

Profiting from licensing: The role of patent protection and commercialization capabilities

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Abstract

Technology transactions, such as licensing and R&D based alliances, have been growing rapidly in recent years. Even as technology licensing has grown, so has patenting. Both trends foreshadow possibly profound changes in firms' strategy. In this paper, we develop a simple structural model in which both patenting and licensing are jointly determined by factors such as patent effectiveness, the presence and strength of commercialization capabilities and their complementarity with R&D activity, and industry and technology characteristics, such as the nature of knowledge and the degree of technological competition. We estimate the model using the 1994 Carnegie Mellon survey on industrial R&D, which provides detailed information on the patenting and licensing activities of manufacturing firms in the U.S. A key feature of the model is that it naturally implies that the impact of patent effectiveness on licensing behavior will be conditioned by commercialization capabilities. We find that increases in patent effectiveness increase both patenting and licensing propensity. Conditional on patenting, increases in patent effectiveness decreases licensing propensity. However, higher patent effectiveness elicits much larger increases in licensing from firms lacking commercialization capability or characterized by a lower degree of complementarities between the R&D and marketing or production functions.

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I. INTRODUCTION

In the last two decades, there has been a virtual explosion of patenting, especially in the US economy. Though the quantitative importance of the various sources of this growth and its causes are still under study, patents have become a growing preoccupation of management (see Grindley and Teece, 1997; Rivette and Kline, 1999). Over the same period, technology transactions, such as licensing and R&D based alliances, have been growing rapidly as well. Startup firms in industries such as biotechnology, semiconductors, instruments and chemicals have relied extensively upon patents to obtaining financing and licensing to appropriate rents from their innovation. Startups are not alone: established firms such as IBM, Qualcomm, Du Pont, Boeing, Proctor & Gamble and Texas Instruments have engaged in extensive licensing as well. These growing markets for technology potentially have significant social welfare benefits, but also have profound implications for firm behavior, boundaries of the firm and entry conditions (Arora, Fosfuri and Gambardella, 2001).

It is plausible that these trends are related and indeed, many scholars have argued that effective patent protection enhances the effectiveness of licensing contracts, and underpin markets for technology, which are otherwise subject to a variety of imperfections.¹ Yet, though there is a substantial body of work on determinants of technology licensing, the available empirical evidence on the relationship between patenting and licensing is limited, typically confined to studies of individual industries, and the empirical findings are mixed.

In this paper, we develop a simple structural model in which both patenting and licensing are jointly determined by factors such as patent effectiveness and the presence of complementary commercialization capabilities, and industry and technology characteristics, such as the nature of knowledge and the degree of technological competition. Building on Arora, Ceccagnoli, and Cohen [2004], we estimate the impact of such factors on the payoff from patenting relative to not patenting,

¹ Technology licensing is fraught with challenges, highlighted by Arrow (1962), and fleshed out in greater detail by scholars such as Mowery (1983), and Williamson (1991). Organization scholars have pointed to challenges due to the nature of underlying knowledge, which is often difficult to articulate or transfer across contexts (e.g., von Hippel (1990, 1994), Winter (1987), Arora and Gambardella (1994), Kogut and Zander (1990).

further distinguishing between profits due to patent licensing and commercialization of patented innovations. We estimate the model using a novel dataset, which provides detailed information on the patenting and licensing activities of manufacturing firms in the U.S., and is the source for the key measures used in our empirical analysis, such as patent effectiveness and commercialization capabilities (Cohen, Nelson, and Walsh, 2000).

This paper builds upon two streams in the literature. Following Teece's seminal paper, (Teece, 1986), we ask how firms seek to appropriate return from investments in R&D, and specifically, how the intellectual property appropriability regime conditions their strategy. However, departing from the framework used in Teece (1986), we do not analyze the question of whether a firm ought to acquire complementary assets or contract for them. Instead, in the spirit of the resource based theory of the firm, we assume that firms are endowed with different levels of complementary capabilities. In essence, we are *assuming* that manufacturing and marketing capabilities that require close interaction with R&D are valuable, difficult to produce, and rare (e.g., Wernerfelt, 1984; Dierickx and Cool, 1989; Barney, 1991; Amit and Schoemaker, 1993). Hence, the question we focus on is: Given the level of complementary capabilities in a firm, when does a firm decide to seek patent protection and how is this related to whether the firm will appropriate rents from the innovation by licensing it.

This paper is organized as follows. Following a background section II, in section III we present a simple model of patenting and licensing behavior, the related hypothesis to be tested and the empirical specification. Section IV describes the data and measures used for estimation, whereas section V discusses the results. A conclusion follows in section VI.

II. Patents, Commercialization Capability and the Market for Technology

Over the last two decades, technology related alliances, such as contract R&D, R&D joint ventures and especially technology licensing have grown rapidly.² Degnan (1998) finds that in 1996, US corporations earned \$66 billion in royalty income through technology licensing to unaffiliated entities.

² Such arrangements are of course not new. Lamoreaux and Sokoloff (1998) document the extensive trade in patent rights in the U.S. in the late 19th century.

Estimates for the 1980s suggest that such alliances account for as much as 10 to 15% of total civilian R&D in OECD countries (Arora, Fosfuri and Gambardella, 2001, p. 43). More broadly, in some sectors of the economy, such transactions are significant enough to be studied as a market for technology.

The growth of markets for technology can have profound consequences for firm strategy, the boundaries of the firm and entry conditions. For instance, recent estimates suggest that of the drugs that entered clinical trials in the U.S. during 1988 and 1994, nearly 15% were licensed, during or before clinical trials. Other estimates suggest that the share of licensed drugs might be substantially higher if one were to also include licenses earlier in the process, such as licenses on lead compounds (Kneller, 2003). Similarly, in semiconductors, firms such as Rambus and ARM have business models that rely upon licensing of intellectual property. Startups are not alone. In semiconductors Texas Instruments pioneered the practice of licensing technology for profit, and IBM is reputed to earn \$1-2 billion a year from technology licensing. Licensing of chemical processes by established firms such as Union Carbide, BP and Shell has been well documented, and now even Dow and DuPont are actively engaged in the market for technology (Arora and Fosfuri, 2003; Fosfuri, 2003a).

However, markets for technology face many challenges.³ A key problem was identified by Arrow (1962) wherein a potential licensee would be unwilling to pay for a “pig in a poke” i.e., without being able to verify the quality of the invention. However, once the inventor discloses the invention, the potential licensee would have little incentive to pay for it. Patents are a possible solution because the innovation can be disclosed without fear of imitation.⁴ However, by now it is well understood that patent protection is not the only or even primary source of appropriating rents to innovation (Levin et. al., 1987). But even in industries where patents are not the primary source of protection, patents are deemed

³ Organization scholars have pointed to challenges due to the nature of underlying knowledge, which is often difficult to articulate or transfer across contexts (e.g., von Hippel (1990, 1994), Winter (1987), Arora and Gambardella (1994), Kogut and Zander (1992, 1993)). Arora, Fosfuri and Gambardella (2001) survey this literature in greater detail.

⁴ Although patents have been thought of primarily in terms of providing incentives for innovation, following Coase, defining property rights in innovation should also make them easier to exchange. In addition, Lamoreaux and Sokoloff (1998) point to the information disclosure aspect of patents.

effective for some fraction of innovations, and correspondingly, firms do apply for patent protection for such innovations (Cohen, Nelson, and Walsh, 2000).⁵

Of course, licensing is possible even without patents. The need for know-how, the need to protect a reputation for honesty, and the possibility of future interactions with the licensee are all possible solutions to the problem. Anton and Yao (1994) provide a theoretical model of how an invention protected only through secrecy can be licensed, in essence by threatening a licensee who reneges with enhanced competition through further disclosure. Arora (1996) provides a model where tacit know-how can be bundled with other inputs (which could include patents) in a self-enforcing contract and also provides supporting empirical evidence. However, though plausible, the empirical importance of these alternative mechanisms remains unknown and a number of inefficiencies are likely to remain. Thus, Teece (1986) has argued, licensing is mainly recommended if the innovator lacks commercialization capabilities, such as manufacturing and marketing capabilities, and enjoys strong patent protection.

Two important ideas emerge from the foregoing discussion. First, that both licensing and patenting depend on choices made by the innovator. Second, that there is an inter-play between the effectiveness of patent protection and the presence of other assets and resources required for commercialization, in conditioning the licensing and patenting choices of innovators. When patent protection is weak, an innovator may forgo patenting and rely upon secrecy or lead time, leveraging its commercialization capabilities. On the other hand, patenting does not preclude the use of these alternatives. If effective, patents can be used to exclude competitors, allowing the innovator to leverage its complementary commercialization capabilities. If however, others have superior commercialization capabilities, the innovator can license to them and potentially derive greater value.

⁵ Indeed, over the last two decades, patenting in the US has grown very rapidly. Part of the growth is attributable to the growth to the increasing importance of patent intensive sectors such as pharmaceuticals. However, part of the increase in growth is due to increases in patent propensity, which has increased in sectors such as semiconductors and electronics, in which patents have not traditionally been seen as very important, reflecting changes in firms' strategy but also the rise of firms that lack the resources required to commercialize their innovations (e.g., Hall, 2003; Kortum and Lerner, 1998; Kim and Marschke, 2003). Changes in the legal and policy environment surrounding patenting have been important as well. In 1982, the Court of Appeals for the Federal Circuit was established to make patent protection more uniform and, indirectly, also strengthened it.

In this paper we examine how the effectiveness of patent protection conditions both the patenting propensity and the licensing propensity, and how this effect varies with the presence of commercialization capabilities.⁶ Our data provide measures of three key variables: a measure of the use of patents, henceforth called *patent propensity*; a measure of the effectiveness of patents, henceforth called *patent effectiveness*; and finally, a measure of the willingness to license, henceforth called *licensing propensity*. Thus, we are able to estimate how patent effectiveness conditions patent propensity, and separately, how it affects licensing propensity. As well, we estimate the impact of complementary commercialization capabilities on these two decisions. A key feature of our model is that it naturally implies that the impact of patent effectiveness on licensing behavior will be conditioned by complementary commercialization capabilities.

Our data are at the firm level, not at the level of the individual innovation within a firm. Thus we do not observe whether an innovation is licensed or patented. Rather, we observe the propensities of the firm to license and patent. Thus we model the licensing and patenting decision as part of the overall portfolio of activities of the firm, instead of modeling isolated transactions. As Fosfuri (2003a) notes, whereas a given licensing deal may be profitable, it may reduce profits in related markets or businesses, reducing overall firm profits.

III. THEORY AND EMPIRICAL SPECIFICATION

In this section, we develop a testable model of the determinants of patenting and licensing choices. In particular, consider an innovation developed by the firm. The firm faces 4 mutually exclusive and exhaustive options, from which it derives 4 alternative payoffs: 1) “Patent and license”; 2) “Patent and not license”; 3) “Not patent and license”; 4) “Not patent and not license”. The probabilities that any given innovation is patented or licensed are then:

⁶ As indicated earlier, commercialization capabilities have to be “complementary” in the sense that they are required for commercialization, but also that they either be differentially suited to the innovation of the firm in question, or otherwise not easily accessible. This is in the spirit of the “resource based theory”, where the capabilities should be valuable, difficult to produce, and rare (e.g., Wernerfelt, 1984; Dierickx and Cool, 1989; Barney, 1991; Amit and Schoemaker, 1993).

$$(1-1) \quad \Pr(\text{Patent}) = \Pr(\text{License \& Patent}) + \Pr(\text{Not License \& Patent});$$

$$(1-2) \quad \Pr(\text{License}) = \Pr(\text{License \& Patent}) + \Pr(\text{License \& Not Patent}).$$

The table below, constructed by dividing firms in our dataset by whether they have positive licensing propensity and by whether they have positive patent propensity, shows that of the 257 respondents in our sample that have positive licensing propensity, less than 10% did not patent at all.⁷ By contrast, nearly one third of non-licensors did not patent. Similarly, of the respondents that did not patent, only 12% claimed to license. By contrast, of the patentees, 40% had positive licensing propensity.

Licensing and Patent Propensity

		Licensing Propensity		
		Null	Positive	Total
Patent Propensity	Null	182	25	207
	Positive	347	232	579
	Total	529	257	786

As is clear, in our sample, firms that do not patent, rarely license. This suggests strongly that the presence of a patent is essential for licensing.⁸ Also, as a practical matter, the data also imply that it will be difficult to estimate the determinants of that choice probability. Accordingly, in the empirical specification we set the “Not patent and not license” option as a zero probability event, i.e., we set $\Pr(\text{License \& Not Patent})=0$ in (1-2).

Let V^{LP} denote the payoff to a firm if it patents and license a particular innovation, and V^{NP} if it patents but does not license the innovation. Similarly, let V^{NS} denote the payoff if the firm keeps the

⁷ Moreover, of the 25 cases that involve positive licensing propensity but zero patent propensity, 16 rated patents or other intellectual property protection as effective, casting doubts about their true patent propensity, and suggesting possible measurement or sampling fluctuations as the cause of the apparent anomaly. As well, non patent forms of intellectual property, such as copyright, may also be part of the explanation.

⁸ Firms that patent may still license some of their unpatented innovations, but given our firm level data, we cannot investigate this possibility systematically. A more general model where firms can license without patenting failed to achieve convergence, mainly due to the lack of sufficient variance for estimation.

innovation secret (does not patent) and also does not license it. Assuming that firms choose the alternatives from which they derive the highest payoff, we obtain:

$$\Pr(\text{License \& Patent}) = \Pr(V^{\text{LP}} = \text{Max} \{V^{\text{LP}}, V^{\text{NP}}, V^{\text{NS}}\})$$

$$\Pr(\text{Not License \& Patent}) = \Pr(V^{\text{NP}} = \text{Max} \{V^{\text{LP}}, V^{\text{NP}}, V^{\text{NS}}\})$$

$$\Pr(\text{Not License \& Not Patent}) = \Pr(V^{\text{NS}} = \text{Max} \{V^{\text{LP}}, V^{\text{NP}}, V^{\text{NS}}\}).$$

Accordingly,

$$(2-1) \quad \Pr(\text{Patent}) = \Pr(V^{\text{LP}} = \text{Max} \{V^{\text{LP}}, V^{\text{NP}}, V^{\text{NS}}\}) + \Pr(V^{\text{NP}} = \text{Max} \{V^{\text{LP}}, V^{\text{NP}}, V^{\text{NS}}\}),$$

$$(2-2) \quad \Pr(\text{License}) = \Pr(V^{\text{LP}} = \text{Max} \{V^{\text{LP}}, V^{\text{NP}}, V^{\text{NS}}\}).$$

For an empirical specification, we incorporate additive stochastic components to each payoff and assume that they are distributed with Type 1 extreme value distributions, and assume that they are independently and identically distributed, so that (McFadden, 1973):

$$(3-1) \quad \Pr(\text{Patent}) = [\exp(V^{\text{LP}}) + \exp(V^{\text{NP}})] / [\exp(V^{\text{LP}}) + \exp(V^{\text{NP}}) + \exp(V^{\text{NS}})];$$

$$(3-2) \quad \Pr(\text{License}) = [\exp(V^{\text{LP}})] / [\exp(V^{\text{LP}}) + \exp(V^{\text{NP}}) + \exp(V^{\text{NS}})].$$

$$(3-3) \quad \Pr(\text{License} | \text{Patent}) = [\exp(V^{\text{LP}})] / [\exp(V^{\text{LP}}) + \exp(V^{\text{NP}})]$$

Note that (3-3) can be derived from (3-1) and (3-2) and moreover, the actual share of patented innovations that are licensed is unobserved. Thus, though we do not use (3-3) for estimation, it will be useful for examining hypotheses about the share of patented innovations that are also licensed. As noted earlier, we do not observe innovation specific data, but only the proportion of innovations that are patented, and the proportion that are licensed. In other words, although this setup is strongly reminiscent of a multinomial logit specification, our dependent variables are not binary variables but proportions. In the empirical specification, we treat the probability of an event as the true mean of the observed proportion. It is also evident from (3-1) and (3-2) that we cannot identify the individual payoffs, but only the differences. By dividing both numerator and denominators of the expression by $\exp(V^{\text{NS}})$ we get the estimating equations:

$$(4-1) Y_1 = [\exp(V^{LP} - V^{NS}) + \exp(V^{NP} - V^{NS})] / [\exp(V^{LP} - V^{NS}) + \exp(V^{NP} - V^{NS}) + 1] + v_{ij}^1,$$

$$(4-2) Y_2 = [\exp(V^{LP} - V^{NS}) / [\exp(V^{LP} - V^{NS}) + \exp(V^{NP} - V^{NS}) + 1] + v_{ij}^2,$$

Here, Y_1 is the patent propensity, Y_2 is the licensing propensity, $(V^{LP} - V^{NS})$ and $(V^{NP} - V^{NS})$ are functions of firm and industry characteristics discussed below, and v_{ij} represent sampling error that account for the difference between the theoretical proportion (represented by the probability of the event) and the observed proportion in the sample. Equations (4-1) and (4-2) can be estimated as a system of nonlinear simultaneous equations. The sampling errors of both equations will also be correlated due to their common dependence on the size of the firm's innovation portfolio, and we use the Generalized Method of Moments (GMM) for estimation.⁹

Determinants of $V^{LP} - V^{NS}$, $V^{NP} - V^{NS}$ and implications for patenting and licensing propensity.

The empirical specification (4-1) and (4-2) makes clear that the decision to patent or license does not depend on the payoffs in a straightforward manner. For instance, a variable that increases both V^{LP} and V^{NP} could increase patenting but decrease licensing, depending on the size of the impact. Accordingly, we develop our hypotheses in two parallel tracks. We first discuss the impacts of patent effectiveness and commercialization capabilities on the payoffs $V^{LP} - V^{NS}$ and $V^{NP} - V^{NS}$. We then develop the implications for patent propensity and licensing propensity. The theoretical predictions are summarized in tables 1a and 1b. Appendix B formalizes the hypothesis developed and provides proofs.

III.1 Patent Effectiveness

In deciding to apply for patent protection, firms have to trade off the benefits of patenting against the various costs of application as well as the opportunity costs, which include disclosure of valuable

⁹ The above specification raises one issue. Licensing may happen at different stages in the lifecycle of an innovation. Thus, some or most patenting decisions may be taken before the licensing opportunities have materialized. However, our empirical measure of licensing propensity is the percentage of R&D carried out with the objective of licensing, and thus suggests estimating a specification where patenting and licensing decisions are made simultaneously, as it is the case for the specification presented above. As a robustness check, however, we also estimated a specification where the licensing decision is made after the patenting decisions (see Appendix A). The results strongly favor the specification developed in the text.

information (Horstmann, MacDonald and Slivinski, 1985). A key determinant of the decision to patent an innovation is the effectiveness of patents. Arora, Ceccagnoli, and Cohen (2003) model patent effectiveness as a control for unobserved firm heterogeneity in the premium a firm earns by patenting. In their framework, innovations differ in terms of usefulness of patenting. Firms choose which innovations to patent, and more effective are patents, the greater the fraction of innovations that are patented by the firm. They find that though the premium on average is negative (implying that the typical invention is not worth patenting), for patented innovations the premium is positive and substantial. We build on this work by estimating the impact of patent effectiveness and other factors separately on the profits from patented innovations, i.e. on V^{LP} and V^{NP} . We hypothesize that increase in patent effectiveness increases both V^{LP} and V^{NP} and leave V^{NS} unchanged.

HYPOTHESIS 1'. Increases in patent effectiveness increases $V^{LP} - V^{NS}$ and $V^{NP} - V^{NS}$. The impact on $V^{LP} - V^{NP}$ is ambiguous.

It is clear that increasing patent effectiveness should increase patent propensity. However, though patents are virtually required for licensing, an increase in patent effectiveness has offsetting effects upon licensing propensity: While more effective patents increase V^{LP} , they also increase V^{NP} , so that the impact on licensing propensity is ambiguous: On the one hand, stronger patent protection increases the efficiency of licensing contracts (increasing V^{LP}), but on the other hand, also enhances the value of the innovation itself (increasing V^{NP}), and thus, raises the opportunity cost of licensing.

In other words, patent effectiveness is likely to increase patent propensity, but may decrease the share of patented innovations that are licensed, so that the overall impact on licensing propensity is ambiguous. Indeed, the available empirical evidence, limited as it is, is mixed. On the one hand, two recent studies found a positive effect of patent protection on licensing. Using a sample of MIT inventions, Gans, Hsu, and Stern (2002) find that the presence of patents increases the likelihood that an inventor will license to an incumbent rather than enter the product market by commercializing the invention. Anand and Khanna (2000) find that in the chemicals sector, where patents are believed to be effective, not only

are there many more technology deals, a larger fraction of these involve arms length licensing deals, a larger fraction of these involve exclusive licenses, and a smaller fractions of deals among related firms, and a larger fraction of ex-ante deals (where the contract is about future rights, rather than rights to existing technologies). On the other hand, Cassiman and Veugelers (2002) do not find that the stronger patents encourage Belgian firms to enter into collaborative R&D arrangements.

Evidence from cross-national data is also mixed. Some studies find a positive association between patents and licensing. Yang and Maskus (2000) report a strong positive relationship between improved IPRs regimes and licensing by U.S. MNCs.¹⁰ Analyzing data on international technology licensing contracts of Japanese firms, Nagaoka (2002) finds that weak patent regimes are associated with an increase in the fraction of transfers to an affiliate (such as a subsidiary), instead of to an unaffiliated firm. Smith (2001) finds similarly that US firms are more likely to export or directly manufacture rather than license technology in countries with weak patent regimes. A study using French data on export of technology services finds that such exports are greater for countries with stronger patents, although the impact is stronger for higher income countries (Bascavusoglu and Zuniga, 2002).

On the other hand, a number of other studies cast doubts on the link between patent strength and the extent or form of international technology licensing. Fink (1997) finds a very weak relationship using German data. Puttitanum (2003) reports a higher response of direct investment than licensing to changes in the level of IPR protection. Fosfuri (2003b) similarly does not find that patent protection significantly affects the extent or composition of technology flow (as joint-venture, direct investment or licensing) in the chemical sector. The mixed nature of the findings is reflected in a recent study by Branstetter, Fisman, and Foley (2002). Using detailed data on the technology royalty payments received by US firms, and controlling for unobserved country, industry and firm fixed effects, they find no evidence of an increase of technology licensing to unaffiliated parties for countries that strengthened patent protection. However,

¹⁰ The form of technology transfer can be important either if MNCs are less cost efficient or if there are political concerns about MNCs dominating domestic markets, or if relying on MNCs reduces learning opportunities for domestic producers. In such cases, stronger patent protection is beneficial.

they find that countries that strengthened patent protection do see an increase in the inflow of technology from multinationals, and a corresponding increase in R&D by the domestic affiliate of the multinational. The above discussion leads us to the following hypothesis.

HYPOTHESIS 1. *Increases in patent effectiveness increases patent propensity. Increases in patent effectiveness may increase or decrease the share of licensing in patented innovations, implying an ambiguous impact of patent effectiveness on licensing propensity.*

III.2 Commercialization Capabilities.

Following Teece (1986), increases in commercialization capabilities increase V^{NP} and V^{NS} . By definition, increases in commercialization capability should increase the payoff to the innovator from commercializing the innovation, with or without a patent. Further, V^{LP} should depend on the commercialization capabilities of the *licensee* rather than those of the licensor.¹¹ Indeed, ideally, one ought to use the distribution of complementary capabilities of potential licensees in V^{LP} , but we lack information on actual or potential licensees for a firm's innovations. Thus, we rely upon industry characteristics, including industry fixed effects, as controls. Given the complementary capabilities of potential licensees, it follows that an increase in commercialization capabilities of the innovator should reduce $V^{LP}-V^{NS}$ and $V^{LP}-V^{NP}$. However, the impact on $V^{NP}-V^{NS}$ is ambiguous.

HYPOTHESIS 2'. *Increases in commercialization capabilities reduce $V^{LP}-V^{NS}$ and $V^{LP}-V^{NP}$. However, the impact on $V^{NP}-V^{NS}$ is ambiguous.*

From (3-1), it follows that the impact of commercialization capabilities on patent propensity are ambiguous because whereas $V^{LP}-V^{NS}$ is likely to fall with increase in capabilities, the other component, $V^{NP}-V^{NS}$ could increase or decrease. From (3-2), it follows that if $V^{LP}-V^{NS}$ and $V^{LP}-V^{NP}$ both fall with

¹¹ The statement is obviously true where the licensor does not commercialize the innovation. The situation is less clear cut where both the licensor and the licensee commercialize the innovation and compete with each other. In this paper our focus is on cases where the licensor does not compete with the licensee, implying that the licensing payoff is independent of the licensor's commercialization capability.

commercialization capabilities, then so must overall licensing propensity fall with increases in commercialization capabilities. Finally, it is also obvious that if $V^{LP} - V^{NP}$ falls with increases in commercialization capability, then the share of licensing in patented innovations should fall. Intuitively, the “gains from trade” to licensing an innovation are higher, the lower are the commercialization capabilities of the innovator compared to those of the licensee. This leads to the following hypothesis.

HYPOTHESIS 2. Increases in commercialization capabilities decrease the share of licensing in patented innovations, as well as overall licensing propensity. The impact on patent propensity is ambiguous.

III.3 Interaction between patent effectiveness and commercialization capabilities.

In addition to the direct impacts, there should be an important interaction between commercialization capabilities and patent effectiveness, in that the effectiveness of commercialization capabilities should *increase* the impact of patent effectiveness. If more effective patent protection implies that rivals are unable to produce close substitutes or otherwise increases imitation costs for rivals, then more effective patent protection should translate into a “larger market” for the innovator. An innovator with greater commercialization capabilities should be able to profit more from a larger market than an innovator with weaker commercialization capabilities. Put differently, if stronger commercialization capability implies the innovative product or service can be produced at lower cost, then this is more profitable, the greater the volume of demand for the product or service. Thus, V^{NP} should increase faster with patent effectiveness for firms with stronger commercialization capabilities than for firms with weaker capabilities.

For the other payoffs, this complementarity between patents and commercialization capabilities is absent. The payoff from not patenting, V^{NS} , cannot vary with patent effectiveness by definition. Thus the impact of complementary capability on it cannot be conditioned by patent effectiveness. Similarly, the payoff from licensing, V^{LP} , should not vary with the commercialization capabilities of the *licensor* and thus, should rise, as patent effectiveness increases, at the same rate for firms with different commercialization capabilities.

It follows that $V^{LP} - V^{NP}$ should fall faster with patent effectiveness for firms with stronger commercialization capabilities than for firms with weaker capabilities. Similarly, $V^{NP} - V^{NS}$ should rise faster with patent effectiveness for firms with stronger commercialization capabilities relative to those with weaker capabilities, but $V^{LP} - V^{NS}$ is unaffected.

HYPOTHESIS 3': The impact of increasing patent effectiveness on $V^{LP} - V^{NS}$ does not change for firms with different levels of commercialization capabilities. However, the impact of increasing patent effectiveness on $V^{NP} - V^{NS}$ is bigger for firms with stronger commercialization capabilities.

Intuitively, firms with weak commercialization capabilities are more likely to resort to licensing if feasible. Thus, for such firms, the share of licensing in patented innovations should rise faster (or decline more slowly) with patent effectiveness than for firms with stronger commercialization capabilities.¹² Extending this intuition further, overall licensing propensity should also increase faster (or decrease more slowly) with patent effectiveness for firms with weak commercialization capabilities. The second order effects on the different payoffs do not directly translate into general predictions for licensing or patent propensity. However, in Appendix B we formally derive the conditions sufficient to guarantee the following hypothesis.

HYPOTHESIS 3. The impact of patent effectiveness on both licensing and the share of licensing in patented innovations is weaker as commercialization capabilities increase.

IV. DATA & VARIABLES

The data used come from the Carnegie Mellon Survey (CMS) on industrial R&D (Cohen, Nelson, and Walsh 2000). The population sampled is that of all R&D labs located in the U.S. conducting R&D in manufacturing industries as a part of a manufacturing firm. The sample was randomly drawn from the eligible labs listed in the Directory of American Research and Technology (Bowker, 1995) or belonging to firms listed in Standard and Poor's Compustat, stratified by 3-digit SIC industry. R&D lab managers

¹² Recall that the share of licensing in patented innovations could rise or fall with patent effectiveness, per hypothesis 1.

were asked to answer questions with reference to the "focus industry" of their R&D unit, where focus industry was defined as the principal industry for which the unit was conducting its R&D. Valid responses were received from 1,478 R&D units, with a response rate of 54%. The survey contains a broad range of information on R&D and patenting activity, such as firms' reported patent propensity, patent effectiveness, the number of patent applications, R&D expenditures. The data refer to the 1991-1993 period. For the analysis we restricted the sample to firms with business units with 10 or more employees. After dropping observations with missing data for the variables of interest, we obtain a final sample of 761 R&D observations.¹³

Table 2 provides descriptive statistics for the variables used in the analysis. As a final note, it is important to keep in mind that we have thus far used the term firm to refer to the unit of analysis and we shall continue to do so to simplify exposition. However, we stress that the unit of analysis is the business unit within the parent firm, operating in the "focus industry" of the responding R&D lab.

Endogenous Variables

Licensing Propensity: The CMS asks respondents to state the % of their R&D projects over the last three years that were undertaken with the objective of earning licensing revenues. (Projects could have multiple objectives.) There were five response categories: <10%, 10-40%, 41-60%, 61-90% and over 90%. We used the mid points of each response category. For the first category, it is plausible that most respondents actually meant zero. Thus, we assigned all respondents in the first category as having zero licensing propensity unless they have a positive patent propensity and indicated in the CMS questionnaire that the possibility of earning licensing revenue was one of the reasons for patenting.¹⁴

Patent Propensity: The CMS asks respondents for the percentage of innovations for which they applied for patents in the 1991-'93 period in the U.S. Responses were indicated for product and process

¹³ The final sample of 776 observations also reflects the exclusion of R&D units reporting more than 50 patent applications per million dollars of R&D and those reporting an R&D budget of less than or equal to \$100,000.

¹⁴ Note that this procedure increases the sample probability of licensing conditional on patenting since only patentees can provide information on whether licensing was a motive for patenting. We also estimated a specification where the mid point of the first category was used and obtained similar results.

innovations separately. We thus computed a weighted average of product and process patent propensities using the % of R&D effort devoted to product and process innovations respectively as weights, as reported by the CMS respondents.

Explanatory Variables.

Patent Effectiveness: The CMS asks respondents to indicate the percentage of their product and process innovations for which patent protection had been effective in protecting their firm's competitive advantage from those innovations during the prior three years. There were five mutually exclusive response categories for product and process innovations separately: 1) less than 10%; 2) 10% through 40%; 3) 41% through 60%; 4) 61% through 90%; and 5) greater than 90%. We use a weighted average of product and process patent effectiveness (using mid points of the response categories), with the % of R&D effort devoted to product and process innovations respectively as weights as our measure of *patent effectiveness*.

Patent effectiveness may be interpreted in several ways (e.g., Cohen, Nelson and Walsh, 2000). For instance, patents that are effective in protecting rents through forcing rivals to enter into negotiations or for blocking a rival may not provide useful protection against opportunism in technology licensing contracts. In a corollary exercise to inform our interpretation of what our patent effectiveness score reflects, we estimated an ordered probit model to analyze the relationship between firms' reasons to patent and the respondents' patent effectiveness scores. We found that the magnitude of the coefficient for conventional motives for patenting such as licensing are comparable to those for less conventional reasons, such as using patents to induce rivals to participate in cross-licensing negotiations or for building patent fences (i.e., patenting substitutes) around some core innovation. However, one reason for patenting that had no significant effect on respondents patent effectiveness scores was the motive of the prevention of infringement suits—that is, defensive patenting (Arora, Ceccagnoli and Cohen, 2004).

Business Unit Size: *Business unit size*, measured by the natural logarithm of the number of business unit employees is an important control variable. It may also capture elements of a firm commercialization

capability not captured by our other measures. We also experimented with overall firm size, measured by the natural logarithm of the total employees of the unit's parent firm, as well as both measures of size, and obtained similar results.¹⁵

Complementary Commercialization capabilities: The CMS provides a measure for the frequency of face-to-face interaction between personnel from R&D and marketing or sales, and between personnel from R&D and production, measured in a 4-point Likert scale.¹⁶ We constructed two binary variables, one for marketing and sales, and another for production. Each binary variable was given a value of 1 if the functions interact more than or equal to the sample median number of days. Thus, daily interaction between R&D and production imply that the variable *complementary production capability* takes value 1, and 0 otherwise. The variable *complementary marketing capability* is similarly defined.

Effectiveness of secrecy: Another determinant of the returns from innovation activities is how effective secrecy is in protecting the innovation against imitation. CMS respondents were asked to indicate the percentage of their product (and separately, process) innovations for which secrecy had been effective in protecting their firm's competitive advantage from those innovations during the prior three years. As with patent effectiveness, there are five, mutually exclusive response categories (less than 10%, 10-40%, 41-60%, 61-90%, over 90%), for which we used the midpoint of the intervals and a weighted average of product and process effectiveness measures to define *effectiveness of secrecy*.

Market Competition: Technological rivalry conditions the returns to patenting and may also condition the payoff from licensing. In particular, technological rivalry is likely to raise the payoff to patenting and may also raise the opportunity cost of licensing, particularly if there is a prospect of valuable knowledge leaking out. The CMU survey provide measures for both the total *number of rivals* and *technological*

¹⁵ Business unit employees is reported by R&D managers from the CMU survey, whereas total firm employees were obtained from sources such as Compustat, Dun and Bradstreet, Moody's, and Ward's.

¹⁶ Respondent were asked: "How frequently do your R&D personnel talk face-to-face with personnel from the following functions?" Possible responses, rated in a 4-point Likert scale (ranging from 1=rarely or never to 4=daily), included "Marketing or Sales," "Production," and "Other R&D units."

rivals, as categorical variables in the following ranges: 0,1-2, 3-5, 6-10, 11-20, or >20 competitors.¹⁷ The responses were recoded to category midpoints. These variables vary across respondents within industries because they represent each respondent's assessment of his/her focus industry conditions, often reflecting a particular niche or market segment.

Nature of Knowledge: Typically, technologies that are strongly science-based are less likely to be tacit and patents are more likely to be effective (Arora and Gambardella, 1994; Winter, 1987). Tacit technology is costly to transfer, implying lower licensing payoff (Teece, 1977). Thus it is important to control for the nature of the relevant knowledge base. The CMS survey provides a number of measures of the degree to which knowledge is science based. We use three such variables. The first two represent survey-based measures of the importance of science. Respondents were asked to rate (on a four-point Likert scale) the importance of different fields of science and engineering in term of their contribution to a firm's R&D activity during the most recent three years (possible fields include Biology, Chemistry, Physics, Computer Science, Materials Science, Medical and Health Science, Chemical Engineering, Electrical Engineering, Mechanical Engineering, Mathematics). One measure, labeled *importance of basic science*, represents the maximum score computed across all the fields except the engineering fields and the Medical and Health Science field. A second measure, labeled *importance of medical science*, represents the importance of the Medical and Health Science field alone. A third variable, included to control for the nature of knowledge, is the reported percentage of *R&D effort devoted to basic research*, defined as scientific research with no specific commercial objective.

Other Controls: We use binary variables indicating whether the firm owning the R&D lab is *Global* (sells products in Japan or Europe), or is *Foreign* (the R&D lab's parent firm is located abroad), and whether the firm is *Public* (publicly traded) to control for possible differences in market access and cost of

¹⁷ Technological rivals are defined in the CMS questionnaire as the number of US competitors capable of introducing competing innovations in time that can effectively diminish the respondent's profits from an innovation, with reference to the lab's focus industry.

contract enforcement. We also include the percentage of *R&D effort devoted to technical service*, such as providing manufacturing support, troubleshooting, etc., as a control for the patentability of the innovative output of the R&D lab.

Industry fixed effects: We include 7 industry dummy variables.¹⁸ In addition to the factors we have already discussed, industry norms may be important in determining patenting, but especially the propensity to license.

V. RESULTS

V.1 OLS Results.

We first present the simple Ordinary Least Squares results, reported in Table 3 (without and with interactions, respectively in specification I and II), relating the exogenous variables and controls on the propensity to patent and to license, estimated as single equations, to explore basic correlations in the data and their consistency with the developed hypothesis.

The results are consistent with the theory developed in the previous section, suggesting that patent effectiveness has a positive and significant effect on patent propensity (Hypothesis 1). We find a smaller positive effect on licensing, consistent with hypothesis 1 as well. Business unit size has offsetting effects on the dependent variables: positive and significant (at the 1% level) on patent propensity, and marginally negative and insignificant on licensing propensity. The effect of the complementary marketing and production capabilities is negative for both patent and licensing propensities. All these results are obviously consistent with Hypothesis 2, according to which any outcome is possible as far as patent propensity is concerned, and negative effects should be found for licensing propensity. The effects of the interaction between patent effectiveness and the measures of commercialization capabilities on licensing propensities are all negative, as indicated by Hypothesis 3. Note however that only the impact of complementary marketing capability is statistically significant.

¹⁸ The industry dummies are based on the following groupings: Chemicals, petroleum and plastics (SIC 28,29,30 excl. 283), biotechnology and pharmaceuticals (SIC 283), computer and electronics (SIC 357 and 36), machinery (SIC 35, excl. 357), transportation (SIC 37), instruments (SIC 38, excl. 384), and medical instruments (SIC 384).

Note also that the industry effects together (not reported) are jointly significant. Specifically, the chemical and bio-pharmaceutical dummies are positive and significant in the patent propensity equation, and the bio-pharmaceutical dummy is positive and significant in the licensing propensity equation.

These are simple reduced form estimates, useful for showing correlations in the data but obviously not useful for understanding the impacts on the payoffs to licensing or not licensing.

V.2 Structural Estimates

Structural estimates have several advantages. In addition to providing more precise estimates, structural estimation allows to disentangle the impact of the explanatory variables on the returns to patenting and licensing, and thus also on firm behavior. Second, these allow us to test hypothesis related to the share of licensing in patented innovations, as distinct from overall licensing. Finally, the theoretical literature mostly relates to payoffs to licensing or patenting. However, the data are on behavior, which also depend upon the opportunity cost of patenting. As we have seen, we need to be careful in extending hypotheses regarding payoffs to hypotheses regarding licensing and patenting propensities. Structural estimation allows us to link the payoffs to behavior in a consistent and coherent fashion.

The structural estimates are shown in Table 4. Recall that these are the results of non-linear estimation, in which we impose the cross equation restrictions, namely that $(V^{LP} - V^{NS})$ and $(V^{NP} - V^{NS})$ are present in the denominators in both equations, and that the numerator in both equations share the coefficients from $(V^{LP} - V^{NS})$. We estimated the system of nonlinear simultaneous equations based on (4-1) and (4-2) using the general method of moments (GMM), which allows us to impose the cross-equation restrictions, accounting for the correlation across errors of the two equations, as well as correcting for possible heteroscedasticity of the econometric error terms (cf. Gallant, 1987: pp. 442-451).¹⁹ Note that the also the estimates for $V^{LP} - V^{NP}$ are reported in the second column of Table 4, which can be obtained from the difference between the estimates of the (net) payoff from licensing $(V^{LP} - V^{NS})$ and the net payoff from patenting for commercialization $(V^{NP} - V^{NS})$.

¹⁹ We used the Model procedure in the SAS software package using the GMM option, which allows us to estimate nonlinear systems of equations and obtain heteroscedasticity consistent standard errors.

Before discussing our hypotheses, we briefly discuss the estimates of key control variables. The effectiveness of secrecy, which should in principle reduce payoffs from patenting as well as licensing, does have a negative coefficient, albeit statistically insignificant. Measures of the codifiability of knowledge have positive and significant coefficients for licensing payoffs but are negative, albeit statistically insignificant, for patenting without licensing. We also find that foreign firms, global firms and public firms have higher payoffs from patenting for commercialization (i.e., without licensing). The impacts on the licensing payoffs are generally positive as well but statistically insignificant. Technological rivalry has a negative impact on patenting for commercialization payoffs, significant at 10%, but only a small and insignificant impact on licensing payoffs. Finally, as expected, the % of R&D devoted to technical service has a positive and significant impact on net licensing payoffs, but a negative and significant effect on payoffs from net patenting for commercialization.²⁰

Our first two hypotheses deal with the implications of patent effectiveness and commercialization capabilities. Given the existence of interaction terms, to evaluate the first order effects of the interacted variables we need to compute a linear combination of the parameters, which are reported in Table 5a. Consistent with Hypothesis 1', the partial derivative of the net licensing payoff ($V^{LP}-V^{NS}$) with respect to patent effectiveness is equal to 2.11, and it is significant at the 1% level. The corresponding partial derivative of the net patenting for commercialization payoff ($V^{NP}-V^{NS}$) is larger, equal to 2.68 and significant at the 1% level.

To examine hypothesis 1 we need to evaluate the impact on licensing and patenting propensity. Table 5b shows the marginal effects, obtained by differentiating Y_1 and Y_2 in 4-1 and 4-2, w.r.t. patent effectiveness and the measures of commercialization capabilities, evaluated at the mean of the sample. Table 5b shows that the share of licensing in patented innovations decreases as patent effectiveness increase, as predicted by Hypothesis 1. The impact of patent effectiveness on patent propensity is positive and significant at the 1% level (a 10% increase in patent effectiveness increases patent propensity by 5%),

²⁰ As already discussed, these are net payoffs, i.e., relative to the payoff from not patenting.

so that the overall impact of patent effectiveness on licensing propensity is positive and significant at the 1 % level (a 10% increase in patent effectiveness increases licensing propensity by 4%). Basically, more effective patent protection does lead to more licensing, but this is mostly driven by the indirect effect of patenting on the propensity to license²¹.

As far as the first order effect of the measures of commercialization capabilities, we find that the marginal effects are generally consistent with Hypothesis 2', except for the effect of the complementary marketing capabilities, which increase licensing payoff, contrary to Hypothesis 2'. The effects are not significantly different than zero. A similar picture obtains for Hypothesis 2. Business unit size has a very small impact on licensing propensity, which is not significantly different than zero. Complementary production capability has a slightly stronger, albeit insignificant negative effect, with estimated elasticities indicating that complementarity with production decreases the probability of licensing by 30%, and the probability of licensing patented innovations by 12%. Complementary marketing capability, however, has an unexpected slightly – and insignificant - positive effect on licensing propensity.

A central finding of this paper relates to the impact of the interaction between patent effectiveness and the measures of commercialization capabilities on licensing payoffs and behavior, related to Hypothesis 3' and 3. Consistent with Hypothesis 3', Table 4 shows the difference in the sign of the coefficients related to the interactions between patent effectiveness and the measures of commercialization capabilities: negative for licensing payoffs and positive for patenting for commercialization. These results imply that effective patent protection and commercialization capabilities are complementary, in the sense that they mutually reinforce their positive impact on the profits due to patenting and commercializing relative to licensing or commercialization without patenting.

The cross-partial derivatives on licensing and patent propensities related to Hypothesis 3 are shown in Table 5b. Consistent with Hypothesis 3, all interactions have a negative effect on the propensity

²¹ The elasticity of the probability of licensing w.r.t. patent effectiveness can be decomposed as follows: Elasticity of $\Pr(\text{Lic}) = \text{Elasticity of } \Pr(\text{Lic}|\text{Pat}) + \text{Elasticity of } \Pr(\text{Pat})$. With the estimated elasticities of the share of licensing equal to -0.15 and of patenting equal to 0.51, the elasticity of the probability of licensing is equal to 0.36.

to license and the share of licensing in patented innovations. The impact on the conditional probability of licensing is negative and large, suggesting that firms with stronger commercialization capabilities will be characterized by a lower marginal impact of patent effectiveness on the propensity to license patented innovations. The most potent conditioning factor relates to the bundling of R&D with production capabilities and, to a lesser extent, with marketing capabilities. Recall that we control for size, so that these results are not merely reflecting scale effects.

Recall that Hypothesis 3 does not require that an increase in patent effectiveness actually decrease licensing for firms with high commercialization capability, although such a result is obviously consistent with it. Indeed, we report in Table 6 the average elasticity of the propensity to license, both unconditional and conditional on patenting, for high and low commercialization capabilities firms. Results clearly show that firms with high complementarities between R&D, marketing and production and higher effectiveness of patent protection are more likely to patent, but less likely to license their patented innovations. Firms characterized by low complementarities and high patent effectiveness are more likely to license, and license a larger share of their patented inventions.

VI. Summary and Conclusions.

The ability of firms to appropriate the returns from their innovations is a key driver of the willingness of firms to invest in innovative activity, and a key determinant of firm strategy in technology intensive industries. In recent years, some firms appear to have resorted to technology licensing as a way of appropriating the returns. But even when licensing is feasible, it is well known that such trades may not take place due to various imperfections in the market for technology. The literature has suggested that patents can ameliorate some of these imperfections, and in particular, the more effective patent protection is, the more efficient is the market for technology. However, more effective patents also enhances the payoff from commercialization, making it important to quantify the impact of patent effectiveness on licensing. Further, licensing strategies are not undertaken in isolation from other strategies for

appropriating the rents from innovation, and in particular, from patenting, a point that has been recognized but hitherto not addressed adequately.

We contribute to this literature by analyzing how patenting and licensing strategies are related, and how patent effectiveness and commercialization capabilities condition the use of these strategies by firms to appropriate rents from innovation. We do so by developing a structural model of licensing and patenting behavior, which is estimated using the Carnegie Mellon survey on industrial R&D.

Our results suggest that formal patent protection can indeed condition the propensity of firms to license their innovations. We show how increases in patent effectiveness indirectly affect licensing by increasing the propensity of firms to seek patent protection for their innovations. However, increases in patent effectiveness may decrease the proportion of patented innovations that are licensed, due to an offsetting positive effect of patent protection on the returns from commercializing the patented innovation, so that the net increase in licensing propensity is smaller.

We also find that firms that have the capabilities and resources to appropriate the returns by commercializing the innovations in-house, as well as greater complementarities between R&D and commercialization capabilities, have lower licensing propensities than firms that lack such resources. Interestingly, we find that the presence of commercialization capabilities critically conditions the impact of patent effectiveness on licensing strategies: Changes in patent effectiveness are most potent for firms that lack commercialization capability. Higher patent effectiveness elicits much larger increases in licensing from firms lacking commercialization capability or characterized by a lower degree of complementarities between the R&D and marketing or production functions. These results point to the need to better understand the rich interplay between different strategic instruments available to firms in their quest to appropriate rents from innovation.

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Table 1a. The predicted effect of patent protection and commercialization capabilities on licensing and patenting payoffs.

	$V^{LP} - V^{NS}$	$V^{LP} - V^{NP}$	$V^{NP} - V^{NS}$
	LICENSING PAYOFFS RELATIVE TO NOT PATENTING	LICENSING PAYOFFS RELATIVE TO PATENTING AND NOT LICENSING	PATENTING AND NOT LICENSING PAYOFFS RELATIVE TO NOT PATENTING
Patent effectiveness (θ)	+	?	+
Commercialization capabilities (ρ)	-	-	?
Interaction between commercialization capabilities and patent effectiveness (ρ and θ)	Null	-	+

Table 1b. The predicted effect of patent protection and commercialization capabilities on licensing and patenting behavior.

	Patent Propensity $Pr(Pat)$	Share of licensing in patented innovations $Pr(Lic Pat)$	Licensing Propensity $Pr(Lic)$
Patent effectiveness (θ)	+	?	?
Commercialization capabilities (ρ)	?	-	-
Interaction between commercialization capabilities and patent effectiveness (ρ and θ)	?	-	-

Table 2. Descriptive statistics.

	Mean	Median	St. Dev.	Min.	Max.
ENDOGENOUS VARIABLES					
Licensing propensity	0.06	0	0.14	0	0.95
Patent propensity	0.29	0.25	0.26	0	1
EXPLANATORY VARIABLES					
Business unit employees (Log)	6.62	6.48	2.08	2.30	13.01
Patent effectiveness	0.35	0.25	0.29	0.05	0.95
Complementary marketing capability	0.43	0	0.50	0	1
Complementary production capability	0.50	1	0.50	0	1
Effectiveness of secrecy	0.53	0.5	0.29	0.05	0.95
% basic research	0.03	0	0.06	0	0.5
Importance of basic science	1.92	2	0.97	0	3
Importance of medical science	0.65	0	0.99	0	3
Number of technological competitors	3.93	4	4.63	0	32
Parent firm is global	0.79	1	0.41	0	1
Parent firm is foreign	0.10	0	0.30	0	1
Parent firm is public	0.65	1	0.48	0	1
% R&D effort for technical service	0.18	0	0.38	0	1
INDUSTRY DUMMIES					
Chemicals, petroleum, and plastics	0.21	0	0.41	0	1
Biotechnology and pharmaceuticals	0.05	0	0.23	0	1
Computer and electronics	0.16	0	0.37	0	1
Machinery	0.11	0	0.32	0	1
Transportation	0.08	0	0.28	0	1
Instruments (excl. medical)	0.07	0	0.26	0	1
Medical instruments	0.07	0	0.25	0	1
N=761					

Table 3. Determinants of patent and licensing propensities: OLS estimates.

	Patent Propensity		Licensing Propensity	
	I	II	I	II
Intercept	-0.064 (0.039)	0.030 (0.047)	0.000 (0.026)	-0.044 (0.032)
Patent effectiveness	0.490** (0.032)	0.253** (0.094)	0.077** (0.019)	0.187* (0.088)
Effectiveness of secrecy	-0.012 (0.025)	-0.018 (0.025)	-0.006 (0.015)	-0.004 (0.015)
Complementary marketing capabilities	-0.011 (0.016)	-0.006 (0.020)	-0.003 (0.010)	0.021 ^a (0.013)
Complementary production capabilities	-0.022 (0.016)	-0.061** (0.022)	-0.018 ^a (0.010)	-0.001 (0.014)
Log business unit employees	0.016** (0.004)	0.006 (0.005)	-0.001 (0.003)	0.002 (0.003)
N. of technological rivals	-0.004** (0.001)	-0.003** (0.001)	-0.001 (0.001)	-0.001 (0.001)
% basic R&D	0.005 (0.135)	-0.008 (0.130)	0.326** (0.109)	0.322** (0.105)
Importance of medical/health science	-0.001 (0.010)	-0.003 (0.010)	0.020 (0.008)	0.022** (0.008)
Importance of basic science	0.002 (0.008)	0.003 (0.008)	0.010 ^a (0.005)	0.009 ^a (0.005)
Parent firm is global	0.052** (0.016)	0.047** (0.016)	0.004 (0.011)	0.008 (0.011)
Parent firm is foreign	0.041 (0.026)	0.043 ^a (0.025)	-0.004 (0.016)	-0.002 (0.015)
Parent firm is public	0.051** (0.018)	0.052** (0.018)	-0.001 (0.013)	0.000 (0.013)
% technical service R&D	-0.033 ^a (0.018)	-0.033 ^a (0.018)	0.040* (0.016)	0.042** (0.015)
Patent effectiveness*Complementary marketing capability		-0.012 (0.059)		-0.072* (0.032)
Patent effectiveness*Complementary production capabilities		0.113 ^a (0.063)		-0.049 (0.036)
Patent effectiveness*Log of b.u. employees		0.029* (0.013)		-0.009 (0.011)
N	761	761	761	761
Adj. R-square	0.44	0.45	0.13	0.13

- Heteroscedasticity consistent standard errors in parenthesis.

**, *, a: Significantly different than zero at the 0.01, 0.05, and 0.10 confidence levels.

- Industry fixed effects estimates are suppressed

Table 4. GMM structural estimates of the system of patent and licensing equations.

	$V^{LP} - V^{NS}$	$V^{LP} - V^{NP}$	$V^{NP} - V^{NS}$
	LICENSING PAYOFFS RELATIVE TO NOT PATENTING	LICENSING PAYOFFS RELATIVE TO PATENTING AND NOT LICENSING	PATENTING AND NOT LICENSING PAYOFFS RELATIVE TO NOT PATENTING
Intercept	-4.924** (0.756)	-2.235* (0.920)	-2.689** (0.420)
Patent effectiveness	2.990** (1.085)	1.747 (1.345)	1.243 ^a (0.682)
Effectiveness of secrecy	-0.144 (0.318)	-0.115 (0.375)	-0.028 (0.182)
Complementary marketing capabilities	0.374 (0.383)	0.553 (0.467)	-0.179 (0.200)
Complementary production capabilities	-0.277 (0.389)	0.293 (0.472)	-0.570** (0.199)
Log business unit employees	0.049 (0.067)	-0.011 (0.085)	0.059 (0.048)
Patent effectiveness*Complementary marketing capabilities	-0.948 (0.589)	-1.194 ^a (0.689)	0.247 (0.395)
Patent effectiveness *Complementary production capabilities	-0.124 (0.638)	-1.259 ^a (0.757)	1.135** (0.416)
Patent effectiveness *Log of business unit employees	-0.062 (0.134)	-0.178 (0.163)	0.115 (0.091)
No. of technological rivals	-0.028 (0.018)	-0.003 (0.025)	-0.025 ^a (0.014)
% basic R&D	2.785** (1.044)	4.296** (1.390)	-1.511 (1.042)
Importance of medical/health science	0.307** (0.100)	0.443** (0.133)	-0.136 ^a (0.077)
Importance of basic science	0.245* (0.113)	0.277* (0.133)	-0.032 (0.061)
Parent firm is global	0.191 (0.220)	-0.175 (0.275)	0.365* (0.145)
Parent firm is foreign	0.026 (0.312)	-0.420 (0.379)	0.446* (0.193)
Parent firm is public	0.059 (0.264)	-0.409 (0.337)	0.469** (0.159)
% technical service R&D	0.591** (0.206)	1.065** (0.281)	-0.474** (0.160)

Heteroscedasticity consistent standard errors in parenthesis.

**, *, a: Significantly different than zero at the 0.01, 0.05, and 0.10 confidence levels.

- Industry fixed effects estimates are suppressed

Table 5a. Marginal effects on licensing and patenting payoffs.

	$V^{LP} - V^{NS}$	$V^{LP} - V^{NP}$	$V^{NP} - V^{NS}$
HP1':			
Patent effectiveness	2.11** (0.29)	-0.57 ^a (0.33)	2.68** (0.20)
HP2':			
Complementary marketing capabilities	0.04 (0.24)	0.14 (0.29)	-0.09 (0.12)
Complementary production capabilities	-0.32 (0.23)	-0.15 (0.28)	-0.17 (0.12)
Business unit employees	0.03 (0.04)	-0.07 (0.06)	0.1** (0.03)
HP3':			
Effectiveness of patent protection* Complementary marketing capabilities	-0.95 (0.59)	-1.19 ^a (0.69)	0.25 (0.39)
Effectiveness of patent protection* Complementary production capabilities	-0.12 (0.64)	-1.26 ^a (0.76)	1.14** (0.42)
Effectiveness of patent protection* Log of business unit employees	-0.06 (0.13)	-0.18 (0.16)	0.12 (0.09)

Table 5b. Marginal effects on licensing and patenting behavior.

	Patent Propensity Pr(Pat)	Share of licensing in patented innovations Pr(Lic Pat)	Licensing Propensity Pr(Lic)
HP1:			
Patent effectiveness	0.469** (0.032)	-0.087 ^a (0.053)	0.065** (0.012)
HP2:			
Complementary marketing capabilities	-0.012 (0.017)	0.021 (0.044)	0.003 (0.010)
Complementary production capabilities	-0.037* (0.017)	-0.022 (0.043)	-0.012 (0.010)
Log of business unit employees	0.016** (0.004)	-0.011 (0.008)	0.0003 (0.002)
HP3:			
Eff. patent protection* Complementary marketing capabilities		-0.186 (0.115)	-0.036 ^a (0.021)
Eff. patent protection* Complementary production capabilities		-0.180 (0.121)	-0.029 (0.024)
Eff. patent protection*Log of business unit employees		-0.023 (0.025)	-0.005 (0.006)

- Heteroscedasticity consistent standard errors in parenthesis.

** , * , a: Significantly different than zero at the 0.01, 0.05, and 0.10 confidence levels.

- Marginal effects obtained using the GMM estimates, computed at the mean of the sample.

Table 6. Elasticity of licensing with respect to patent effectiveness, by complementary capabilities.

		Elasticities w.r.t. patent effectiveness of:	
		Licensing propensity	Propensity to license patented innovations
Complementary marketing capabilities	Low	0.52	0.04
	High	0.14	-0.40
Complementary manufacturing capabilities	Low	0.53	0.05
	High	0.19	-0.36

Appendix A: Sequential Decisions

For the sequential decision making, we estimated a slightly modified version of the foregoing setup. Let $V^{NP} - V^{NS} = V_{ij}^P + \eta_{ij}$, where the subscript i indexes the firm and j indexes the innovation. Thus, V_{ij}^P represents the firm and innovation specific factors that determine the net payoff from patenting vis a vis secrecy for an innovation that shall not be licensed, and η_{ij} represents the unobserved factors that condition this net payoff. Similarly, let $V^{LP} - V^{NP} = V_{ij}^L + \varepsilon_{ij}$, where V_{ij}^L represents firm and innovation specific factors that determine the net payoff from licensing, such as demand for licensing, and ε_{ij} represents the unobserved factors that condition the net licensing payoff. Then, since only patented innovations can be licensed (recall $V_{LS} \approx 0$), $\Pr(\text{License}_{ij} | \text{Patent}_{ij}) = \Pr(V^{LP} - V^{NP} > 0) = \Pr(\varepsilon_{ij} > -V_{ij}^L)$. The expected payoff from patenting the j th innovation by firm i , Π_{ij}^P is thus:

$$\Pi_{ij}^P = V^{NP} + (V_{ij}^L + \varepsilon_{ij}^*) \Pr(\varepsilon_{ij} > -V_{ij}^L), \text{ where } \varepsilon_{ij}^* = E(\varepsilon_{ij} | \varepsilon_{ij} > -V_{ij}^L). \text{ Hence,}$$

$$\Pr(\text{Patent}) = \Pr(\Pi_{ij}^P - V^{NS} > 0) = \Pr(\eta_{ij} < -V_{ij}^P - (V_{ij}^L + \varepsilon_{ij}^*) \Pr(\varepsilon_{ij} > -V_{ij}^L))$$

This yields the system to be estimated,

$$\Pr(\text{License}_{ij}) = \Pr(\text{License}_{ij} | \text{Patent}_{ij}) \cdot \Pr(\text{Patent}_{ij})$$

$$= \Pr(\varepsilon_{ij} > -V_{ij}^L) \Pr(\eta_{ij} < -V_{ij}^P - (V_{ij}^L + \varepsilon_{ij}^*) \Pr(\varepsilon_{ij} > -V_{ij}^L))$$

$$\Pr(\text{Patent}_{ij}) = \Pr(\eta_{ij} < -V_{ij}^P - (V_{ij}^L + \varepsilon_{ij}^*) \Pr(\varepsilon_{ij} > -V_{ij}^L))$$

The upshot from this model is that it allows one to estimate the option value of licensing. With sequential decision making, firms do not observe the payoffs from licensing at the time of the patenting decision and take expectations. Estimation of the model parameters rejects the existence of uncertainty over the licensing premium at the time of the patenting decision (estimation results are available from the authors upon request).

Appendix B: Determinants of the Profits from Licensing

Hypotheses 1' and 1

We can formalize the comparative statics summarized by our hypotheses using a simple model. Consider an innovation. In terms of the notation developed above, we can write $V^{LP} = \sigma\Pi - F$, where Π represents the gross value to the licensee of the technology, σ represents the share captured by the licensor, and F represents contracting costs and other “deadweight losses”, for instance due to transfer costs. Finally, let W represent $\text{Max}\{V^{NP}, V^{NS}\}$, the value of the highest paying alternative i.e., the opportunity cost of licensing. The payoff to licensing is then equal to $V^{LP} = \sigma\Pi - F$. Therefore, licensing takes place if $Q = V^{LP} - W > 0$.

The licensing payoff thus depends upon two basic considerations: the expected revenue to be earned (*revenue effect*) and the direct (*transaction*) cost of licensing. The *decision to license* also includes a third consideration, namely the *opportunity* costs of licensing, represented by W . In terms of our setup, patents decrease F and may also increase σ (by increasing the bargaining power of the licensor). However, patents also affect Π and W .

More formally, let θ represent an index of patent effectiveness. Then the derivative of the payoff from licensing with respect to θ is $dV^{LP}/d\theta = \Pi(d\sigma/d\theta) + \sigma d\Pi/d\theta - (dF/d\theta)$. The first term shows the effect on the revenue due to the effect on the share of the surplus captured by the licensor. To the extent that stronger patents enhance the bargaining power of licensors, we expect this term to be positive. The second term represents how stronger patents raise the payoff to the licensee. We expect this term to be positive since a licensed technology protected by stronger patents will yield larger payoff to the licensee. The third term represents the impact of patent effectiveness on the “transaction costs” of licensing. Thus, we expect the third term to be positive as well. As argued in the text, it is obvious that V^{NP} is increasing in θ , whereas V^{NS} is independent of θ by assumption.

Confirming hypothesis 1', increases in patent effectiveness increase both $V^{LP} - V^{NS}$ and $V^{NP} - V^{NS}$. The impact on $V^{LP} - V^{NP}$ is however ambiguous. Licensing requires that V^{LP} be greater than $\text{Max}\{V^{NP}, V^{NS}\}$, which leads to the empirical specification of the probabilities as derived in the text:

$$\Pr(\text{Patent}) = [\exp(V^{LP} - V^{NS}) + \exp(V^{NP} - V^{NS})] / [\exp(V^{LP} - V^{NS}) + \exp(V^{NP} - V^{NS}) + 1]$$

$$\Pr(\text{License}) = [\exp(V^{LP} - V^{NS})] / [\exp(V^{LP} - V^{NS}) + \exp(V^{NP} - V^{NS}) + 1]$$

It follows that:

$$\frac{d \Pr(Lic)}{d\theta} = \frac{\Pr(Lic)}{A} \left(\exp(V^{NP} - V^{NS}) \frac{d(V^{LP} - V^{NP})}{d\theta} + \frac{d(V^{LP} - V^{NS})}{d\theta} - 1 \right), \text{ where} \quad \text{Since}$$

$$A = \exp(V^{NP} - V^{NS}) + \exp(V^{LP} - V^{NS}) + 1.$$

the sign of $\frac{d(V^{LP} - V^{NP})}{d\theta}$ is ambiguous, so is the overall expression. Similarly, it also follows that the share of licenses in patented innovations could either increase or decrease with respect to patent effectiveness. Finally,

$$\Pr(Pat) = \frac{1}{1+B}, \quad B = \frac{1}{\exp(V^{NP} - V^{NS}) + \exp(V^{LP} - V^{NS})}. \text{ Since both } (V^{LP} - V^{NS}) \text{ and } (V^{NP} - V^{NS}) \text{ are}$$

non decreasing in θ , it follows that B is decreasing in θ and so $\Pr(\text{Patent})$ is increasing in θ . This demonstrates hypothesis 1.

Hypotheses 2' and 2.

Let ρ be an index of commercialization capability. It is unlikely that σ or F would be affected by ρ . Further, since Π reflects the payoff to the licensee, this too is unlikely to be affected by ρ , which refers to the licensor's capabilities. Therefore, V^{LP} should be independent of ρ . Moreover, both V^{NP} and V^{NS} should be increasing in ρ . Thus, as hypothesis 2' states, $V^{LP} - V^{NS}$ and $V^{LP} - V^{NP}$ are decreasing in ρ , but the impact on $V^{NP} - V^{NS}$ is ambiguous.

To get the implications for licensing and patenting behavior, note that the probability of licensing can be rewritten as $\Pr(\text{License}) = 1 / [\exp(V^{NP} - V^{LP}) + \exp(V^{NS} - V^{LP}) + 1]$. It is easy to see that the denominator is increasing in ρ , and hence, the probability of licensing is decreasing in ρ . Similarly, $\Pr(\text{Lic}|\text{Pat}) = 1 / [\exp(V^{NP} - V^{LP}) + 1]$, which is also decreasing in ρ . It is also evident, following the lines of the discussion for hypothesis 1 above, that the impact on the probability of patenting is ambiguous because the impact of ρ on $V^{NP} - V^{NS}$ is ambiguous. This demonstrates hypothesis 2.

Hypothesis 3' and 3.

By definition, $dV^{NS}/d\theta = 0$ since patent effectiveness can have no effect if the innovation is not patented, and hence $d^2V^{NS}/d\rho d\theta = 0$. Similarly, $dV^{LP}/d\rho = 0$ because if the innovation is licensed, what matters is the commercialization capability of the licensee, not those of the innovator.

In the text we argued that $d^2V^{NP}/d\rho d\theta > 0$ because stronger patents are more valuable to firms with stronger commercialization capability. This intuition can be formalized by using a standard two-stage model of R&D competition, where in stage one 2 firms choose the amount of cost reducing R&D, the cost of which is quadratic in R&D, and in stage two firms compete *à la Cournot* in a homogeneous product market with linear demand ($p=1-Q$). Such models have been widely used to model R&D competition (cf. d'Aspremont and Jacquemin, 1988; De Bondt et al., 1992, and Ceccagnoli, 2003). For simplicity, assume there are two firms, i and j . Marginal costs are equal to $c_i = c - \rho_i - R_i - (1-\theta_j)R_j$ for firm i , where ρ_i is an index of firm i complementary capabilities, $(1-\theta_j)$ represents the fraction of rival j 's R&D which contributes to firm i 's costs, with $0 \leq \theta_j \leq 1$. A greater θ_j reflects stronger patent protection for firm j , implying lower cost reducing R&D spillovers to the rival i . Analogously, rival j 's marginal costs are equal to $c_j = c - \rho_j - R_j - (1-\theta_i)R_i$. Profits from commercialization and patenting for firm i , in this model, are equal to $V_i^{NP} = (q_i^c)^2 - \frac{1}{2}R_i^2$, with $q_i^c = \frac{1}{3}[-2c_i + c_j]$ representing the *Cournot-Nash* first-stage

equilibrium quantities in the product market. It is easily verified that $\frac{\partial^2 V_i^{NP}}{\partial \rho_i \partial \theta_i} = \frac{4}{3}R_i > 0$, which formalizes the intuition presented in the text and demonstrates hypothesis 3'.

To verify hypothesis 3 note that:

$$\frac{d^2 \Pr(Lic)}{d\rho d\theta} = \frac{1}{\Pr(Lic)} \frac{d \Pr(Lic)}{d\theta} \frac{d \Pr(Lic)}{d\rho} + \Pr(Lic) \left[\frac{d \Pr(Lic)}{d\rho} \left(\frac{dV^{NP}}{d\theta} - \frac{dV^{LP}}{d\theta} \right) - \frac{dV^{NP}}{d\theta} \frac{d \Pr(Pat)}{d\rho} - [\Pr(Pat) - \Pr(Lic)] \frac{d^2 V^{NP}}{d\rho d\theta} \right].$$

The first term in the expression for $\frac{d^2 \Pr(Lic)}{d\rho d\theta}$ is negative if the probability of licensing is increasing in patent effectiveness and decreasing with complementary commercialization capability. The former is empirically true, as shown in Table 5b. Theory suggests that licensing propensity tends to decrease with complementary capabilities. The second term depends on three sub terms inside the square brackets, of which only the third is predicted to be negative by our theory. The signs of the first two sub-terms are indeterminate in theory. However, a sufficient condition for the first two sub-terms to be negative is that:

- a) The conditional probability of licensing is decreasing in patent effectiveness is negative, so that $\frac{dV^{NP}}{d\theta} - \frac{dV^{LP}}{d\theta} > 0$. This is true empirically.
- b) The first order effect of complementary capabilities on the probability of patenting is positive, i.e., $\frac{d \Pr(Pat)}{d\rho} > 0$. This is also true empirically, except for business unit size, for which the effect is close to zero.

The impact on the share of licensing in patented innovations is also indeterminate without additional assumptions. If, as is true in our empirical findings, the first order effect of patent effectiveness on the probability of licensing conditional on patenting is positive (so that $\frac{dV^{NP}}{d\theta} - \frac{dV^{LP}}{d\theta} > 0$), and if the probability of not licensing conditional on licensing is greater than the probability of licensing (as is also true in our sample), and if $\frac{d \Pr(Lic | Pat)}{d\rho} < 0$ then the first term is positive. The second term is negative if the cross partial is positive.

$$\frac{d^2 \Pr(Lic | Pat)}{d\theta d\rho} = \frac{d \Pr(Lic | Pat)}{d\rho} \left(\frac{dV^{LP}}{d\theta} - \frac{dV^{NP}}{d\theta} \right) [\Pr(NotLic | Pat) - \Pr(Lic | Pat)] - \Pr(Lic | Pat) \Pr(NotLic | Pat) \left(\frac{d^2 V^{NP}}{d\theta d\rho} \right)$$