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DETERMINANTS OF INVENTION COMMERCIALIZATION: AN EMPIRICAL EXAMINATION OF ACADEMICALLY SOURCED INVENTIONS

ATUL NERKAR[1]* and SCOTT SHANE[2]
[1] *Kenan-Flagler Business School, University of North Carolina at Chapel Hill, Chapel Hill, North Carolina, U.S.A.*
[2] *Department of Economics, Weatherhead School of Management, Case Western Reserve University, Cleveland, Ohio, U.S.A.*

We examine the attributes of technological inventions that influence their commercialization. Using a unique dataset of the Massachusetts Institute of Technology (MIT)-licensed patents, we show that the likelihood of invention commercialization, which we measure by the achievement of first sale, is positively associated with two characteristics of licensed technological inventions—scope and pioneering nature—and has an inverted U-shaped relationship with the age of the invention. Copyright © 2007 John Wiley & Sons, Ltd.

INTRODUCTION

Past research in strategic management argues that the ability to commercialize technological inventions is an important driver of firm success (Cohen and Levinthal, 1990; Eisenhardt and Martin, 2000; Zahra and Nielsen, 2002). Thus, an important strategic management question is: What explains the differences in performance of firms at invention commercialization?

Much research has argued that this performance is the result of firm capabilities (Dougherty and Hardy, 1996; McGrath *et al*., 1996; Pennings and Harianto, 1992; Teece, 1986; Teece, Pisano, and Shuen, 1997), human resource practices (Nerkar, McGrath, and MacMillan, 1996; Scott and Bruce, 1994), incentive structures (Nevens, Summe, and Uttal, 1990; Teece, 1986), human capital of top management teams (Bantel and Jackson, 1989; Howell and Higgins, 1990) and the environment in which firms operate (Abrahamson and Rosenkopf, 1993; David, 1988; Wade, 1996). While this literature has informed us greatly about the factors that influence invention commercialization, it has, by and large, neglected to discuss the effects of the attributes of technological inventions themselves (Henderson and Clark, 1990; Tushman and Anderson, 1986).

However, empirical examination of the effect of the attributes of inventions on their subsequent commercialization is important to strategic management research for several reasons. First, many researchers have argued that the performance of high-technology firms depends less on the strategic

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* Correspondence to: Atul NErkar, Kenan-Flagler Business School, University of North Carolina at Chapel Hill, CB #3490, McColl 4068, Chapel Hill, NC 27599-3490, U.S.A.
E-mail: nerkar@unc.edu

choices of managers than on the effect of their technology base and the network in which they are located (Merges and Nelson, 1994; Podolny and Stuart, 1995; Robinson, 1990; Rogers, 1982).

Second, some technologies are easier to commercialize, more appropriable, and less risky than other inventions, and therefore are more likely to be commercialized (Colyvas *et al*., 2002; Gopalakrishna and Damanpour, 1994). Basic scientific inventions, for instance, are seen as difficult to appropriate and so are less likely than more applied inventions to be commercialized (Arrow, 1962). Thus, consideration of the effect of the attributes of technological inventions themselves on their subsequent commercialization is important to the development of an accurate understanding of the performance of firms at invention commercialization (McEvily and Chakravarthy, 2002).

Third, accurate testing of theories about the effect of firm capabilities requires estimation of the effect of the attributes of inventions on their commercialization. Because researchers are unable to conduct experiments on invention commercialization, they typically test theories about the effect of firm capabilities through regression analysis. For these regressions to yield accurate estimates, researchers need to control for the effects of the inventions themselves on the likelihood of commercialization. By measuring the effects of different dimensions of inventions on their likelihood of commercialization, this study provides useful information for future researchers to more precisely test theories regarding the effect of capabilities on invention commercialization.

Lack of data is the main reason for our lack of information on the effect of the attributes of technical inventions on their commercialization. To examine the effect of attributes of inventions on their commercialization, researchers need to gather data on the characteristics of a set of inventions before the commercialization process occurs. Unfortunately, most researchers lack access to information about inventions at risk of commercialization prior to the initiation of the commercialization process. Therefore, they cannot address questions about the effect of the characteristics of inventions on their commercialization.

This study makes use of a unique dataset—the population of 966 efforts by private firms to introduce new products and services to the marketplace using inventions assigned to the Massachusetts Institute of Technology from 1980 to 1996 and licensed to private firms—to overcome this problem of data access. Because a great deal of information was collected on these inventions prior to the efforts to commercialize them, and because information is available on the outcomes of those commercialization efforts, these data shed light on the effect of the attributes of inventions on their likelihood of commercialization.

We concentrate this article on those attributes that enhance the appropriability of the returns to innovation. The attributes of technological inventions influence their likelihood of commercialization in so many different ways as to make the study of all of them simultaneously empirically intractable.[1] Moreover, the mechanisms underlying the effect of most of these attributes on the commercialization of inventions are largely undeveloped theoretically, rendering them unready for empirical testing.

We focus our attention on the attributes of inventions that affect the ability of firms to appropriate returns from successful commercialization. This focus was selected because appropriability is central to the decisions of firms about invention commercialization and because the arguments about how the mechanism works are well enough developed in the theoretical literature to permit empirical testing (Arrow, 1962; Cohen and Levinthal, 1989; Nelson, 1959).

THEORETICAL BACKGROUND AND HYPOTHESES

To explain why the effect of the attributes of inventions should influence their likelihood of commercialization, we must first explain the nature of invention commercialization and explain why appropriability is important to motivating private firms to engage in that process. The introduction of a new product or service to the marketplace is 'a process that begins with an invention, proceeds with the development of the invention, and results in the introduction of a new product, process or service to the marketplace' (Schumpeter,

[1] For example, Winter (1987) implies that the different attributes of an invention, including the degree to which it is codified, part of a system, and observable, affect its commercialization. Nelson (1982) argues that the public–private dimension of inventions influences their likelihood of commercialization. Malerba and Orsenigo (1996) argue that the cumulativeness of technology underlying the development of technological inventions also affects the likelihood of their commercialization.

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1934: 66, 1950). This statement suggests that one important mechanism that affects the commercialization of an invention is the willingness of firms to 'proceed with the development' of an invention to transform it into a new product or service for introduction to the marketplace.

The willingness of firms to engage in the process of invention commercialization is influenced by expectations about the returns that they will capture from commercialization if they are successful. At least since Nelson (1959) and Arrow (1962), researchers have believed that private firms will not have an incentive to transform technological inventions into commercial products and services unless they can appropriate the returns from commercialization. Therefore, those factors that increase the appropriability of the returns from invention commercialization lead firms to invest more heavily in that activity, and so increase the likelihood of commercialization (Levin *et al*., 1987).

Prior research indicates that at least three attributes of technological inventions influence the expectations of firms about the appropriability of the returns that would be earned from successful commercialization of the invention: the scope of the patent on the invention, the pioneering nature of the invention, and the age of the patent (Shane, 2001).[2] As we explain more fully in the subsections below, patent scope defines the breadth of intellectual property protection. Broader patents protect inventions against imitation from a wider range of potentially competing inventions than narrower patents (Merges and Nelson, 1990). The pioneering nature of the invention examines the degree to which the invention opens up new technology domains. More pioneering inventions offer firms the possibility of learning curve and lead time advantages as well as broader property rights (Levin *et al*., 1987; Ahuja and Lampert, 2001). Finally, the age of the invention examines the balance between the passage of time necessary for the diffusion of an invention and the time remaining on patent protection. In the subsection below, we develop specific hypotheses about the relationship between these attributes of inventions and the performance of firms at invention commercialization.

[2] Other attributes of patented technological inventions may also influence the expectations of firms about the appropriability of the returns that would be earned from successful commercialization of inventions; however, data limitations allow us to empirically examine only these three attributes.

Scope of the patent

The commercialization of technological inventions is highly uncertain (Zahra and Nielsen, 2002). Firms cannot know for sure whether they can create products or services from these inventions before trying. Inventions with broader scope of patent protection permit the appropriation of greater returns if commercialization is successful than inventions with narrower scope of patent protection (Merges and Nelson, 1990). Broader scope protection increases the likelihood that any trial-and-error efforts that are necessary to develop new products and services will result in something for which returns can be appropriated because broader patent scope allows the firm exploiting the invention to explore product and service applications over a wider range of technical areas (March, 1991). Moreover, such trial-and-error processes can allow multiple successful applications to emerge from the same technological invention, which increases the potential returns that can be appropriated.

Furthermore, broader scope of patented inventions provides a wider range of alternative inventions that can be blocked by the patent, generating greater appropriability and increasing the value of the patented invention (Merges and Nelson, 1990). For instance, in the case of patented inventions belonging to biotechnology firms, Lerner (1995) shows that a one standard deviation increase in patent scope is associated with a 21 percent increase in firm valuation. Similarly, Shane (2001) shows that the greater the scope of a patent, the greater the likelihood of new firms being formed to try to commercialize the invention covered by the patent. These arguments lead to the first hypothesis:[3]

[3] The broader the patent, the more incentive the firm has to bring to market an invention protected by it. The greater the incentive, the more resources the firm will put toward this commercialization effort and, consequently, the greater the likelihood of commercialization. This argument does not mean that there is no practical limit to the breadth of a patent. From a societal point of view, a patent can be too broad. Too broad patents deter nonholders of the patent from inventing new technologies that would be blocked by the broadness of the patent. The patent office imposes a practical limit on the breadth of a patent. If the proposed patent is too broad, the patent office will not allow it. However, conditional on a patent having been issued by the patent office, which is what we examine empirically, the breadth of scope increases the likelihood of its commercialization. To confirm this argument, we examined a regression model with a squared term for patent breadth and found that the results did prove statistically significant. Thus, the likelihood of commercialization is proven to increase with a broader-breadth patent.

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Hypothesis 1: All other things equal, the greater the scope of the invention's patent, the greater the likelihood of its commercialization.

Pioneering nature of invention

A second characteristic of an invention that we consider is its pioneering nature, or the degree to which the invention opens up new technology domains. We expect that the degree to which inventions are pioneering will increase the likelihood of commercialization because the pioneering nature increases the incentive of owners of the invention to invest time and money in its commercialization (Danneels and Kleinschmidt, 2001).

One of the primary reasons that firms try to commercialize inventions is to secure Schumpeterian rents that come from the creation of new products and services (Roberts, 1999; Winter, 1995). The use of technological inventions to create new products and services sometimes generates these rents by providing first mover (Lieberman and Montgomery, 1988) and learning curve advantages (Levin *et al*., 1987).

Pioneering inventions are more likely than other inventions to provide first mover and learning curve advantages. The degree to which inventions draw on other inventions increases the likelihood that those inventions will be imitated (Ahuja and Lampert, 2001). Even when patented, inventions can be worked around, allowing others who have capabilities in an area to create similar products and processes (Nevens *et al*., 1990). The more pioneering an invention is, the less available is the technology on which it builds. Hence, the more pioneering an invention, the lower the likelihood that it will be imitated.

Moreover, the breadth of property rights that the patent office assigns to inventions increases with the pioneering nature of inventions because less pioneering inventions must accommodate the property rights that have been given out to others already (Trajtenberg, 1990). This prior assignment of property rights reduces the appropriability of the returns to successful efforts to commercialize the inventions, and so makes firms more likely to pursue efforts to commercialize more pioneering inventions than less pioneering ones.[4] These arguments lead to the second hypothesis:

Hypothesis 2: All other things equal, the more pioneering an invention, the greater the likelihood of its commercialization.

Age of the invention

Initially, as inventions age, the likelihood that they will be commercialized increases. In the beginning, technological inventions are nascent and considerable time and effort need to be invested in them before they can be transformed into commercially viable products and services (Jensen and Thursby, 2001). In addition, when inventions are new, their value is uncertain, leading them to be eschewed by potential adopters (Utterback, 1994). However, over time, the uncertainty about inventions is reduced, increasing information about their value, and hence the likelihood of their commercialization.

Ultimately the effect of invention age on the likelihood of commercialization turns negative. First, the returns from the commercialization of an invention that can be appropriated by a firm decline as the time remaining on a patent shrinks (Grabowski and Vernon, 1986). Second, the longer an invention has been around, the greater the possibility that substitutes for it will emerge (Agarwal and Gort, 2001). These substitutes reduce the returns that the firm can appropriate from commercializing the invention. These arguments lead to the third hypothesis:

Hypothesis 3: There is an inverted U-shaped relationship between the likelihood of commercialization of an invention and its age.

RESEARCH METHODOLOGY

Research site

We examine the effect of invention characteristics on the likelihood of their commercialization. Because the effects of invention characteristics on their commercialization are confounded with firm

[4] However, inventions can be so novel that commercialization will be slow to occur, lessening the likelihood that firms will license them. The decision to license an invention depends on the identification of a purpose for the invention by the licensee. Thus, firms will not license inventions if the need for products or services based on them is not there or if the real implication of the invention is not properly understood. Because our sample consists of inventions that have been licensed, the likelihood of commercialization increases with the pioneering nature of the invention.

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capabilities at technological invention for inventions generated within firms, we examine externally generated inventions that are then commercialized by firms. Universities provide the best source of inventions that are generated outside of, but commercialized by, firms (Henderson, Jaffe, and Trajtenberg, 1998). Therefore, we focus on the commercialization of university-generated inventions. Our specific source of externally generated inventions is the Massachusetts Institute of Technology (MIT).

Description of sample

Our unit of analysis is any effort made by a private firm to commercialize a patent assigned to MIT between 1980 and 1996 and licensed to a private firm. Thus, our sample consists of the population of all 966 licensing attempts by private-sector firms, assembled using data obtained from the records of the MIT Technology Licensing Office, the administrative unit responsible for management of intellectual property assigned to MIT.

In general, the inventions that are licensed from MIT, and are found in our sample, are very early-stage inventions. Consistent with the work of other scholars who have examined this topic (e.g., Jensen and Thursby, 2001), the inventions are typically at the proof of principle or proof of concept stage, and are rarely prototypes that are ready for manufacture or production. For example, one invention in the sample is a 'cross-flow filtration molding method' that is 'particularly useful for forming complicated shapes from dispersions of particles in a liquid medium.' Another invention is 'a method for forming metal, ceramic or polymer compositions' in which 'fine-grain metal, ceramic or metal–ceramic or metal–polymer compositions are formed by impinging at least two liquid streams of metal, ceramic and/or polymer, upon each other to form a turbulent mixture having small eddies.'

Because the inventions in the sample are very early-stage inventions that require additional development to reach the commercialization stage, this sample is appropriate for testing our hypotheses. To commercialize these inventions, firms must first engage in additional development that may or may not result in a commercial product. As a result, the effect of appropriability on the decision to develop technologies to commercialize them is salient in this setting.

Moreover, MIT patents provide a documented population of attempts by private-sector firms to commercialize inventions identified before commercialization efforts begin. As a result, we can avoid sampling on the dependent variable, a problem that plagues many studies of invention commercialization efforts.

Furthermore, our focus is on understanding the characteristics of inventions themselves, as opposed to the environment or the capabilities of the firms that try to commercialize them. By focusing on attempts to license patented MIT inventions, we can examine a set of inventions for which we can obtain comparable characteristics of the inventions themselves.

Analysis

We use event history analysis to examine the probability that an attempt by a firm to commercialize an MIT invention leads to a first sale (Sorensen and Stuart, 2000). A spell begins when an MIT patent is licensed by a particular firm and continues until a first sale is reported. If a licensed patent does not lead to first sale, it is treated as censored. We use Cox regression models to analyze the data, as we make no claims about the functional form of time dependence (Cox, 1972; Kalbfleisch and Prentice, 1980). The analysis incorporates both time-varying and time-invariant covariates. We cluster the standard errors on the number of licensing attempts to correct for the non-independence of the observations. The model specification is given below where $h(t)$, the hazard function, is the limit of the probability that a first sale event will occur between time t and $t + \nabla t$:• AQ2

$$h(t) = \lim \frac{\Pr\{t \leq T \leq t + C | T \geq t\}}{\nabla t}$$
$$= \exp\{\sum_{j=1}^{n} \beta_{ij} X_{ij}\}$$

The hazard function quantifies the instantaneous risk that a patent licensed from MIT will lead to first sale for the firm licensing it. The vector $\bullet X_{ij}$ AQ3 represents the set of explanatory variables.

Selection correction

Commercialization of an MIT patent is not possible if no one licenses the patent. This observation

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is important because the probability that a patent is licensed may be influenced by the characteristics of the invention itself. For example, private firms may be more likely to license drug inventions than chemical, electrical, or mechanical inventions because of the historical success of universities at the commercialization of biotechnological inventions (Zucker and Darby, 1996). As a result, we need to provide a selection correction for those inventions that are licensed by firms. We create such a variable, using Lee's (1983) generalization of the Heckman selection model. This control variable makes the estimates of our predictor variables more precise by mitigating the effects of omitted variable bias (Greene, 2000). To create our selection correction variable, we use a Cox regression model that predicts the hazard of the license for all 1397 MIT inventions patented between 1980 and 1996 to generate our selection correction variable, λ:

$$\lambda_{it} = \frac{\phi\left[\Phi^{-1}(F_i(t))\right]}{1 - F_i(t)}$$

where $F_i(t)$ is the cumulative hazard function for project i at time t, ϕ is the standard normal density function, and Φ^{-1} the inverse of the standard normal distribution function (Lee, 1983).

An effective selection correction variable requires at least one variable that should influence the likelihood of licensing, but not commercialization of the invention. We include the source of funding for the invention (e.g., government funded, industry funded) as a covariate in the regression to predict licensing. Firms should be more likely to license industry-funded research because firms tend to obtain a right of first refusal to license inventions that are derived from research that they support. is then included as a variable in the Cox regressions to predict commercialization.

Measurement

Dependent variable

- *Commercialization of the invention*. We operationalize the dependent variable, invention commercialization, as the achievement of first sale of a product or service that makes use of the invention. We measure this variable as the receipt of the first dollar of revenue by the licensing firm. While our measure does not necessarily represent 'commercial success' because many firms that achieve first sale for their new products or services fail to generate much profit from those products or services, this measure is nevertheless something important to predict. The achievement of first sale is a necessary condition for commercial success because firms cannot generate profit from products and services that never reach first sale (King and Tucci, 2002; Mitchell and Singh, 1996; Zahra and Nielsen, 2002).

Independent variables

- *Invention patent scope*. Following Lerner (1995), we measure this variable as the number of international patent classes that a patent has on its front page.
- *Pioneering nature of the invention*. Following Ahuja and Lampert (2001), who use the lack of prior art to measure the pioneering nature of inventions created by firms, we measure it as the number of prior patents referenced by a patent.
- *Age of the invention*. This is measured as time elapsed in years since the patent was granted.

Control variables

- *Technical fields*. We control for the technical field in which the licensed invention is found—chemical, drug, electrical, mechanical (•other is the base case)—because the rate of invention commercialization differs across technical fields. The existence of technological opportunities, the resource requirements and time needed to commercialize inventions, the tendency of inventors to disclose their inventions, and other factors all vary across technical fields (Cohen and Levinthal, 1989). By controlling for the technical field, we can partial out this type of variation from the data.
- *Year*. We control for the time period when the patent was filed because of a variety of changes to university technology licensing during the 1980–96 period.
- *Number of licensees*. This variable controls for the number of licensees to each patent. The ability to commercialize inventions could spill over

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from one licensee to another. Moreover, a variety of different approaches to commercialization efforts could enhance the pace of commercialization. Therefore, accurate estimation of the effects of our independent variables on commercialization requires controlling for the number of entities seeking to commercialize each patent at a given point in time.

- *Exclusivity of invention*. Because we posit that the appropriability of an invention affects the likelihood of commercialization, it is important for us to control for the effect of the licensing agreement. If the sourced invention is also available to other firms, or is part of the public domain, incentives to commercialize can be undermined (Narin, Hamilton, and Olivastro, 1997). Based on MIT records, we classify each licensed patent as to whether it was licensed exclusively in a field of use. This variable is a dummy variable and is coded 1 when the license is exclusive and 0 when it is not. Readers should note that there can be multiple licensees to an exclusively licensed patent because exclusivity can include exclusivity in a field of use. In that case, the multiple licensees are exploiting the inventions in different fields of use.
- *Firm experience*. As mentioned earlier, one of the factors that explain differences in performance of invention commercialization is firm capability. We control for firm effects by including a variable that measures the prior experience of the licensing firms at commercializing MIT inventions. Based on MIT's records, we include a variable that measures the number of MIT patents licensed by the firm prior to the focal patent. This variable is skewed and we use a logarithmic transformation to normalize it.
- *Start-up firm*. New firms are more likely than existing firms to suffer from liabilities of newness, absence of capabilities, and lack of legitimacy, which make them less likely to commercialize inventions. Therefore, we control for start-up firms with a dummy variable of 1 if the records of the MIT Technology Licensing Office indicate that the licensee was a firm that did not exist prior to the year of the license.

RESULTS

The descriptive statistics are reported in Table 1 along with the correlation matrix. The highest correlation between any two independent variables is $r = 0.45$ between the log of firm experience and year. This level of correlation indicates that there

Table 1. Descriptive statistics and correlation matrix ($N = 3581$)

	Mean	S.D.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Scope of invention (1)	1.38	0.69	1.00											
Pioneering nature of invention (2)	7.55	9.72	−0.05	1.00										
Industry-funded invention (3)	0.17	0.37	0.04	0.02	1.00									
Drug (4)	0.29	0.45	0.14	−0.30	−0.07	1.00								
Chemical (5)	0.30	0.46	0.00	−0.05	−0.02	−0.41	1.00							
Electrical (6)	0.25	0.43	−0.02	0.04	0.04	−0.37	−0.38	1.00						
Mechanical (7)	0.03	0.18	−0.06	0.01	0.14	−0.12	−0.12	−0.11	1.00					
Number of licensees (8)	2.05	1.78	0.09	−0.01	−0.09	0.01	0.06	0.02	−0.08	1.00				
Age of invention (9)	6.63	4.21	0.00	−0.14	−0.14	0.07	0.02	−0.06	−0.01	0.20	1.00			
Year (10)	•1992	3.59	0.04	0.23	0.13	−0.20	0.02	0.14	−0.02	0.20	0.26	1.00		
Firm experience (11)	1.90	1.27	−0.09	−0.08	−0.05	0.15	0.02	−0.13	−0.01	0.04	0.45	0.22	1.00	
Start-up (12)	0.32	0.47	−0.02	0.02	−0.05	−0.06	0.01	0.00	−0.02	−0.11	0.08	−0.02	−0.00	1.00
Exclusive (13)	0.80	0.40	−0.09	0.11	−0.00	0.01	−0.01	−0.10	0.02	−0.06	−0.19	0.08	0.01	0.02

All correlation coefficients above 0.05 are significant at $p < 0.05$.

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is little likelihood of multicollinearity influencing the validity and generalizability of our results.

Table 2 reports the results of the Cox proportional hazard regression analysis of the characteristics of inventions on the likelihood of first sale. In sum, all three hypotheses were supported. In Table 2, the likelihood of first sale is the dependent variable as described above. The first model reports the baseline where technical field (chemical, drug, electrical, mechanical), year, and other controls were included. The overall model is significant ($\chi^2 = 58.80$, $p < 0.0001$). In Model 2, the scope variable is added. Models 3 and 4 introduce the independent effects of pioneering nature and age, respectively. Model 5 is the full model, which includes all variables.

In Hypothesis 1, we proposed that inventions with broader patent scope were more likely to reach first sale than inventions with narrower patent scope. Model 2 presents evidence with respect to this hypothesis. The overall model is significant ($\chi^2 = 74.08$, $p < 0.0001$). The coefficient for the scope variable is positive and significant ($\beta = 0.2914$, $p < 0.0001$).

Hypothesis 2 proposed that the pioneering nature of the invention would positively influence the likelihood of first sale. This hypothesis is supported. Model 4 is significant ($\chi^2 = 74.49$, $p <$ 0.0001). The effect of pioneering nature (which is

Table 2. Cox regression to predict the hazard of first sale

	Model 1	Model 2	Model 3	Model 4	Model 5
Scope of invention	#	0.2914**** (0.0798)	#	#	0.2969**** (0.0790)
Pioneering nature	#	#	−0.0261* (0.0112)	#	−0.0270* (0.0117)
Age of invention	#	#	#	0.1355* (0.0617)	0.1328* (0.0612)
Age × Age	#	#	#	−0.0083* (0.0037)	−0.0084* (0.0037)
λ	−0.1584 (0.1421)	−0.2005 (0.1413)	0.0530 (0.1643)	−0.1666 (0.1419)	0.0002 (0.1645)
Drug	0.2744 (0.2764)	0.1612 (0.2724)	−0.1588 (0.3451)	0.2683 (0.2761)	−0.2800 (0.3382)
Chemical	0.5312^{t} (0.2747)	0.4061 (0.2765)	0.4145 (0.2780)	0.5657* (0.2753)	0.3228 (0.2786)
Electrical	0.1543 (0.3190)	0.1515 (0.3206)	0.1315 (0.3084)	0.1866 (0.3201)	0.0582 (0.3132)
Mechanical	−0.2800 (0.6570)	−0.3456 (0.6735)	−0.3103 (0.6512)	−0.1948 (0.6605)	−0.3017 (0.6739)
Exclusivity	0.4019^{t} (0.2114)	0.4631* (0.2148)	0.3955^{t} (0.2113)	0.3796^{t} (0.2117)	0.4287* (0.2151)
Number of licensees	0.1333**** (0.0347)	0.1307**** (0.0342)	0.1234**** (0.0345)	0.1271**** (0.0355)	0.1161*** (0.0347)
Firm experience	0.0256**** (0.0047)	0.0284**** (0.0045)	0.0258**** (0.0047)	0.0258**** (0.0049)	0.0291**** (0.0046)
Start-up firm	0.0636 (0.1502)	0.0707 (0.1495)	0.0762 (0.1502)	0.0809 (0.1546)	0.1076 (0.1538)
Year	0.0038 (0.0251)	−0.0015 (0.0252)	0.0091 (0.0250)	0.0042 (0.0256)	0.0047 (0.0258)
Number of observations	3581	3581	3581	3581	3581
Number of licensing attempts	966	966	966	966	966
Number of events	197	197	197	197	197
Log-likelihood	−1201.24	−1197.14	−1198.80	−1198.95	−1192.23
χ^2 model	58.80****	74.08****	74.49****	67.82****	99.31****

Significant at: **** $p < 0.0001$ level; *** $p < 0.001$ level; ** $p < 0.01$ level; * $p < 0.05$ level; ^{t} $p < 0.10$ level.
#, variable not included in the regression.
Robust standard errors in parentheses, clustering on licensing attempts.

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coded inversely) in Model 3 in Table 2 is significant and negative ($\beta = -0.0261$, $p < 0.05$).

In Hypothesis 3 we predicted that age of innovations would have an inverted U-shaped relationship with likelihood of first sale. Overall, Model 4 is significant ($\chi^2 = 67.82$, $p < 0.0001$). The coefficients of the single term and the squared term are significant and in the hypothesized directions ($\beta_{age} = 0.155281$, $p < 0.05$; $\beta_{agesquared} = -0.0083$, $p < 0.05$). The point of inflection at which the association between likelihood of first sale and age of innovation turns negative is 7.9 years and is within the range of the data.

The full model with all the explanatory variables and controls is presented as Model 5. The hypotheses continue to be supported; the coefficients are significant and in the hypothesized direction, while the overall model is also significant ($\chi^2 = 99.31$, $p < 0.0001$). The relative strengths of each of the independent variables in the full model can be examined by keeping each variable at its mean level, while examining the increase in the focal variable. Thus, an increase of one international patent class (our measure of scope) increases the hazard of first sale by 34.5 percent, while each prior citation on a patent (our measure of the lack of pioneering nature) leads to a reduction in the hazard of first sale by 2.7 percent. Similarly, an increase of one year in the age of invention from its average increases the hazard of first sale by 14.2 percent until the patent reaches 7.9 years of age, at which time each one-year increase in the age of the patent decreases the hazard of first sale by 1 percent.

Readers should note that the selection correction for the hazard of licensing is insignificant in the main regression analyses and does not influence the magnitude of the effects of scope, age, or pioneering nature on the likelihood of invention commercialization. Because the lambda for licensing is insignificant in our main regressions, we examined the effect of scope, age, and pioneering nature without correcting for the hazard of licensing in unreported regressions. This alternative analysis allows us to relax assumptions about the form of the relationship between the error terms in the selection and second-stage equations. We find qualitatively the same results for our predictor variables under this alternative specification. Thus, we can also say that, conditional on an invention being licensed, the effects of scope, age, and pioneering nature on the likelihood of commercialization are as we had hypothesized.

DISCUSSION

This article examined the effect of three characteristics of inventions that affect the degree to which firms can appropriate the returns from their commercialization on the likelihood that those inventions achieve first sale. Using a unique dataset of all 966 attempts by private sector firms to commercialize inventions licensed from MIT between 1980 and 1996, we showed that scope, pioneering nature, and age of inventions influence the likelihood of their commercialization.

Implications

The results of this study have several implications for research on technology strategy. First, our effort provides empirical evidence that the characteristics of technological inventions, which theory suggests should increase the appropriability of returns from the introduction of new products and services (e.g., Arrow, 1962; Nelson, 1959), do affect the likelihood that firms commercialize inventions.

Second, our effort reminds researchers of the importance of considering the effect of the nature of technological inventions themselves, rather than just firm capabilities, on the commercialization of inventions. While research in strategic management offers empirical support for the argument that commercialization capabilities influence performance at technology commercialization, this research often loses sight of the fact that inventions themselves are unique and influence performance at technology commercialization through the incentives that they provide to firms. It is important to tease apart the effects of firm capabilities and the effects of the characteristics of inventions in order to gain an accurate understanding of invention commercialization.

Because we explore efforts by private sector firms to commercialize patented inventions from a single university, we examine data in which the effects of the invention attributes on commercialization efforts were independent of the university's effort to develop the inventions. Thus, we isolate the effect of invention characteristics on the

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post-invention commercialization efforts of private sector firms, and show that invention attributes that affect the appropriability of the returns to commercialized inventions influence those commercialization efforts.

Third, our study provides a useful methodological tool for researchers interested in examining the effect of firm characteristics on the commercialization of inventions. Accurate testing of many theories of firm performance (for technology-intensive firms) requires estimation of the effect of the attributes of inventions (such as the ones we use in this research) on their commercialization. By measuring the effects of different dimensions of inventions on their likelihood of commercialization, our study provides useful information about accurately controlling for the characteristics of inventions that future researchers can use to test theories of firm performance more precisely. For instance, future research examining differences in the commercialization capabilities of firms on their performance at invention commercialization need to control for the dimensions of inventions that we have found to affect commercialization—scope, pioneering nature, and age of invention—to obtain accurate estimates of the effect of capabilities on performance, given the possible correlation between firm capabilities and invention characteristics.

Fourth, our results provide insight into strategic efforts by firms to source inventions from outside organizational boundaries. Previous research has shown that external sourcing is important to many firms, which obtain access to new technologies to enhance their performance (Chesbrough and Teece, 1996; Cohen and Levinthal, 1990; Tripsas, 1997). However, the literature offers little guidance about what externally sourced inventions are more likely to be commercialized than others. Our results show that, all other things being equal, externally sourced inventions that have broad scope, are pioneering, and are of average age are more likely to be commercialized than other externally sourced inventions. While managers would need to balance these attributes against other factors, such as cost and risk, in making decisions about which inventions to source externally, these results offer insight consistent with other research (Jensen and Thursby, 2001) about which externally sourced inventions firms should select.

Limitations

To overcome the confounding relationship between firm capabilities and invention characteristics present with inventions that are developed within firms, we examined the commercialization of externally generated inventions. This approach limits our ability to generalize our findings to internally created inventions. However, we believe that this trade-off is worthwhile because the commercialization of externally generated inventions is, in and of itself, a phenomenon of significant importance to firms (Chesbrough and Teece, 1996; Cohen and Levinthal, 1990; Tripsas, 1997).

The generalizability of our results is also limited by the representativeness of MIT inventions. On average, university inventions are more important and more general than private sector inventions (Henderson *et al*., 1998). Moreover, MIT's inventions may have more commercial potential than inventions from other academic institutions because of the research prowess of the institution and its closeness to industry. Future research that examines a broader set of externally sourced inventions is necessary to show the generalizability of our findings to other sources of invention.

While our analysis supports our hypotheses, other variables may also influence the commercialization of MIT-licensed inventions. We control for firm effects by including the past experience of the firm in licensing from MIT, but this is a crude proxy. If correlations exist between the invention characteristics we examine and unobserved attributes of licensees, our coefficients will be overstated. Future research that controls for more firm characteristics can improve the precision of our estimates of the effect of invention characteristics on their commercialization.

Our study predicts the likelihood of invention commercialization, not 'successful' commercialization. We focused on the likelihood of commercialization because researchers disagree about how to define 'success' at commercialization, but recognize that the achievement of first sale is a necessary condition for all measures of 'success' (King and Tucci, 2002; Zahra and Nielsen, 2002).

The factors that this study showed to predict the likelihood of commercialization may not predict many things that researchers define as 'success' at commercialization. For instance, some researchers (Nerkar and Roberts, 2004) have considered 'successful' commercialization to be the

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achievement of a certain level of sales for a number of years. Other researchers have considered 'successful' commercialization to be a high number of new product introductions (Katila, 2002). Future research that examines the effect of the attributes of inventions on the achievement of these and other measures of 'success' would be necessary before researchers could say that the attributes of inventions that we examined explain anything more than the likelihood of invention commercialization. It is possible that additional research would show that that the attributes of the inventions that we measured do not predict these different measures of 'successful' commercialization.

Despite these limitations, this paper shows that the likelihood of invention commercialization is positively associated with two characteristics of licensed technological inventions—scope and pioneering nature—and has an inverted U-shaped relationship with the age of the invention. These findings have important implications for firms that source technological inventions externally.

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