for the potential licensee the payoff from acquiring the license is $\Pi_L = (1-\lambda)[V(P) - (K - K_C)]$. Thus the reservation values are $\lambda_I = \eta \left(\frac{P}{F(\theta_I)\mu}\right)^{\beta-1} \times \frac{P}{P - F(\theta_L)\mu}$ and $\lambda_L = 1 - \frac{L_0}{\Omega_L}$. For low levels of uncertainty $\lambda_I < \lambda_L$ and licensing is possible, however if $\sigma \rightarrow \infty$ then $\lambda_I \rightarrow 1$ and no licensing takes place. (Note that $\eta \left(\frac{P}{F(\theta_I)\mu}\right)^{\beta-1}$ and $\frac{P}{P - F(\theta_L)\mu}$ tend to one as uncertainty increases). (ii) If $P \in [0, P_L^E)$ the reservation values are $\lambda_I = \left(1 - \frac{K_C}{P}\right)^{\beta-1} < \lambda_L$, the innovator makes an offer where $\lambda = \lambda_I$, the licensee accepts and the patent is not embodied. ■

Chapter 3

Does uncertainty affect the licensing of disembodied knowledge? Evidence from Spanish patents

3.1 Introduction

In the pursuit of profits, economic agents seek to innovate and introduce new technologies to the market. Profiting from innovation does not only imply discovering and patenting an idea. Inventions have no economic value if they are not embodied in goods and services that can be commercialized. The invention's commercialization process requires that firms or individuals invest in creating the productive capacity needed to exploit the idea. This represents allocating more resources on the construction or extension of production plants, the creation of new marketing and commercialization channels and the training of plant and sales personnel among others. In other cases, the innovator can also decide to transfer the idea to another firm instead of gathering all the necessary assets needed to exploit the invention in-house.

In the last decades, firms have increased their patenting activity, however many of these patents have not been commercially exploited.[1] This situation seems puzzling confronted with the recent trend in technology licensing that allows firms to exploit the value of the innovation not only commercializing the patent in-house, but also profiting from the idea without having to invest to create any productive capacity.[2] For example, recently Motorola has engaged in an aggressive process of technology licensing, but according to the Semiconductor Products Sector's director of intellectual property licensing, Paul

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[1] A survey conducted by the British technology Group in 1998, reported that firms, universities and other research organizations have a large share of unexploited patents.

[2] Rivette and Kline 1999, reported that IBM's licensing related revenues reached \$1 billion in 1998. This represents more than 10 percents of IBM's net profits for the same year.

Reidy some technologies are not licensed because it is too early to commercialize them.[3]

Why do firms having the opportunity to license, prefer to keep patents unexploited? This article empirically approaches this puzzle looking at the determinants of technology licensing considering a new justification for keeping patents unexploited.[4] In particular, I explore the effect of commercialization uncertainty on the likelihood that a patent that has never been commercialized before will be licensed. Even though patented inventions have surpassed the technical uncertainty associated to the R&D process, firms are always handicapped to anticipate the future commercial impact of innovations, even after technical feasibility has been established (Rosemberg 1996).[5]

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[3] Clarke 2003 " La technologie de Motorola est à vendre par concession de licences de propriété intellectuelle " EETimes France.

[4] A firm may also patent to signal technical superiority to investors (Long 2002), as a measure to prevent potential hold-up problems in markets for technology (Hall and Ziedonis 2001, Ziedonis 2004) or to strategically block a competitor's entry (Gilbert and Newbery 1982). In this paper I depart from the fact that firms have a large stock of patents that may be exploited through licensing but still unused (Grindley and Teece 1997 , Rivette and Kline 1999) .

[5] The relevance of uncertainty in the innovation process can be traced back at least to Schumpeter (1934). He suggested that innovation is an activity fraught with uncertainty and therefore to foster such a risky activity the entrepreneur must be awarded by some type of "insurance". Subsequent research on this domain has focused mainly on the uncertainty attached to the R&D process. For example, Loury (1979) classifies uncertainty as technological and market based. The former can be associated to the stochastic relationship between the investment in R&D and the date at which the innovation will be discovered. This un-

Traditionally uncertainty has been seen as an element positively affecting the licensing of new technologies. The reason is that a firm prefers to share (or eliminate) the risks of launching an uncertain technology licensing it out (Bousquet et al. 1998). However, in Gonzalez (2004), I find that under irreversible embodiment costs and having the possibility of delaying the investment timing, commercialization uncertainty increases the option value of the patent making the innovator hold the innovation unexploited instead of licensing. Using data derived from a survey of European inventors and EPO data, I construct a measure of commercialization uncertainty at technological level. Among the main results of this article I find evidence supporting that patents associated with higher levels of market uncertainty and higher value, are less likely to be licensed. Furthermore, I show that when the patent is closely related to the technological domain of the firm, the likelihood of licensing it is also negatively affected.

There is relatively little empirical research on how uncertainty affects firms' investment behavior and even less in the domain of licensing.[6] Probably one of the most import reasons for this lack of empirical evidence is the difficulty to come up with a good measure of demand uncertainty. The strand of literature looking at firm investments and demand uncertainty has used as a proxy for uncertainty the variance of stock market returns (Leahy and Whited 1996) and

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certainty is in general contingent to the degree of R&D investment and disappears once the invention is patented. The latter, captures the unknown effect of competitor's R&D effort on the future completion date of the invention.

[6] The empirical literature in licensing is not abundant, some exceptions are Arora and Ceccagnoli (2004), Fosfuri (2003), Gambardella et al. (2005) and Palomeras (2003)

survey data asking firms its subjective probability distribution of the evolution of the future demand for its product (Guiso and Parigi 1999). The main problem with the existing measures of demand uncertainty to be applied to the problem studied in this paper is that are mainly based on all relevant sources of risk associated to the firm and not focused to a given technology. Moreover, given that some inventions can be completely new to the world it may not even exist an asset that will help us to replicate the expected uncertainty of the patent. This article introduces a measure of uncertainty that overcomes some of these problems, although is not immune to criticism. I look at the novelty of the knowledge upon which the invention has been built, to have a proxy for the demand uncertainty associated to the new patent. Inventions based mainly on new knowledge are subject to higher demand uncertainty because consumers are not familiar with the technology.

The rest of the article proceeds as follows. Section 3.2 presents the theoretical framework and hypothesis to be tested. Section 3.3 describes the methodology followed and the main characteristics of the data. Sections 3.4 and 3.5 present the results and discuss the results obtained. Finally section 3.6 concludes.

3.2 Background theory and hypothesis

The process of licensing technologies that have never been commercialized before it is subject to the uncertainty on how consumers and competitors will react to the introduction of the new idea; the need to gather organizational resources required to successfully exploit the innovation; and finally on its commercial value. In a related topic, the existing literature on economics and management, has approached the question about the decision to license or exploit a patented technology in-house, mainly from the perspective of organizational capabilities and informational asymmetries. On the one hand, organization capabilities theory suggest that firms specialize in some range of activities developing critical assets that can be physical, human or organizational, allowing the firm to successfully create and appropriate the value from innovations. When an invention arrives, it may not fit completely into the existing firm's assets and therefore the innovator may prefer to license the idea to another firm (Teece 1986). On the other hand, the transfer of knowledge is subject to important informational asymmetries. First, the transfer of know-how is difficult to verify and usually characterized by double sided moral hazard problems (Arora 1995). Second, the knowledge itself it is costly to transfer and the lack of well developed markets for technology exacerbates mismatching problems.

The model developed above suggests that, in order to construct a valid test to study how the option value affects the licensing of disembodied patents, we need to explicitly consider the drivers of commercialization strategy (i.e. market uncertainty, innovation complementarities and value) and have information on the current use of the patent.[7] The results obtained from the empirical test support the claims derived from the theoretical model. First, I show that

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[7] I will concentrate on the effects of these commercialization drivers on the licensing process, rather than developing a direct test examining the magnitude and existence of an

market uncertainty decreases the probability of licensing disembodied patents. Second, the ownership of complementary assets also reduces the likelihood of licensing. Finally, a disembodied patent with high value is less likely to be licensed. I begin the empirical analysis with a brief discussion of the main hypotheses to be tested and continue presenting the data and methodology used. The results of the statistical models are then presented, and a discussion of the results closes the paper.

Market uncertainty: this is the uncertainty connected with the future profitability of the patent and it is driven by the uncertainty on the size of market demand. Novel technological products have risks associated with their commercialization and future adoption. For example, Roberts and Hauptman 1987's study on the pharmaceutical industry presents empirical evidence on this issue, looking at a group of pharmaceutical firms that have introduced new products. They find a significant relationship between product radicalness and the presence of risks associated with the use of new drugs and therefore on the final market that will be captured by the patent. Thus while patents building more on new ideas are more risky and difficult to evaluate, patents based on existing knowledge that have been around for a longer time are clearly less uncertain.

The concept of market uncertainty used in this paper is rooted on this idea of how recent is the knowledge upon which the patent has been built. Knowledge "recency" have been used in the literature to show how the tem-

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option to wait. See Ziedonis (2002) for evidence of real options on the licensing of university inventions.

poral dimension of knowledge can determine the creation of new knowledge (e.g. Sorensen and Stuart 2000, Katila 2002, Nerkar 2003). A similar rationale can be used to explain market uncertainty simply because we are looking at two different sides of the market. While the literature on knowledge creation examines the supply side of the innovation; market uncertainty relies on the demand side. However, in both cases the knowledge characteristics of the innovation are similar, but the implications for each side of the market are different. I argue that knowledge recency can explain the uncertainty on market demand, by the uncertain response in consumer's adoption to new knowledge. Patents building over most contemporary areas of research and with a high degree of novel knowledge are new to consumers. Therefore the uncertainty on future demand faced by the innovator it is stronger than if the technology to be introduced were already well known.

Knowledge recency can also be associated with technological discontinuities. Radical technological changes introducing a new technical practice contain a high degree of new knowledge than inventions that refine and develop an existing technology (Dewar and Dutton 1986). However, the existing literature is not clear in defining technological regimes and how market uncertainty is associated to them.[8] For example, an innovation is considered as radical when it represents such an advance that any other existing technology is no longer a viable substitute (Arrow 1962, Reinganum 1983, Henderson 1993). Although, this definition underlines the idea that radical technologies are im-

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[8] Surprisingly, market uncertainty has never been directly linked with technological regimes (whether the innovation is radical or incremental) in a formal way. This may be to the apparent belief that the underlying idea may be too obvious to be explored more deeply.

mediately adopted (and therefore no market uncertainty is allowed), the case is that technologies are not de facto adopted and there is always some degree of market uncertainty present (Farrel and Saloner 1986, Choi 1994).[9] When the invention breaks the existing way of thinking or creates a new technological field, the content of novel knowledge of the idea is much higher than in the case of making a small improvement over an existing technological base. Thus, the higher the novelty content of the invention the larger it is the market uncertainty. Conversely, knowledge that has been created and used for a longer time is usually considered as more reliable (March 1991) and therefore the market uncertainty is lower.

Consider for example the microprocessor. The first microprocessor patented by Intel was a radical invention based mostly on new knowledge. The market uncertainty associated with the technology was high since consumers were not familiar with the new technology. Today, most of the new microprocessors are based on small changes over an existing technology with a lower degree of commercialization uncertainty.

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[9] A possible reason may be that along this literature it is assumed that after the patent has been granted market uncertainty disappears because the superior technology is always adopted by consumers; and perfect patent protection discourages the entrance of competing technologies.

Hypothesis 1: *Ceteris paribus, a disembodied patent is less likely to be licensed as the market uncertainty associated with the commercialization of the technology increases.*

Complementary assets: The process of licensing disembodied technologies is driven by the tradeoff between capturing the whole value created by the innovation, at the cost of making an irreversible investment to gather the organizational assets needed to commercially exploit the idea; or transferring the patent to another firm who has stronger capabilities to exploit the patent. In the later case no investments are required, but the value appropriated by the innovator may vary depending on the contract achieved with the potential licensee. Innovation is a random process based on the creation of new knowledge. This knowledge created can be closely related (or not) with the existing capabilities already developed by the firm. For example, developing the new generation of microprocessors is an incremental innovation activity for Intel, but at the same time it is a complementary task given that all the productive assets of the firm are associated with this activity. In the case of close relatedness between the new patent and the technological and organizational domain of the firm, licensing is less likely to happen because embodying the idea becomes relatively easy for the firm.

From the organization theory perspective, a radical invention is the one that departs so fundamentally from existing practices that all the previous skills, abilities and knowledge developed to exploit the innovation are destroyed. Conversely, incremental inventions can substitute older technologies but do not erode the knowledge base of the firm (Tushman and Anderson 1986). Therefore under this view, the radicalness of an innovation has less to do with the novelty (or uncertainty) of the technology than its conformity with the existing capabilities of the firm (Kogut and Kulatilaka 2001). Inventions with an important degree of new knowledge content require new investments in creating capabilities needed to extract its commercial value. However, in contrast with the view of organizational theory, I argue that capabilities are not "destroyed" when a radical invention arrives. Since organizational capabilities are costly to create (Nelson and Winter 1982) when an invention is based mainly on new knowledge it takes time and resources to adapt the existing organizational structure to embody the new idea into goods and services that can be sold in the market. Nevertheless, previous capabilities are kept as part of the knowledge base of the firm. For example, in the early XX century, Dupont discovered nylon, but it was a firm specialized in the production of rayon and explosives. This major shift obliged the firm to invest heavily in acquiring the capabilities needed to commercially exploit nylon. However, its previous experience in chemicals was an important asset to leverage the transformation (Hounshell and Smith 1988).

Hypothesis 2: *Ceteris paribus, a disembodied patent is less likely to be licensed the higher the complementarities to exploit it in-house.*

The inventor's incentive to license is determined by the trade-off between the market uncertainty and the complementary assets needed to commercially exploit the patent. This is depicted in the $2x2$ matrix shown in $Figure$ 2.

Radical inventions with high degree of novel knowledge content are linked to higher market uncertainty. Because market uncertainty increases the option value of the patent, the possibility of licensing is reduced even in the case where the inventor does not own complementary assets.[10] For radical disembodied technologies the incentives to license will be low independently of the allocation of complementary assets. On the one hand, when asset complementarities are high, the cost of acquiring new organizational capabilities to exploit the new idea are low. Therefore, the innovator may do as well as any other firm in the market exploiting the innovation in-house, thus decreasing the likelihood of licensing. Moreover, since radical inventions have high uncertainty, the innovator's reservation value for the patent increases, making optimal to keep the patent unexploited rather than licensing (*quadrant* 1). On the other hand, when asset complementarities are low, the firm would have to incur on important sunk investments to embody the new patent. Traditionally when the innovator lacks of the complementary assets to exploit the innovation, the patent is licensed. However, given the high option value, no firm will find optimal to commercially exploit the patent and licensing is restricted only to those cases where the potential licensee acquires the patent to keep it unexploited (*quadrant* 2). For the case of incremental innovations associated to a low level of knowledge content, market uncertainty is also lower. Therefore, the option value of the patent decreases and the firm will be willing to license more easily instead of keeping it in-house. Nevertheless, complementarities play also an important role: If the firm's productive assets have a strong complementarity

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[10] Lack of access to complementary assets is one of the strongest reasons supporting technology licensing in general.

with the new patent, the inventor will do better producing in house than licensing (*quadrant* 3). For the case of low complementarities it will be always optimal for the innovator to license (*quadrant* 4).

Figure 2

STRATEGIC INCENTIVES FOR LICENSING DISEMBODIED KNOWLEDGE

	Innovator's Asset Complementarities	
Market Uncertainty	High $\theta_I = 1$	Low $\theta_I = 0$
High (Radical innovation)	– High option value – Low embodiment costs – The innovation is always kept unexploited.	– High option value. – High embodiment costs – The innovation can be kept unexploited or licensed.
Low (Incremental innovation)	– Low option value. – Low embodiment costs. – The innovation can be exploited in-house or Licensed.	– Low option value. – High embodiment costs. – The innovation is always licensed.

Patent value: The value of new technologies is always difficult to measure given the different factors that can affect it. The concept of value used in this article is associated with the initial value of the patent at the moment of being patented. In this case, the assessment of value is mainly based on the technological characteristics of the innovation and the *expected* market value.

The value of the innovation plays an crucial role on the licensing strategy of the firm. A patent with a high value will be not licensed in most of the cases, because the firm will always be able to acquire the capabilities needed to commercially exploit the patent in-house. Nevertheless, patents with lower value may not be attractive enough to the innovator and therefore may be better candidates for licensing.[11]

Hypothesis 3: *Ceteris paribus, the higher the initial value of the patent the less likely it is to be licensed*

3.2.1 Methodology

Sample: The primary data for this study comes from the survey of inventors "The Value of European Patents".[12] In this paper I use the survey run in Spain during the year 2003 on the universe of 623 granted patents in the period 1993-1997. Inventors were localized through their home and work addresses as registered in the patent application. Considering the time elapsed, there were quite a few of inventors who changed work or home addresses. Some of these mobile inventors were localized through different methods (telephone directories, Internet, later patents, various public and private directories). The

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[11] It is important to stress that I am considering patents that have never been commercialized before (disembodied). Once the technology is mature and the firm has built a productive capacity it may be the case that high value patents can be licensed.

[12] This survey was conducted with the financial support of the European Commission contract HPV2-CT-2001-00013.

total number of inventors interviewed amounted to 270.[13] Finally the rest of the data used on this paper comes from the EPO database.[14]

Patents belong mainly to the chemical and pharmaceutical (26% of total) and to mechanical engineering (25% of total) sectors.[15] About less than 10 percent of the observations includes patent filed by individuals, universities and research centers, I have excluded them from the final sample as well as those firms not having a manufacturing capacity in place. Thus I focus on those patents only filed by firms, that are held unexploited or that have been transferred to another firm through licensing.

Dependent Variable: Patent licensing

The dependent variable $LICENSED$, measured at patent level, represents if the patent has been licensed or has been kept unexploited by the firm. To construct this variable I have used the rich information contained in the PatVal-EU database that allows me to discriminate between those inventions that have been (*i*) exclusively licensed, (*ii*) commercially exploited in-house and licensed (*iii*) exclusively commercially exploited in-house and (*iv*) not used at all (not licensed and not commercially exploited in-house). Since I am only

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[13] Unfortunately, for this version of the paper, I have access only to the Spanish sample of PatVal-EU. The rest of the sample includes more than 9,000 patents from France, Germany, Italy, the Netherlands and the United Kingdom. I expect to have access to the rest of the data in a short period of time.

[14] EPO data was provided by the Steunpunt O&O Statistieken, Leuven (Belgium)

[15] The technological areas are created following the Macro ISI classification system.

interested in those patents for which the firm has not previously built any commercialization capacity, only patents that have been exclusively licensed and not used at all are considered. Thus, the variable $LICENSED$ is coded 1 if the patent was reported as licensed and 0 if has not been used at all. After cleaning for missing values and other problems the sample was left with 101 patents from which 23% are licensed and the rest kept unexploited.

Predictor and control variables

Uncertainty: Finding a good proxy for market uncertainty is a very difficult task, given that in most of the cases it is impossible to find an existing technology with similar characteristics from which we may be able to replicate the evolution of uncertainty. Other work has dealt with this problem using a panel of experts in the field or directly asking the inventors to determine the degree of market uncertainty (see for example Green et al. 1995). To explain the uncertainty associated with a single patent, I use a measure that accounts for the age of the citations made to previous patents. Patents citing recently filed patents are building over the most contemporary areas of research and therefore contain a high degree of new knowledge. Conversely, patents citing old prior art are building on mature knowledge (Sorensen and Stuart 2000). I expect that patents with high degree of new knowledge content are associated with a higher degree of market uncertainty.[16]

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[16] In a related study, I examine the robustness of the uncertainty measure used in this paper testing for the potential correlation with the volatility in the price of the product associated with the patent once it has been launched. Preliminary results support the

Patent citations record the knowledge or "prior art" over which the new patent builds (Hall, Jaffe, Trajtenberg 2001). These citations are added by the inventors and checked by the patent examiner who verifies that citations made to previous patents are indeed the right building blocks of the new knowledge. Patent data has been used previously to measure the degree of technological discontinuities (See for example, Rosenkopf and Nerkar 2001, and Lerner 1994). However, these measures are biased to the patent class where the firm has been filed and therefore are not good proxies for market uncertainty. Using a measure related to technological patent classes to determine the degree of radicalness becomes a problem when we want to disentangle market uncertainty from organization capabilities. Moreover, this measure has some problems capturing the radicalness of the invention. For example, consider the patent for first microchip granted to Intel Corporation (see $Figure\ A-1$), using their measure of innovation radicalness on this revolutionary patent surprisingly scores as a non-radical invention.[17]

I have constructed the uncertainty variable by calculating the average of the inverse age for all the backward citations made by patent i. This calculation allows me to normalize for the number of backward citations and at the same time obtaining a measure that increases with the recency of the knowledge used. The following formula was used:

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potential relationship between knowledge recency and the volatility on product prices.

[17] The methodology used by Rosenkopf & Nerkar is to count the number patents cited by patent i that do not belong to its own patent class (and are not self-cites). The higher the count, the more radical it is the patent. For the Intel patent 3,821,715 all the backward citations are on the same patent class as the patent.

$$UNCERT_i = \frac{1}{N} \sum_{j=1}^{N} \frac{1}{a_{ij}} \tag{3.1}$$

where a_{ij} denotes the age of the jth citation made by patent i, out of N citations.[18] A patent that cites many patents within a year will have a higher score than a patent that cites the same number of patents more distant in time. To illustrate more in detail the uncertainty measure used in this paper I have taken all US patents with the same characteristics as the Intel-4004 patent. This means all patents granted in 1974 with application date of 1973 and with the same technological patent classification (USPTO:711/2). From *Figure* 3 we can observe that the patent with the higher uncertainty measure is the Intel-4004, followed by a “virtual memory system” filed by IBM. Conversely, the patent with the lowest market uncertainty score and also the highest average backward citation age is a patent filed by DIGITAL Corp. on an “overlap memory system”. This patent is the improvement of an existing DIGITAL technology, built largely on existing knowledge.

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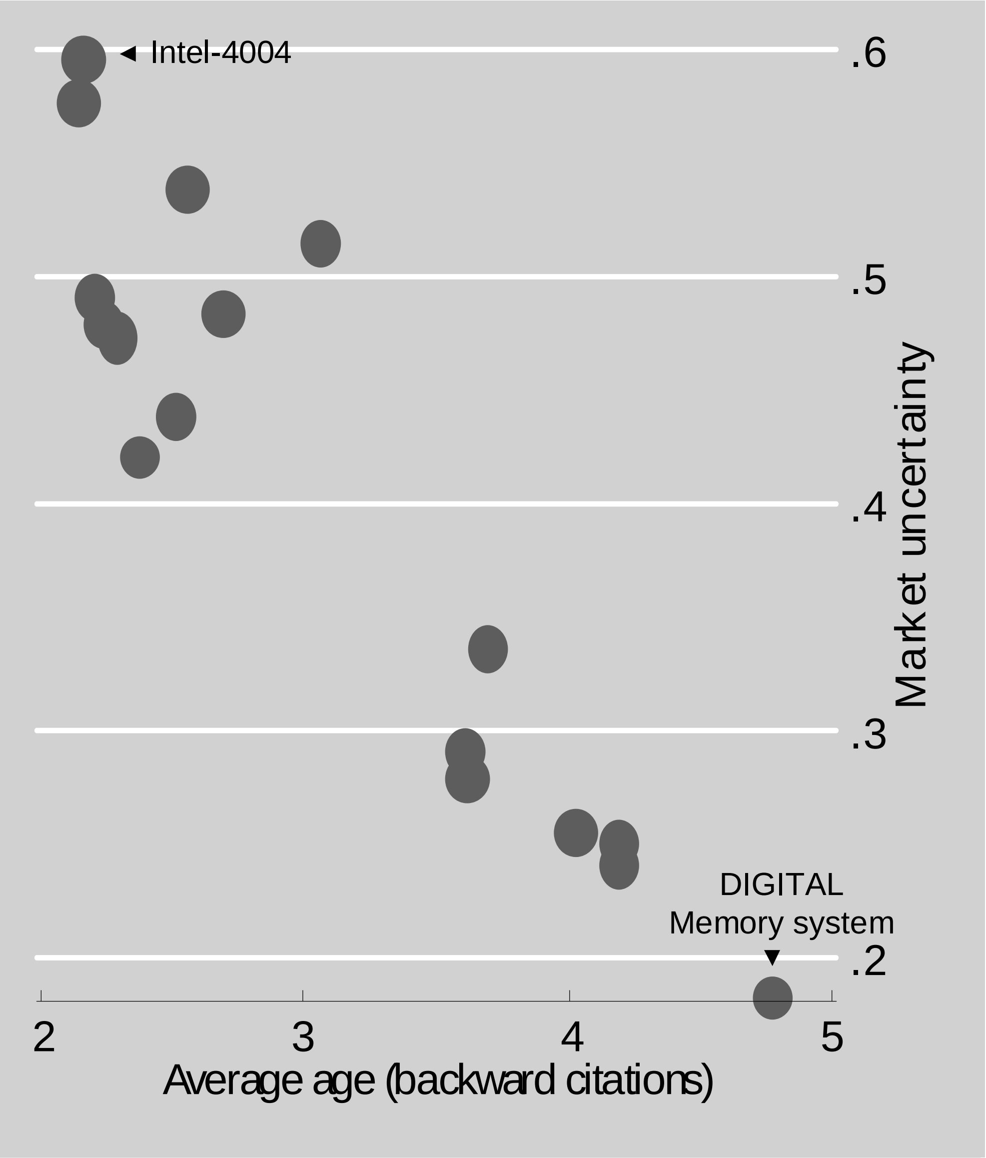
[18] Age compares the grant date of the citing patent with respect to the grant date of the backward citations of that patent. For example, for the case of a patent granted in January 2005 that cites only one patent granted in January 2003, the citation age is of two years.

Figure 3

MARKET UNCERTAINTY VERSUS AVERAGE CITATION AGE*



* Includes all US patents applied for in 1973 and granted in 1974, on the same technological class (711/2 Electrical computers and digital processing systems: Memory)

Complementarities: I measure complementarities between the invention and the assets already developed by the firm using a binary variable that scores $COMPLEM = 1$ if there are complementarities and $COMPLEM = 0$ if not. A patent is complementary with the existing assets developed by the firm if the technological field of the new patented idea belongs to the same technological field where the firm has more intensively patented. The concept of technological relatedness has been previously used in the literature (see for example Jaffe 1986). This type of measure attempts to replicate the degree of congruence between the field where the firm has most of its knowledge assets and the knowledge needed to exploit the new patent. Firms with tight closeness between its core patenting technological area and the new knowledge created should be able to exploit the new patent easily.

I determine the technological field of the firm following a similar procedure as Song et al. (2003). They capture the core technological area of a firm, looking at the most frequent patent class in the portfolio for a given time window. To this end, I constructed a patent portfolio including all the patents filled by the firm between 1993 and 1997. Even though the information regarding the applicant name is available in the EPO data, there are several issues that complicate the construction of patent portfolios. First, there is not a perfect match between the applicant names for the same firm in different patents. For example, one patent assigned to "Shell Ltd." may appear in another patent assigned to "Shell France". Moreover, an important number of patent applicant names are misspelled, which requires an important work of cleaning and double checking. Secondly, many of the patents granted to a firm are given under the name of a subsidiary or parent firms. I have used the directory of corporate affiliations to solve this problem.

Patent value: To proxy the value of the patent ($VALUE$) I use a survey question that asks the inventor about "the economic and strategic value of this patent rated in comparison with other patents in the inventor's industry or technological field". There are three possible categories: 0 for the top 10%, 1 for the top 25%, but not top 10%, 2 for the top 50%, but not top 25% and finally 3 for the bottom 50%.

Control variables: A number of control variables are included in the model. In addition to controlling for various firm, industrial, technological and geographical characteristics suggested by the existing literature, I have added some specific controls on patenting purposes.

Technological class ($Tclass - i$): Technological variables include five technological class dummies constructed according to the technological macro class defined by the ISI-INPI-OST classification (5 macro areas).[19] This is similar to the classification method followed by Hall, Jaffe and Trajtenberg (2001).

Firm size ($Size{-}i$): To control for firm size, I use the number of employees per firm. Larger firms are better positioned than small firms to take advantage of the innovation since they have preferential access to acquire the complemen-

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[19] Technology-oriented classification system jointly elaborated by the German Fraunhofer Institute of Systems and Innovation Research (ISI), the French patent office (INIPI) and the Observatoire des Science and des Techniques (OST).

tary assets needed to exploit the patent in-house (Schumpeter, 1950). This variable consist on three dummies for $Firm - large$ (more than 250 employees), $Firm - medium$ (Between 100 and 250 employees) and $Firm - small$ (less than 100 employees).

Time ($Time$): I control for the year of patent grant. Since the possibility that a patent can be commercialized or licensed varies with respect to the time the patent has been granted, older patents have more opportunities to have been licensed than recently created patents. This variable is constructed counting the years between the grant date and a reference date.[20] For example, a patent granted in 1997 is six years old with respect to the reference date.

Competition ($Comp$): This variable tries to capture the competitive environment in which the patent has been developed. The proxy I have used for this control variable follows a question from the questionnaire related to competitive pressures at the time of patenting. The question reads as follows: "it was decided to patent the invention as it was, because the invention had to be patented quickly, as the inventor's organization was aware of other inventors, research groups or firms that were working on inventions in the same field. The variable takes a value of 1 if the answer to the above question is "Yes" and 0 if "No".

Patenting purposes: a patent can be also held unexploited because it may be used as a blocking mechanism to potential competitor's entry (Gilbert

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[20] Most of the questionnaires where filed in year 2003 and therefore this is the reference date selected this measure.

and Newbery 1982), to protect against imitation or just to build reputation as an innovative firm. To work out this variable I have constructed three dummy variables with information coming from the PatVal-EU survey. The variables are *Block*, *Imitation* and *Reputation* respectively for whether the patent was filled as a blocking instrument, to prevent imitation from other firms and to built reputation.

3.2.2 Empirical results

Summary statistics

Descriptive statistics for the two categories of the dependent variable and the t-tests for differences in means are presented in *Table* 2. Of the 101 patents included in the Spanish sample, only 34% were licensed. All explanatory variables reflect significant differences in means and higher mean estimates for the subgroup of unexploited patents. The larger proportion of licensed patents belongs to the technological classes of Process and Mechanical engineering,[21] whereas the largest share of unexploited patents is observed in the Chemistry & Pharmaceutical technological class. The age of the patents in the sample (measured by *Time*) goes from less than one to six years old. The average age is about 2.6 years, and the group of licensed patents is less than one month older in average in comparison with the unexploited group. The proportion of

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[21] These technological groups include sectors such a metallurgy, textiles and food processing.

patents with least than 3 years of age for unexploited and licensed sub-groups is 78% and 68% respectively, indicating that are slightly more "younger" unexploited patents than licensed. Regarding patenting purposes, a large share of unexploited patents have been filed to protect current or future inventions by patenting the findings surrounding an existing invention (*Imitation*). *Table* 3 provides the correlation matrix. The levels of correlation between the explanatory variables are very low, supporting the idea that these measures capture different drivers for the commercialization of unexploited patents. The highest correlation level $\rho = -0.75$, in absolute terms, it is observed between the control variables *firm-large* and *firm-small.*

Regression results

Estimation results for a probit model of whether the firm decide to license a disembodied technology or not are presented in *Table* 4. The coefficients presented are the marginal effects of the independent variables on the probability of licensing, keeping all other factors constant. Robust standard errors are in parenthesis. Regression (1) predicts the likelihood of licensing including technological, temporal, firm and patenting characteristics. Regression (2) reports the results for the likelihood of licensing adding the measures of uncertainty, complementarities and value. The group of explanatory variables shows the expected signs and all variables are significant at $p < 0.001$. Uncertainty is the variable with the strongest effect on the likelihood of licensing followed by complementarities and value. Once controlling for competition, the uncertainty coefficient increases in absolute terms, while complementarities and value remain almost equal as shown by regressions (2) and (3) . The more significant change is observed in the uncertainty variable, suggesting the important interaction between competition and uncertainty on the likelihood of licensing. The intuition for this result, is that higher market competition reduces the option value of waiting increasing the likelihood of licensing a disembodied technology. The negative sign on large firms is consistent with the argument that established incumbents will be less prone to license their patents given their possibilities to exploit inventions in-house. Technological dummies are all significant except the electrical engineering field.

The effect of uncertainty may not be independent from the other two variables considered, in particular it may be the case that the likelihood of licensing may be affected by the interaction between uncertainty and complementarities. Regression (4) shows us the results for the probit regression including all the previous variables plus two interaction effects. The first interaction term relates uncertainty with complementarities ($int1 = UNCERT \times COMPLEMENT$) and the second relates uncertainty with patent value ($int2 = UNCERT \times VALUE$). In this regression none of the independent variables is significant, however they still have the expected sign. From the two new variables added only $inter1$ is significant and with negative sign. When looking the set of controls we find that in all cases the sign and the level of significance remains equal.

3.2.3 Econometric issues and robustness checks

The results from this study are constrained by some potential limitations common to this type of empirical research, therefore they must be regarded with caution. There are two main problems associated with the type of data used and the construction of variables. Using survey data has the problem that respondents may have potentially misunderstood or overstated some of their answers leading to measurement problems. However, a more serious problem is created from the lack of a direct measure of commercialization uncertainty, which may lead to conceptual errors (is one measuring what one thinks?) as well as measurement errors.

The potential measurement errors coming from survey respondents can arise on the dependent variable ($LICENSE$) and the explanatory variable capturing the value of the patent ($VALUE$). In order to control for potential measurement errors in the construction of the dependent variable, I have developed an alternative measure to control for the accuracy on respondent answers. Given the way the questionnaire was constructed it exists the possibility that some respondents may have reported that a patent was commercially exploited in-house and licensed (*group ii*), when indeed the patent may have been only licensed. In particular, the question asking whether the patent was commercially exploited in-house or not reads “has the applicant/owner ever used this patent for commercial or industrial purposes?”. However, the inventor may have understood that “used for commercial purposes” may also include the possibility of licensing (even though the following question in the questionnaire explicitly asked this). This potential error may have increased the number of patents reported as commercially exploited in-house and licensed, reducing at the same time the group of "exclusively licensed" patents (recall section 5.1.1). This problem has been tackled using another question of the survey that asks for the original motivations for patenting the innovation. In this case respondents were asked whether they patented with the purpose of licensing (in a five points scale). Thus, patents with a score of 5 were expected to be very likely to be licensed at the moment of filing the patent. It is clear that some patents that were initially filed with the intention of being licensed, may have been used differently later. However, I expect that the difference between the group of actually licensed patents and those reporting a high score as to be initially created for this purpose not to be significantly different. After checking for possible differences, the group of actually licensed was lower than the control measure by 20%, also the test on differences in means could not reject systematic differences among group means. In the case of patent value, I controlled for the robustness of the variable employed, creating alternative measures of value. First, I used the number of forward citations as a proxy for patent value (Lanjouw and Schankerman 2004) The second variable tested was the patent value as reported by the inventors in the PatVal-EU survey. In this case inventors where asked to report in a 1 to 10 scale the monetary value in euros of their patents. *Table* 5 shows the results using the alternative measures. Regression (1) uses the original measure of patent value and regressions (2) and (3) present forward citations ($VALUE1$) and monetary value ($VALUE2$) respectively. The results obtained are robust to the use of alternative measures.[22]

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[22] The results for the control variables are similar than in the previous cases.

Another important caveat is related to the problems that may arise from the lack of a direct measure of market uncertainty. Thus, even though the proxy of uncertainty used in this paper seems to fit into the theoretical framework presented, additional measures and further research is needed to corroborate the findings of this study. Moreover, there is also room for some degree of endogeneity derived from measurement errors or unobserved uncertainty factors correlated with the uncertainty measure that can affect the likelihood of licensing a disembodied patent.[23] In order to address the potential endogeneity problem, I will use a two-step regression procedure. This procedure consists on regressing first the uncertainty variable on all the variables I have assumed as exogenous (including instruments). In the second step I use the predicted value of the endogenous variable as independent variable in the structural equation.[24] For instrumenting the endogenous variable I use two different exogenous regressors. The first instrument is the degree of knowledge spillovers to which the inventors where exposed during the innovation process. In environments with high knowledge spillovers, firms will share similar knowledge bases and inventions built more on existing ideas. The second instrument is the number of 4-digit technological classes (IPC) in which the patent was classified. The technological diversity captured by the IPC classification reflects the scope of the patent. Thus higher technological concentration in one area

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[23] This variable has been artificially constructed to proxy an unobservable variable such as commercialization uncertainty which may lead to the classical errors-in-variables problem. See Wooldridge (2002) for further details.

[24] I'm estimating a probit model with an endogenous (continuous) explanatory variable. The methodology commonly used to solve this problem follows Rivers and Vuong (1988).

can be associated to patents that built more on existing knowledge. *Table* 6 presents the regression results after correcting for endogeneity. Regression (1) shows the results for the probit regression without any endogeneity correction and regressions (2) and (3) show the results for the first and second step regression procedure. As can be observed from columns (1) and (3), the correction for endogeneity does not change the previous findings on the sings and significance of the coefficients, but significantly increases its magnitude.[25]

3.3 Conclusions

In this chapter I have performed an empirical test to study the determinants of commercialization for disembodied patents. The results obtained in this chapter must be seen with caution. There are two important caveats to keep in mind before discussing the results: First, I have a small sample size, which can compromise the robustness of the results. Second, the measure of uncertainty I have used may be capturing other effects, rather than the market uncertainty at the moment that the patent is going to be launched.

The empirical results support the hypothesis that higher levels of market uncertainty, negatively affect the likelihood of licensing a disembodied patent. This result is significant, after controlling for firm size, technological class and patent age. Another interesting result, is that patents with high value are

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[25] The Hausman test for endogeneity was performed but the null hypothesis could not be be rejected.

less likely to be licensed. This contradicts the existing literature on licensing, where high value patents are more likely to be licensed. The reason is because this literature considers only patents for which firms have already built some productive capacity and therefore the option value to wait has disappeared.

Even though the empirical model does not address directly the question of how important is the option value for disembodied technologies, looking at the COMPETITION variable we can have an idea of the effects driving the results. The option value exists when the firm has the possibility to wait before committing to an irreversible investment. However, if firms compete to commercialize substitute technologies, the option value is reduced by the fear of preemption. Examining this result in comparison with the existing literature, we see that competition at the downstream level has been seen as a factor leading to more licensing in the case of mature technologies. This chapter provides empirical evidence showing that, competition at knowledge creation level helps to foster the licensing of new technologies.

Table 1 Description of variables

(Spanish sample)

Variable	Definition
Licensed	Licensed = 1 if patent is licensed and 0 if the patent is not exploited in any other way.
Uncert	Average of the inverse age for all backward citations made by patent *i.*
Complem	Complementarities = 1 if patent i belongs to the same technological category where firm n has patented the most and 0 otherwise.
Value	Economic and strategic value of this patent rated in comparison with other patents in the inventor's industry or technological field. Value = 0 for the top 10%, 1 for the top 25%, but not top 10%, 2 for the top 50%, but not top 25% and finally 3 for the bottom 50%.
Value1	Number of forward citations
Value2	Minimum price (in Euro) the applicant would ask a potential competitor interested in buying the patent on the day it was granted, should the applicant have by then all the information on the value of the patent that is available today.
Technological class	Dummy variable for each of the five technological macro classes defined by the ISI-INIPI-OST. (1) Electrical engineering, (2) Instruments, (3) Chemistry and pharmaceuticals, (4) Process engineering, special equipment and (5) Mechanical engineering, machinery
Block	Importance of blocking patents (avoid that others patent similar inventions) for patenting the invention. Block = 1 highly important as a blocking instrument 0 otherwise.
Imitation	Importance of prevention from imitation (protect present or future inventions by patenting the "findings around") for patenting the invention. Imitation = 1 highly important for preventing imitation 0 otherwise.
Reputation	Importance of reputation (patents as an element of evaluation of the inventors/research unit) for patenting the invention. Reputation = 1 highly important as a reputation mechanism 0 otherwise.
Firm Size	Dummy variable for each of the three firm sizes. (1) large firm (more than 250 employees), (2) medium firm (Between 100 and 250 employees) and (3) small firm (less than 100 employees).
Comp	It was decided to patent the invention as it was -as opposed to further develop it by devoting additional resources-, because the invention had to be patented quickly, as the inventor's organization was aware of other inventors, research groups or firms that were working on inventions in the same field. Competition = 1 if the answer to the question above was affirmative and 0 otherwise.
Time	Age of the patent (in years) measured as the number of years between the day the patent wass granted and 2003.
Tech-Diversity	Number of 4-digit technological classes (IPC) in which the patent was classified.
Spillovers	Importance of interactions (discussions, meetings, sources of ideas, etc.) with people (apart from co-inventors) belonging to other organizations (unaffiliated).

Table 2 Descriptive statistics
(Spanish sample)

Variable	Mean *(N=101)*	Min	Max	Mean Unexploited patents *(N=67)*	Mean Licensed patents *(N=34)*	Difference in means
UNCERT	0.054	0.006	0.129	0.058	0.047	0.012** (0.006)
COMPLEM	0.634	0	1	0.761	0.382	0.379*** (0.095)
VALUE	1.386	0	3	1.567	1.029	1.386*** (0.099)
Technological class						
Tclass-electrical	0.129	0	1	0.179	0.029	0.129*** (0.033)
Tclass-mechanical	0.297	0	1	0.269	0.353	0.297 (0.046)
Tclass-instruments	0.030	0	1	0.030	0.029	0.030 (0.017)
Tclass-prossesing	0.277	0	1	0.224	0.382	0.277* (0.045)
Tclass-chemistry&Pharma	0.267	0	1	0.299	0.206	0.093 (0.094)
Patenting purposes						
Block	0.644	0	1	0.642	0.647	-0.005 (0.102)
Imitation	0.782	0	1	0.776	0.794	-0.018 (0.088)
Reputation	0.475	0	1	0.433	0.559	-0.126 (0.105)
Firm Size						
Size-Large	0.634	0	1	0.731	0.441	0.634*** (0.048)
Size-medium	0.119	0	1	0.134	0.088	0.046 (0.069)
Size-small	0.248	0	1	0.134	0.471	-0.336*** (0.085)
Comp	0.178	0	1	0.164	0.206	-0.042 (0.081)
Time	2.584	0	6	2.567	2.618	-0.050 (0.354)

Note: t-test on equality of means Ho: mean(0) - mean(1) = diff = 0
Standard deviations are in parenthesis. Confidence levels of: ***(1%), ** (5%) and * (10%)

Table 3 Bivariate Correlations for the Independent Variables (n=101)

(Spanish sample)

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1 UNCERT	1.00															
2 COMP	0.00	1.00														
3 VALUE	0.09	0.07	1.00													
4 Time	-0.05	-0.07	-0.02	1.00												
5 Competition	0.15	-0.08	0.08	0.01	1.00											
6 Electrical	0.07	0.05	0.03	-0.08	-0.02	1.00										
7 Instruments	-0.06	0.13	0.05	-0.10	-0.08	-0.07	1.00									
8 Chemistry	0.23	0.09	0.19	-0.16	0.13	-0.23	-0.11	1.00								
9 Prosessing	-0.05	-0.13	-0.24	0.00	0.06	-0.24	-0.11	-0.37	1.00							
10 Mechanical	-0.20	-0.05	0.01	0.25	-0.13	-0.25	-0.11	-0.39	-0.40	1.00						
11 Blocking	-0.02	-0.09	0.16	0.19	0.08	0.10	0.01	-0.06	-0.09	0.08	1.00					
12 Imitation	0.03	-0.05	0.11	0.17	0.06	-0.01	-0.05	-0.06	0.01	0.08	0.51	1.00				
13 Reputation	0.14	0.11	-0.17	0.07	-0.08	-0.01	-0.05	0.05	0.03	-0.05	0.21	0.26	1.00			
14 Large	0.09	0.10	0.15	-0.12	0.09	0.11	0.13	0.18	-0.17	-0.14	-0.09	-0.15	-0.18	1.00		
15 Medium	0.00	0.15	0.04	-0.06	0.07	0.04	-0.06	-0.01	-0.02	0.03	0.21	0.12	0.14	-0.48	1.00	
16 Small	-0.10	-0.23	-0.20	0.17	-0.15	-0.15	-0.10	-0.19	0.21	0.13	-0.05	0.08	0.10	-0.75	-0.21	1.00

Table 4 Results for Probit estimation

(Spanish sample)

Variable	(1)	(2)	(3)	(4)
UNCERT	-	-4.704***	-5.376***	-2.857
		(1.944)	(2.008)	(3.349)
COMPLEM	-	-0.419***	-0.414***	-0.084
		(0.106)	(0.106)	(0.221)
VALUE	-	-0.098**	-0.097**	-0.116
		(0.056)	(0.056)	(0.122)
Competition	0.172	-	0.217*	0.223*
	(0.129)		(0.136)	(0.148)
Time	-0.027*	-0.023	-0.026	-0.021
	(0.032)	(0.032)	(0.033)	(0.029)
Tclass-mechanical	0.447**	0.486***	0.472***	0.426**
	(0.181)	(0.179)	(0.178)	(0.192)
Tclass-instruments	0.486	0.659**	0.656**	0.635**
	(0.261)	(0.171)	(0.168)	(0.229)
Tclass-prossesing	0.443**	0.485***	0.437**	0.362**
	(0.188)	(0.171)	(0.176)	(0.195)
Tclass-chemistry&Pharma	0.317*	0.489***	0.445**	0.406**
	(0.191)	(0.178)	(0.184)	(0.204)
Block	0.050*	-0.022	-0.046	-0.085
	(0.126)	(0.125)	(0.127)	(0.122)
Reputation	0.120	0.193*	0.200*	0.172*
	(0.107)	(0.108)	(0.109)	(0.105)
Size-Large	-0.376***	-0.256**	-0.288**	-0.276***
	(0.123)	(0.120)	(0.125)	(0.118)
Size-medium	-0.283**	-0.197	-0.212	-0.177
	(0.089)	(0.112)	(0.106)	(0.088)
Uncertainty x Comp	-	-	-	-9.537**
				(4.296)
Uncertainty x Value	-	-	-	0.959
				(2.198)
Chi-squared	22.17	44.73	49.58	43.88
LL	-53.79	-44.38	-43.53	-41.55
Pseudo R2	0.17	0.31	0.33	0.36
N	101	101	101	101

Note: Robust standard errors are in parenthesis. The coefficients are the marginal effect of the independent variable on the probability of licensing, keeping all other variables constant. For dummy variables, it is the effect of a discrete change of 0 to 1. Confidence levels of: *** (1%), ** (5%) and * (10%)

The variables *Technological class electrical, Imitation* and *firm size small* are not included because are never significant.

Table 5 Results for Probit estimation (Alternative measures for patent value)

(Spanish sample)

Variable	(1)	(2)	(3)
UNCERT	-5.376***	-5.610*	-5.420***
	(2.008)	(2.035)	(2.001)
COMPLEM	-0.414***	-0.415*	-0.389***
	(0.106)	(0.104)	(0.109)
VALUE	-0.097**	-	-
	(0.056)		
VALUE1	-	-0.110*	-
		(0.057)	
VALUE2	-	-	-0.015*
			(0.017)
Chi-squared	49.58	55.80	54.36
LL	-43.53	-44.67	-43.14
Pseudo R2	0.33	0.31	0.33
N	101	101	101

Note: Robust standard errors are in parenthesis. The coefficients are the marginal effect of the independent variable on the probability of licensing, keeping all other variables constant. For dummy variables, it is the effect of a discrete change of 0 to 1. Confidence levels of: *** (1%), ** (5%) and * (10%)

Table 6 Results for Probit and Instrumental variables estimation

(Spanish sample)

Variable		(1)	(2)	(3)
		Probit	2-step	
	Dependent variable	LICENSE	UNCERT	LICENSE
UNCERT		-5.376***	-	-11.996**
		(2.008)		(6.740)
COMPLEM		-0.414***	-0.024	-0.437***
		(0.106)	(0.006)	(0.108)
VALUE		-0.097**	0.002	-0.082*
		(0.056)	(0.003)	(0.058)
Tech-diversity		-	0.009*	-
			(0.004)	
Spillovers		-	-0.014***	-
			(0.002)	
Chi-squared		49.58	-	47.63
F		-	2.13	-
LL		-43.53	-	-43.06
Pseudo R2		0.33	0.22	0.33
N		101	101	

Note: Robust standard errors are in parenthesis. The coefficients are the marginal effect of the independent variable on the probability of licensing, keeping all other variables constant. For dummy variables, it is the effect of a discrete change of 0 to 1. Confidence levels of: *** (1%), ** (5%) and * (10%).

Column (2) is a linear regression while columns (1) and (3) are Probit regressions.

Figure A-1

PATENT FOR THE FIRST SINGLE CHIP MICROPROCESSOR (THE INTEL 4004)

United States Patent [19]
Hoff, Jr. et al.

[11] **3,821,715**
[45] **June 28, 1974**

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[54] **MEMORY SYSTEM FOR A MULTI-CHIP DIGITAL COMPUTER**

[75] Inventors: **Marcian Edward Hoff, Jr.**, Santa Clara; **Stanley Mazor**, Sunnyvale; **Federico Faggin**, Cupertino, all of Calif.

[73] Assignee: **Intel Corporation**, Santa Clara, Calif.

[22] Filed: **Jan. 22, 1973**

[21] Appl. No.: **325,511**

[52] **U.S. Cl.** .... **340/172.5**, 340/173 R, 340/173 SP, 307/238

[51] **Int. Cl.** **G06f 13/00**, G11c 11/44

[58] **Field of Search** .... 340/172.5, 173 SP, 173 R; 307/238, 279

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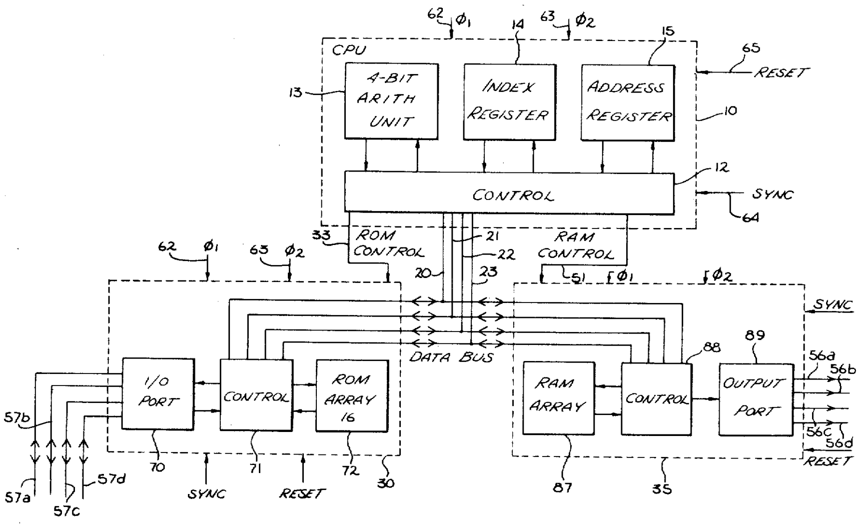
Assistant Examiner—Melvin B. Chapnick
Attorney, Agent, or Firm—Spensley, Horn & Lubitz

[57] **ABSTRACT**

A general purpose digital computer which comprises a plurality of metal-oxide-semiconductor (MOS) chips. Random-access-memories (RAM) and read-only-memories (ROM) used as part of the computer are coupled to common bi-directional data buses to a central processing unit (CPU) with each memory including decoding circuitry to determine which of the plurality of memory chips is being addressed by the CPU. The computer is fabricated using chips mounted on standard 16 pin dual in-line packages allowing additional memory chips to be added to the computer.

17 Claims, 5 Drawing Figures



Chapter 4

Spillovers at the research unit level

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[1] This chapter has been written together with Walter Garcia-Fontes

4.1 Introduction

Quantifying the extent and impact of knowledge spillovers is crucial for the design of an adequate scientific and technological policy. Theoretically, it is clear that knowledge may have a public good nature, due to non-rivalry in consumption and non-appropriability of research returns. This may lead to external benefits of private investments in knowledge creation, and a market failure that justifies government intervention by subsidization of R&D investments or the creation of public research laboratories[2].

There has been extensive research in the identification and quantification of knowledge spillovers, at least since the seminal contribution of Griliches (1979), where he proposed different strategies to measure the contribution of R&D to economic growth. The main lines of research have dealt with the construction of "knowledge pools", by finding "close" firms, using geographical, technological or firm characteristics as distances. But most researchers recognize that spillovers cannot be measured exactly, because there are almost no observable that can be associated with the appropriation of external knowledge, and different sources that increase the knowledge pool of a firm cannot be identified separately[3]. In a recent paper, Kaiser (2002) tried to compare different approaches to the identification of spillover pools, and he found that pools based on uncentered correlations of firm characteristics seem to fit best.

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[2] See Jaffee (1986,1988) for a discussion on options of technological and scientific policies to face the possibility of knowledge spillovers.

[3] See for instance Krugman (1991).

One line of research that has tried to overcome this unobservability of knowledge flows is the one advocated by Jaffe (1986,1988) and his coauthors, who have proposed to use patent citations to identify knowledge flows between firms. The main assumption is that patent citations are sufficiently correlated with knowledge flows to identify spillovers. This approach is subjected to the shortcomings of patent statistics indicated by Griliches(1990), who questioned the quality of patents and related indicators, such as citation on patents, due to the heterogeneity of these indicators as a measure of the intensity of innovation activities.

Within this fairly vast literature, there has been fewer examples of attempts to identify spillovers looking at the particular mechanisms of communication that actually permit knowledge to flow. An exception can be found in more recent work by Jaffe et. al. (2000). Through a more detailed survey on inventors, these authors look at modes and mechanisms through which knowledge flows actually take place.

This paper also looks at the possibility of knowledge flows using a survey of inventors. We propose to try to assess the existence of spillovers at the research unit level, defining as such the network of inventors that arises from the research done to create new patentable knowledge. We propose to value a research unit in a novel way, using valuation techniques similar to the ones used in the theory of the firm, and therefore our measure can be interpreted as the renewal cost of intellectual capital. Our approach is first to determine the optimal rule of capital accumulation for the research unit. For this, we construct a stochastic dynamic program for the production of ideas and allow for the interaction of knowledge spillovers and knowledge capital accumulation. Secondly, we are interested in assessing empirically the importance of spillovers at the research unit level, by estimating the effect of spillovers on the present discounted value of the research unit adjusted by the replacement cost of intellectual capital.

The paper starts by setting the basic theoretical framework in section 4.2. Section 4.3 describes the data used. In section 4.4 we propose the empirical specification of the model. Section 4.5 presents a discussion of the main econometric issues and results, while section 4.6 concludes.

4.2 The basic framework

We consider a research unit (RU) created at some given moment in time to produce ideas that can be patentable. Over the life of the RU, multiple ideas are produced but only few can be patented. The arrival of patentable ideas relies over two main elements. On the one hand we have the research effort to search for patentable ideas. This effort is represented by the R&D investment to acquire new knowledge and it is also affected by external pools of knowledge available to the RU. On the other hand, we have the stock of knowledge accumulated by the research unit. The latter is represented by all the skills, know-how and experience that have been already acquired. The rate of accumulation of knowledge capital as well as the rate of arrival of patentable ideas depends on the R&D investments to acquire new knowledge. Whereas the quality of the patents produced by the RU relies on the level of knowledge capital accumulated.

The research technology:

To create a new patent the RU has to invest in innovative effort. Since, knowledge creation is also determined by the flow of ideas across different research units, we introduce the spillover pool directly affecting the investment flow of the RU. In particular, we define the *effective* R&D productivity of the $i-th$ research unit as:

$$x_i = (1+s)\, z(\tilde{x}_i) \tag{4.1}$$

where $\tilde{x}_i$ is the research investment of RU i and $s = \sum_{i \neq j} \tilde{x}_j$ represents the spillover's pool available. This is given by the aggregate intensity of research investment from other research units in the same technological area where research unit i belongs.[4] Finally, $z(\tilde{x}_i)$ determines the research productivity of each unit of investment in R&D made by firm i. This function is strictly increasing in the R&D investment $\tilde{x}_i$, twice continuously differentiable, with $z'(\tilde{x}_i) > 0$ and $z''(\tilde{x}_i) < 0$ for all $\tilde{x}_i \in [0, \infty)$ and satisfies that $z(0) = \lim_{x_{it} \to \infty} z'(\tilde{x}_i) = 0$. These assumptions allow for the possibility of initial increasing returns to scale in R&D. According to expression (1) the effective R&D productivity is determined by the own R&D investment of the RU and the positive externality from the research investment by other RU's. Under the absence of spillovers the effective research effort of the RU is equal to it's own R&D productivity $x_i = z(\tilde{x}_i)$. Also, there is no free lunch, in the sense that knowledge spillovers can only affect the R&D productivity of research unit i if $\tilde{x}_i > 0$.

The RU is expected to generate a sequence of patents with associated expected values of $v_0, v_1, ..., v_T$. The value of the v_t patent depends on the level of capital accumulated by the RU at the moment of discovery K_{it}. The intuition is that research units with more experienced and skilled teams will come up with better quality patents that are more valuable in the market for ideas. The value function $v_t(K_i)$ is homogeneous of degree one and similar for all RU's in the market. The sequence of patent values is assumed to be

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[4] Note that we can create the spillover pool aggregating research units belonging to the same geographical area, industry, etc.

deterministic, however the timing of the patent arrival is uncertain. At each stage t the RU commits to a level of R&D investment intensity given the amount of knowledge spillovers available. This choice determines the random variable $\tau(x_i)$, which represents the uncertain date at which the R&D project will lead to a new patent. We will also assume that the process of arrival follows a Poisson arrival. Thus, the probability that an idea with patentable attributes arrives at or before t is $\Pr\{\tau(x_i) \leq t\} = \Phi(t) = 1 - e^{-x_i t}$ and the rest of ideas produced in the interval $[0, t]$ have no value. Since the RU chooses the research intensity that will devote to reach the innovation in each stage[5] the probability density of getting the patent depends only on time.

4.2.1 The research unit's problem

The problem of the research unit, is to find the optimal rule of knowledge accumulation that maximizes the value of the research unit today given the initial stock of knowledge $K = K_0$. The objective function for the RU can be stated as (to simplify notation the subscript i has been dropped)

$$V(0) = \max_{\{\tilde{x}_\tau\}_0^t} \int_0^\infty [\pi - p\tilde{x}]\, e^{-\rho t} dt \tag{4.2}$$

where the expected revenue $\pi = \phi(t)\, v_t(K)$ is determined by the probability density $\phi(t) = e^{-xt}x$ that a patent with value $v_t(K)$ arrives at on before t, p is the price paid for each unit of R&D investment $\tilde{x}$ and ρ represents the discount

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[5] A stage is the time period between two consecutive patents.

rate. The RU solves (2) choosing the level of R&D investment subject to the capital accumulation equation,[6]

$$\dot{K} = s\psi\left(K, \tilde{x}\right) - \delta K, \qquad K_0 \text{ given} \tag{4.3}$$

The first term in the right hand side, represents the *learning function*, that depends on the level of knowledge stock, the RU's own R&D investment and the size of the spillover pool s.[7] The learning function is strictly increasing and concave in $\tilde{x}$, reflecting that not all the R&D investment made by the research unit is transformed in knowledge capital. However, the larger the spillovers across research units and the current level of knowledge stock the "easier" it is for the research unit to accumulate knowledge. The second term represents the depreciation factor of the knowledge stock capturing the idea that knowledge becomes obsolete over time. The intuition for the rule of capital accumulation is that when the RU commits into new research, only a fraction of the investment in creating new knowledge becomes knowledge capital. Moreover, since $\psi\left(0\right) = 0$ the research unit can take advantage of the research conducted outside the organizational boundaries, if has previously invested in accumulating the knowledge that will allow to identify and use externally generated knowledge (Cohen and Levinthal 1989)

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[6] Our model can also be stated considering labor (L) as another argument in the value function, obtaining the same results. Therefore we could have $\pi = \phi\left(t\right) v_t\left(K, L\right) - wL$ where w is the price of labor.

[7] A similar specification was introduced by Uzawa (1969). However, his idea was to capture the existence of adjustment costs associated with investment.

The hamiltonian for this optimization problem is,

$$\mathbf{H} = \left[\pi - p\tilde{x}\right] e^{-\rho t} + \mu_t \left[s\psi\left(K, \tilde{x}\right) - \delta K\right]$$

Since the research intensity $\tilde{x}$ is constant during the interval between the arrival of two patents, the probability of patenting depends only on time $\phi\left(t\right) = e^{-xt}x$.[8] Using equation (1) and letting $\lambda = \mu_t e^{\rho t}$ be the current value multiplier the first-order conditions for optimality are:

$$p = \lambda s \psi_{\tilde{x}} \tag{4.4}$$

$$\dot{\lambda} = \left(\rho + \delta - s\psi_K\right)\lambda_t - \pi_K \tag{4.5}$$

and the transversality condition

$$\lim_{t\to\infty} \lambda_t K_t e^{-\rho t} = 0 \tag{4.6}$$

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[8] At period $t = 0$ the RU selects the rate of R&D investment $\tilde{x}$ the research unit will commit for each infinitesimal period until the patent arrives. This intensity also determines the level of effective R&D investment x_0 given the pool of knowledge spillovers available in this period. Therefore the process of capital accumulation starts with a given probability of success $\Phi\left(x_0; t\right) = 1 - e^{-x_0 t}$ and a given level of knowledge $K = K_0$. To obtain the probability density function of getting a patent with value $v_0(K_0)$ we just find the partial derivative with respect to time $\partial\Phi\left(x_0; t\right)/\partial t = \phi\left(t\right) = x_0 e^{-x_0 t}$. Therefore, each period innovation the firm selects a probability of discovery and given this flow new knowledge is accumulated until the patent arrives. The process continues this way until the T patent arrives.

Expression (5) shows that λ is the discounted value of future revenues generated by the increase in one unit on the R&D investment intensity. Expression (4) characterizes the R&D investment function of the research unit, relating the marginal value of investment to the shadow price of knowledge capital. To have a more insightful interpretation we will write (4) in the following way,

$$(1 - s\psi_{\tilde{x}})\,\lambda + p = \lambda \tag{4.7}$$

The first term in (7) represents the implicit learning costs associated with the creation of new knowledge capital. If learning costs were not present the market value of the research unit would increase by λ for each unit of knowledge invested. However, given that not all R&D invested is transformed in new knowledge, the stock knowledge increases only by $s\psi_{\tilde{x}}$. Also the higher the level of knowledge spillovers, the more effective will become the acquisition of new knowledge. On the right had side of expression (7) we have the market value of the research unit for each additional unit of knowledge invested.

As in the literature of the Tobin's Q, the main problem is that we can not observe the marginal value of the investment and thus we have to use the ratio of the existing capital to its replacement cost (average q) for empirical tests. In the rest of this section, we follow the same approach introduced by Hayashi (1982). In particular we will show that those results obtained by Hayashi for the capital accumulation of the firm can equivalently be stated for our specific set up considering the value of the research unit.

Proposition 1, shows that marginal Q defined as $q = \lambda/p$, and average

Q defined as $\bar{q} = V/pK$ are equivalent for a research unit that values its innovations in a competitive market for ideas and where the value function and the learning function are homogeneous.

Proposition 1 Assuming inventions are valued in a competitive market and the transversality condition holds. Then

$$\frac{\lambda}{p} = \frac{V(0)}{pK_0} \tag{4.8}$$

If and only if the value function $v(K)$ is linearly homogeneous in K, and the learning cost function $\psi(K, \tilde{x})$ is linearly homogeneous in K and $\tilde{x}$.

4.3 Data

Our data comes from the survey of inventors "The Value of European Patents" (PatVal-EU)[9] including more than 9,000 patents from France, Germany, Italy, the Netherlands, Spain and the United Kingdom with priority dates between 1993-1997. Inventors were localized through their home and work addresses (registered in the patent application). Considering the time elapsed, there were quite a few of inventors who change work or home addresses. Some of these mobile inventors were localized through different methods (telephone directories, Internet, later patents, various public and private directories). The questions in the survey dealt with three main issues: (1) Inventor's characteristics, including educational background, personal details about age, place of birth and professional career. (2) Information about the invention process: nature of the inputs that were critical for developing the innovation, importance of contacts with external sources of knowledge and estimated cost of developing the patent. (3) The economic value of patents and the commercialization scheme: Inventor's were asked to give an economic and strategic estimate of the patent value and a detailed description on the motivations for patenting as well as the final commercial use of the patent.

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[9] This survey was conducted with the financial support of the European Commission contract HPV2-CT-2001-00013. For more details on the survey see Giuri et al. (2005)

4.3.1 Unit of analysis

Whereas the traditional unit of analysis for valuation purposes has been the firm, we look in this paper at research units. A research unit is defined as the network of inventors that have produced the same group of patents. To construct the RU's we have used the entire sample of $9,621$ EPO patents from the PatVal-EU survey containing more than twenty thousand inventors. The major challenge in the data preparation has been to mach the $18,315$ inventor's names we have identified, which involves a careful work of cleaning and checking for possible misspellings. Then we grouped all patents with at least one inventor in common to create the research units. Given the high number of inventions produced by inventors that are not related to any other group of inventors[10], our sample was reduced to $3,781$ patents and $1,382$ research units. In $Table$ 1 some descriptive statistics can be found. The highest number of inventors per research unit is 16 and the lower is 2. The average RU has about five patents and the average value of the patents produced is 9.5 millions of euros.

4.4 Empirical implementation

In the spirit of Griliches (1981) we assume that the value of the research unit is equal to the value of the assets that are used for production. Since our RU

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[10] These are inventors that have produced one patent once and have never produced any other patent again.

does not uses physical capital as a production input, the market value should be equal to the sum of the per period effective R&D productivity and the knowledge capital accumulated. Thus we define the value of the RU as,

$$\begin{aligned} V_i &= \bar{m}\left(x_i + K_i\right) && (4.9) \\ &= \exp\left(\omega + \epsilon_i\right)\left(x_i + K_i\right) && (4.10) \end{aligned}$$

where x_i is the effective R&D investment, K_i is the knowledge capital and $\bar{m}$ represents the average multiplier of market value relative to the replacement cost of R&D and knowledge capital. This term consists of two components that are assumed to augment value multiplicatively: The first component it is a market index $\omega = s_i + (\sum_k \theta_k D_{ik}^{CO}) + (\sum_k \phi_k D_{ik}^{IP})$, that depends on the degree of knowledge spillovers available, commercialization opportunities, and IP protection. The second component is a RU-specific disturbance error term. Now consider a particular functional form for the **research productivity function** $z\left(\tilde{x}_i\right) = \tilde{x}_i^{\beta}$ and $\beta = 1$ implying constant returns to scale on the research productivity. Finally substituting (1) in (9) we obtain,

$$V_i = \exp\left(\omega + \epsilon_i\right)\left[\left(\gamma_1 + \gamma_2 s_i\right)\tilde{x}_i + K_i\right] \tag{4.11}$$

taking logs, letting $k_i = \tilde{x}_i / K_i$, $q = \log V_i - \log K_i$ and using the approximation $\log\left(1 + y\right) \cong y$ for y small

$$\begin{aligned} \log V_i - \log K_i &= \left(\gamma_1 + \gamma_2 s_i\right) k_i + \omega + \epsilon_i && (4.12) \\ q &= \gamma_1 k_i + \gamma_2 s_i k_i + \gamma_3 s_i + \sum_i \theta_i D_{ik}^{CO} + \sum_i \phi_i D_{ik}^{IP} + \epsilon_i && (4.13) \end{aligned}$$

From *proposition* 1 it can be easily verified that $\frac{\lambda_0}{p} = \bar{q}$

4.4.1 Dependent variable:

Our dependent variable is the market to replacement value of knowledge capital (q). This is the logarithm of the ratio between the value of the research unit today and the current stock of knowledge capital. As a proxy for the latter, we take the average value of the patents produced by the RU. Letting n be the productivity of research unit i, measured in terms of patented inventions, then we define $V_i = \sum_{i=1}^{n} \phi_i b_i$. Where b_i is the individual patent value and $\phi_i = 1/n$ is the adjustment factor. In measuring the knowledge capital (K), we would ideally capture the cost in current prices of reproducing the knowledge needed to create new patents. The main problem we face for this variable is how to model the stock of knowledge associated to a research unit. With this variable we want to capture the skills, and accumulated knowledge of the members of the research team. Our proxy in this case is the number of patented inventions associated to all the members of the research team at some given point in time. Consider for example a research team with five researchers, then assuming that each scientist has patented one invention before joining the team the total knowledge stock is five. The final expression for the dependent variable is $q = \log(\sum_{i=1}^{n} \phi_i b_i) - \log(K)$.

4.4.2 Explanatory variables

R&D investment: as a proxy for the R&D investment we use how much the RU has invested in developing the latest patent. This variable was obtained from a PatVal survey question that asked the “inventor’s best estimate of the total cost (in Euro) of the research leading to this patent up to the date of application excluding legal fees or any other fees related to the patent application".

Spillovers: This variable measures the pool of knowledge available to the research team outside their research lab. There are different ways to construct spillover pools that have been considered in the literature. The identification and estimation of spillovers is a controversial issue, since spillovers cannot be observed directly. Therefore the most common strategy is to consider different ways to construct these pools to check for the robustness of the results. We constructed two types of spillover pools based on information regarding specific characteristics associated to technologies and sources of knowledge and transmission.

Our measures are based on the methodology proposed by Jaffe (1986), which consists on determining the degree of closeness between the R&D activities between two different firms. In our setting, this can be done constructing a weight that accounts for the ability of research unit i to absorb the knowledge accumulated by research unit j. Therefore, RU's that have more similarities on their R&D patterns will be more likely to capture a larger part of the knowledge created by their counterparts and viceversa. Thus, the spillover pool of RU i can be expressed as the sum of all other research units R&D effort $\tilde{x}_j$ weighted by the closeness factor p_{ij}.

$$s_i = \sum p_{ij} \tilde{x}_j \tag{4.14}$$

The closeness factor between R&D activities can be obtained constructing vectors for each research unit, that gather different characteristics. For example, if we consider n different characteristics of the inventors conducting research in RU i the vector will be given by $F_i = (f_1, f_2, ..., f_n)$. To measure the proximity between RU's i and j we use the uncentered correlations between vectors F_i and F_j:

$$P_{ij} = \frac{F_i F_j'}{((F_i F_i')(F_j F_j'))^{1/2}}$$

The idea is that if the research activity of research unit i and research unit j coincide, this weight takes the value of 1 and we will consider that there will be high spillovers between the research units, while if the research activity of these research units are very different, the weight will have a low value and we will not consider any spillover between the research units.

Spillover1: (Technological characteristics): The first measure that we used was based on the number of patents filed by the research unit in each technological class. The EPO classification system contains eight mayor patents categories (A: Human necessities, B Performing operations, C: Chemistry, D: Textiles, E: Fixed constructions, F: Mechanical engineering, G: Physics and H: Electricity), we constructed the vectors of technological characteristics with the proportion of patents filed by research unit i in technological class k out all the patents filed by the research unit. This type of measure has been criticized because it may simply gather heterogeneity across technological classes.

Spillover2: (Spillovers characteristics): In this case we fill the vector with dummy variables that account for the characteristics of research contacts that contributed to the creation of the patent. In particular we look at the geographical dimension of knowledge spillovers and if the interactions are mostly based on external collaborations with researchers from other labs or from the same organization. We constructed four dummy variables based on the following PatVal-EU questions: (1) if interactions with people (apart from co-inventors) belonging to the organization of the inventor (including affiliates) and located within a one hour reach, were important during the research that lead to the patented invention (2) if interactions with people (apart from co-inventors) belonging to the organization of the inventor (including affiliates) and located beyond a one hour reach, were important during the research that lead to the patented invention (3) if interactions with people (apart from co-inventors) belonging to organizations other (unaffiliated) than the inventor's and located within a one hour reach, were important during the research that lead to the patented invention (4) if interactions with people (apart from co-inventors) belonging to organizations other (unaffiliated) than the inventor's and located beyond a one hour reach, were important during the research that lead to the patented invention. The four questions where rated from 0 (no interactions) to 5 (indicating that interactions were very important)

Commercialization Opportunities: the value of the research unit is closely linked to the commercial success of the patents created. We keep track of the commercial impact of these patents including information on how they were commercially exploited. We consider three possible patent uses: (1) the patent was commercially exploited by the innovator ($DIRECT$), (2) the patent was commercialized by a third party ($LICENSE$) or (3) the patent was used to create a new firm ($VENTURE$). We consider a dummy variable for each of these options that scores one if has been used and zero if not.

IP protection: The value of ideas not only depends on the potential applications and technological superiority but also on the possibility of protecting these ideas from potential competitors. To account for IP protection we use three different dummy variables measuring the patent scope, the number of claims and whether the patent has been subject to opposition or not. $SCOPE$: Following Lerner (1994) we use the number of 4-digit patent sub-classes where the patent has been classified by the EPO. Patents with a higher count will be associated to higher patent scope. The number of claims in a patent document establish the boundaries of the property rights for the innovation. $CLAIMS$: Claims can be divided in two types: First, the principal claims define the main novel features of the invention. Second, the subordinate claims describe detailed features of the innovation claimed. We expect the number of claims to be associated with greater IP protection. $OPPOSITION$: we measure opposition using a dummy variable capturing if any of the patents of the research team was ever been subject of opposition or appeal at the European Patent Office. We expect that an opposition procedure can influence positively the value of the research team.

Control variables: A number of control variables are included in the model. We control for firm, industrial, technological and geographical characteristics suggested by the existing literature.

Technological class: Technological variables include five technological class dummies constructed according to the technological macro class defined by the ISI-INPI-OST classification (5 macro areas).[11] This is similar to the classifi-

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[11] Technology-oriented classification system jointly elaborated by the German Fraunhofer

cation method followed by Hall, Jaffe and Trajtenberg (2001).

Firm size: To control for firm size, we use the number of employees per firm. Larger firms are better positioned than small firms to take advantage of the innovation since they have preferential access to acquire the complementary assets needed to exploit the patent in-house (Schumpeter, 1950). This variable consist on three dummies for $Firm-large$ (more than 250 employees), $Firm-medium$ (Between 100 and 250 employees) and $Firm-small$ (less than 100 employees).

Organization Type: These are a set of dummy variables that take the value of 1 if most of the inventors in the research unit are affiliated to a firm, university, research lab, or government organization.

Region: These are a set of dummy variables that take the value of 1 if the first inventor of patent i is a national of country k and zero otherwise. ($k = 1:$ France, $k = 2:$ Germany, $k = 3:$ Italy, the $k = 4:$ the Netherlands, $k = 5:$ Spain and $k = 6:$ the United Kingdom)

Institute of Systems and Innovation Research (ISI), the French patent office (INIPI) and the Observatoire des Science and des Techniques (OST).

4.5 The valuation equation

The results of the estimation for the valuation equation are reported in tables 2 and 3. Table 2 includes estimates for a simple OLS regression. The interaction between the spillover pool and the ratio of own R&D over Knowledge capital as well as the spillover measure shows up significant and positive. The results for the spillover pools (1) and (2) do not show important differences. Regarding the commercialization opportunities, we find as should be expected, that direct exploitation or licensing of the patented knowledge positively affects the value of the research unit. In the case of IP protection, patent claims is the only IP variable that becomes significant for all regressions.

An important issue that can arise in the estimation of our model is the potential endogeneity of the right-hand side own R&D stock variable. This endogeneity can come both from measurement error and from simultaneity. It is also likely that research units will differ in ways that cannot be described by our variables. These unobservables will be included in the error terms from our research valuation equations. With panel data the classical solution would be to assume that these unobservables do not change with time, and therefore the problem could be taken into account with a "within" fixed-effects estimator, for instance. In our case, since we have a cross-section, we will hope that this problem is also solved by instrumenting the potential endogenous variable.

We will address the potential endogeneity problem, using a two-step estimation procedure. This consists on regressing first the R&D stock/Knowledge Capital variable on all the variables we have assumed as exogenous (including instruments). In the second step we use the predicted value of the endogenous variable as independent variable in the structural equation. We instrumented this variable using all the exogenous variables in the model plus gender, year of academic degree and a dummy for type of academic degree. The results for the Instrumental Variables estimation can be found in Table 3. Instrumenting the ratio of R&D over knowledge capital increases the coefficients for all the different specifications of spillover pools.

4.6 Conclusions

In this paper we try to assess the extent and impact of spillovers at a fairly disaggregated level which has not been treated, the research unit level. After developing a theoretical framework based on the valuation research unit, we propose to estimate a model where the dependent variable can be interpreted as the value of the research unit adjusted by the replacement cost of intellectual capital.

Our main results show that spillover pools, constructed under three alternatives across technological classes, turn out to be positive and significant. Under the current specification it is not easy to come up with a quantitative assessment of the size of spillovers, but a rough approximation shows that the size is on the high end.

Future refinements of the current model should include the inclusion of firm characteristics, to try to account to the unobserved heterogeneity that may be present in the current data. This is possible by crossing the survey of inventors with data from firm databases. Another important issue to be addressed is the potential selection bias in our sample. Our model implies that we consider only patents for which a positive value of the research unit has been assessed by the inventors composing it, that is successful inventors who granted patents. We have corrected for this problem by applying Heckman's two-step estimation procedure that controls for sample selection in a previous version of this paper, and the sample bias shows to be not a significant problem.

4.7 Appendix

Proof of proposition 1. Following Hayashi 1982 we first differentiate the transversality condition (5) obtaining,

$$\frac{d}{dt}\left[\lambda K_t e^{-\rho t}\right] = \left(\dot{\lambda} K + \lambda \dot{K} - \rho \lambda K\right) e^{-\rho t} \tag{4.15}$$

Since v is an homogeneous function

$$\pi / K = \pi_K \tag{4.16}$$

Also using the homogeneity of ψ we can show that

$$\psi = \psi_K K + \psi_{\tilde{x}} \tilde{x} \tag{4.17}$$

Now substituting equations (2), (4) , (9) and (10) into (8) can be shown that along the optimal path

$$\frac{d}{dt}\left[\lambda K_t e^{-\rho t}\right] = -\pi + \lambda \psi_{\tilde{x}} \tilde{x} \tag{4.18}$$

Multiplying equation (2) by $\tilde{x}$ and substituting into (11)

$$\frac{d}{dt}\left[\lambda K_t e^{-\rho t}\right] = -\left[\pi - p\tilde{x}\right] \tag{4.19}$$

Integrating both sides from zero to infinity and using the transversality condition can be easily shown that

$$\lambda K_0 = \int_0^{\infty} \left(\pi - p\tilde{x}\right) e^{-\rho t} dt \tag{4.20}$$

Dividing both sides by pK_0 and using expression (1) we obtain

$$\frac{\lambda}{p} = \frac{V\left(0\right)}{pK_0} \tag{4.21}$$

The converse can be easily derived. ■

Table 1 Research Units. Descriptive statistics
(N=1,379)

Variable	Mean	Min	Max
Number of inventors per research unit	4	2	16
Number of patents per research unit	5	2	69
Research unit's value (in thousands of Euros)	9,516	30	50,000
R&D investment (in thousands of Euros)	612	1	15,000
Knowledge stock (in number of patents)	68	5	900

Table 2: The Research Unit Valuation Model
OLS regression Results

Variable	*Spillover Pool 1*		*Spillover Pool 2*	
k = R&D/Knowledge Stock	0.046	***	0.060	*
	(0.008)		(0.066)	
k x spillover pool	0.039	***	0.063	*
	(0.007)		(0.068)	
Spillover pool	0.289	***	0.883	***
	(0.016)		(0.023)	
Commercialization Opportunities				
Direct	0.192	***	0.045	***
	(0.018)		(0.014)	
License	0.050	**	0.050	***
	(0.025)		(0.019)	
Venture	0.002		0.080	**
	(0.047)		(0.035)	
IP protection				
Scope	0.173	***	0.007	
	(0.013)		(0.010)	
Claims	0.022	***	0.005	***
	(0.002)		(0.001)	
Opposition	0.078	***	0.012	
	(0.028)		(0.022)	
R-squared	0.92		0.95	
N	1097		1097	

Table 3: The Research Unit Valuation Model
IV regression Results

Variable	*Spillover Pool 1*		*Spillover Pool 2*	
k = R&D/Knowledge Stock	1.073	***	2.202	***
	(0.274)		(0.326)	
k x spillover pool	0.860	***	2.168	***
	(0.192)		(0.324)	
Spillover pool	0.646	***	0.934	***
	(0.073)		(0.029)	
Commercialization Opportunities				
Direct	0.179	*	0.046	***
	(0.101)		(0.018)	
License	-0.184		0.035	
	(0.149)		(0.024)	
Venture	-0.383		0.055	
	(0.479)		(0.044)	
IP protection				
Scope	0.059		-0.002	
	(0.046)		(0.013)	
Claims	0.001	*	0.001	*
	(0.006)		(0.002)	
Opposition	0.099		-0.002	
	(0.107)		(0.028)	
R-squared	0.93		0.96	
N	1097		1097	

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