Technological Opportunities and New Firm Creation

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Research on the creation of new high-technology companies has typically focused either on industry-level factors such as market structure and technology regime or on individual-level factors such as the work experience of entrepreneurs. This study complements these approaches by examining the effect of technological opportunities on firm formation. In particular, the study shows that the probability that an invention will be commercialized through firm formation is influenced by its importance, radicalness, and patent scope.
(*Entrepreneurship; Patents; Technology Opportunities*)

The creation of new firms is an important mechanism through which entrepreneurs use technology to bring new products, processes, and ways of organizing into existence (Schumpeter 1934). Moreover, recent research has shown that the rate at which new firms are created is increasing in the U.S. economy (Gartner and Shane 1995), and that the pace of technological change influences the rate of firm formation (Shane 1996). However, inventors do not always start firms to exploit technological opportunities. Sometimes they sell these opportunities (Audretsch 1995); other times they simply abandon them prior to exploitation (Roberts 1991). The fact that opportunity discovery does not correlate perfectly with firm creation raises the question of when new firms are created to commercialize new technological opportunities.

Previous research has provided two categories of explanations for the creation of new technology firms. The first is that firm formation depends on industry-level factors, such as market structure (Audretsch 1995) or technology regime (Winter 1984). Industry-level arguments hold that when industries are young, unconcentrated, composed of small firms, have limited requirements for complementary assets, have access to capital, and are not R&D intensive, people tend to form new firms to exploit opportunities (Audretsch 1995). The second explanation is that firm formation depends on individual-level factors, such as the psychology of entrepreneurs (Roberts 1991) or their career experience (Carroll and Mosakowski 1987). Individual-level arguments hold that when the individuals who discover opportunities are more experienced in firm creation (Carroll and Mosakowski 1987), more creative (Schumpeter 1934), more imaginative (Shackle 1979), more risk tolerant (Khilstrom and Laffont 1979), higher in need for achievement (Roberts 1991) or more tolerant of ambiguity (Begley and Boyd 1987), they tend to form new firms to exploit opportunities.

Unfortunately, empirical tests to predict the creation of new firms on the basis of the characteristics of individuals (see Low and MacMillan 1988, Busenitz and Barney 1997) or industry (see Geroski 1995, Cohen and Levin 1989) have provided limited explanatory power. One reason for these weak empirical results is that industry and individual-based explanations fail to consider the nature of the opportunity discovered. Technological opportunities differ from each other on several dimensions, which influence the decision to found a new firm. Using a unique dataset of 1,397 inventions patented by the Massachusetts Institute of Technology over the 1980–1996 period,

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I examine the effect of three dimensions of technological opportunities—importance, radicalness, and patent scope—on the probability that they will be commercialized through firm formation.

This paper makes three contributions to our understanding of high-technology entrepreneurship. First, it provides an empirical test of the effect of technological opportunity on the decision to establish a new firm. Such a test complements existing explanations of new firm formation that examine only industry or individual-level factors. Second, the study disentangles the behaviour of established firms entering new markets from the behaviour of independent entrepreneurs. Although previous research has shown that new entrants are more likely to adopt certain technologies than are incumbent firms, this research has confounded established firms entering new markets with independent entrepreneurs. This study shows that independent entrepreneurs make similar exploitation decisions to those of new entrants in general. Third, this study controls for individual-level factors in the examination of firm formation. Most studies of firm formation in high-technology settings assume away learning curves and individual-level variation in preferences for firm creation, and treat all potential entrants as equally willing and able to exploit an opportunity by founding a company (Audretsch 1995, Caves 1998). However, extensive research shows that entrepreneurship involves a significant component of learning-by-doing (Carroll and Mosakowski 1987). This finding means that whoever obtains decision rights over a new technology can influence the mode of commercialization. This study improves upon prior examination of the firm-formation decision in technology settings by controlling for the attributes of the individuals making the commercialization decision.

I have divided the paper into three sections. In the next section, I explain why dimensions of technology opportunity should influence the decision to found a firm. In the third section, I describe the dataset and the methods used for analysis. In the final section, I summarize the findings and discuss their implications for future research and the practice of entrepreneurship.

Theoretical Development

The linkage between technological change and firm formation is one of the oldest relationships in the study of business organization. Schumpeter (1934) argued that the creation of new technology firms that displace incumbent firms through a process of creative destruction is a major source of innovation in a capitalist system. In particular, Schumpeter argued that the process by which independent entrepreneurs use exogenously created inventions to produce new goods, services, raw materials, and organizing methods is central to understanding business organization, the process of technical change, and economic growth.

Subsequent research in the Schumpeterian tradition has expanded the complexity of this framework by incorporating the possibility that entrepreneurial opportunities will be sold in markets (Casson 1982) or abandoned prior to exploitation (Roberts 1991). Consideration of multiple phases in the invention-to-firm creation process has led researchers to propose three categories of factors that influence the decision to exploit an invention through firm creation: the nature of the individual making the decision (Roberts 1991), the nature of the industry in which the opportunity would be exploited (Audretsch 1995), and the nature of the opportunity itself (Henderson 1993). In the decades since Schumpeter's seminal work, economists of technical change have tested the effects of numerous industry characteristics on firm formation (Audretsch 1995). Similarly, applied entrepreneurship researchers have tested the effects of a variety of individual attributes on firm formation (Roberts 1991). To date, however, researchers have not directly examined the effect of the attributes of new technologies themselves on firm formation.

Nevertheless, researchers working in the related area of technological innovation and industry entry (e.g., Christiansen and Bower 1996, Lerner 1994, Audretsch 1995) have proposed several attributes of technological opportunities that could influence the probability that new firms will be created to exploit them. This paper explores three of these attributes: importance, radicalness, and patent scope.[1]

[1] Data limitations preclude the measurement of other constructs. However, this limitation should not severely handicap the

Importance measures the magnitude of the economic value of an invention. Radicalness measures the degree to which an invention, however large or small in economic value, differs from previous inventions in the field. Patent scope measures the breadth of intellectual property protection for the invention, however large or small its economic value, and however similar or different the invention is to previous inventions in the field.

Both prior research and field interviews conducted with MIT inventors indicate that each of these attributes captures a different dimension of technological opportunity, that entrepreneurs see these dimensions as conceptually distinct, and that these dimensions increase the probability of firm formation. In the subsections below, I argue why these dimensions of opportunity should influence the decision to create a new firm.

Importance. The importance of an invention should increase the likelihood that a new firm will be founded to commercialize it because more important inventions have higher economic value (Harhoff et al. 1999)[2] and, therefore, provide a larger potential payoff to firm formation. In explaining the decision of a person to start a firm, Knight (1921, p. 273) argued that "the laborer asks what he thinks the entrepreneur will be able to pay, and in any case, will not accept less than he can get from some other entrepreneur, or by turning entrepreneur himself." For a person to "turn entrepreneur," he or she must expect an entrepreneurial profit which exceeds (a) the opportunity cost of not engaging in other activities (Amit et al. 1995), (b) a premium for the illiquidity that results from the investment of financial resources in a form that cannot be easily turned into cash (Venkataraman 1997), and (c) a premium for bearing uncertainty (Khilstrom and Laffont 1979).

Technological change is an uncertain process, in which developments are sometimes small and other times large. As a result, the potential economic value created by technological advances is highly varied (Trajtenberg 1990). Empirical evidence of the skewness of the distribution of patent value (Pakes 1986) indicates that most patents have no commercial value and a few have a large value (Trajtenberg et al. 1997). Consequently, "a great majority of patents are never exploited commercially, and only a very few are associated with major technological improvements" (Cohen and Levin 1989, p. 1063).

Given the skewness in their commercial value, most inventions do not provide sufficient potential to justify the investment of time and money in the uncertain process of creating a new firm. Field interviews with MIT inventors confirmed the effect of this process on inventors' decision making. When individuals make what they believe to be important technological discoveries, they anticipate greater economic value than when they make minor discoveries. Moreover, inventors point out that the importance of technological discoveries increases their willingness to incur the opportunity cost of not undertaking other activities, making illiquid investments in new firms, and bearing the technical, market, competitive, and financial uncertainty of establishing a new company. Consequently, both the prior theoretical literature and fine-grained case information from inventors suggests that the more important the inventors' technical discoveries, the greater their impetus to create new firms. This argument leads to the first hypothesis:

HYPOTHESIS 1. *The more important the invention, the higher the probability that it will be commercialized through the establishment of a new firm.*

Radicalness. One of the central concepts in the literature on technological change is that refining and improving an existing technology (an incremental improvement) and introducing a new approach to technical practice (a radical improvement) are fundamentally different things (Reinganum 1983). In particular, an incremental improvement reinforces the activities of established firms, while a radical improvement may undermine those activities (Tushman and Anderson 1986).

Researchers have argued that independent entrepreneurs, rather than managers in established

investigation described here because the paper does not posit a fully specified model of the relationship between technological opportunity and firm formation.

[2] Some inventions may be more important than others because they have great social value, even if they have little economic value. This study does not consider the social dimension of importance.

firms, will be the ones most likely to introduce radical technological developments. Three separate arguments have been put forth for why this should be the case. First, radical technologies destroy the capabilities of existing firms because they draw on new technical skills. Since organizational capabilities are difficult and costly to create (Nelson and Winter 1982, Hannan and Freeman 1984), established firms are organized to exploit established technologies. Firms find it difficult to change their activities to exploit technologies based on different technical skills. Therefore, established firms often choose not to pursue radical opportunities, leaving them to independent entrepreneurs. Second, established firms have less incentive to invest in the development of technologies that undermine the value of the assets that they already possess. The desire not to cannibalize existing assets leads established firms to underinvest in the development of new technologies (Arrow 1962). Independent entrepreneurs, with no existing assets to protect, do not face this resistance to invest, and are more likely to be the ones to pursue these opportunities. Third, firms develop routines for filtering information based on what is likely to be valuable for what they are doing currently (Henderson 1993). These routines limit the search process to those technologies which are conceptually close to the technologies with which firms are currently working (Podolny and Stuart 1995). Knowledge transfer from outside is impeded when new information is not the logical extension of existing knowledge possessed by the organization. Since radical inventions are often based on things that are not the logical extension of the firm's internal information, they are difficult for established firms to understand and evaluate (Rosenbloom and Christiansen 1994). Consequently, established firms often filter out information about radical technologies in situations in which independent entrepreneurs do not.

Field interviews with fifty MIT inventors support the arguments of the previous theoretical literature. These inventors explained that the technical skills upon which an invention draws influence their decisions to start companies. In particular, these inventors identified the problem of market failure in finding established companies interested in their technological developments when those developments draw on technologies unfamiliar to established companies. Moreover, these inventors also pointed out the relative ease of obtaining venture capital funding for technologies that did not fit with the activities of established companies, particularly those that had the potential for generating new industries. Consequently, both the prior theoretical literature and fine-grained case information from inventors suggests that the more radical the inventors' technical discoveries, the greater their impetus to create new firms. This argument leads to the second hypothesis:

HYPOTHESIS 2. *The more radical the invention, the higher the probability that it will be commercialized through the establishment of a new firm.*

Patent Scope. Technological opportunities with broader intellectual property protection are more likely to be commercialized through firm creation. When an entrepreneur decides to start a new firm in response to the invention of a new technology, he or she typically does not yet possess complementary assets, like a distribution system, which might provide a competitive advantage in the industry in which the technology would be exploited (Teece 1986). The more effectively an opportunity can be protected against appropriation by competitors, the more likely the entrepreneur will be to obtain necessary complementary assets before the competitive advantage of its new technology has dissipated.

Broad patents enhance the probability that the entrepreneur can protect the technology against appropriation. Patents provide a legal right to prevent others from imitating a particular technological development in areas delineated by the patent claims. The scope of the patent is important because "the broader the scope, the larger number of competing products and processes that will infringe the patent" (Merges and Nelson 1990, p. 839). When a patent is narrow in scope, the holder of the patent will have less incentive to develop the technology through the creation of a new firm because it will have a smaller space of technology that is protected against imitation by other firms (Merges and Nelson 1990).

Although established firms might also be more likely to commercialize broad patents, they are disproportionately important to independent entrepreneurs who lack complementary assets. "For small, start-up ventures, patents may be a relatively effective means of appropriating R&D returns, in part because some other means, such as investment in complementary sales and service efforts may not be feasible. The patents held by a small, technologically oriented firm may be its most marketable asset" (Levin et al. 1987, p. 797).

Potential entrepreneurs and their investors appear to respond to the influence of patent scope in the firm-formation decision process. Field interviews with fifty MIT inventors revealed that many of them ask patent attorneys for a judgement as to the scope of patent protection before they decide to start new firms to exploit their inventions. Moreover, they report that their investors are concerned with the breadth of the protection of the technology against appropriability and prefer broader patents in the decision of whether or not to fund a new venture. Lerner (1994) also provides large-sample statistical evidence for this investor effect. He found that patent scope has a substantive and significant impact on the valuation of venture capital financed biotechnology start-ups. Consequently, both the prior theoretical literature and fine-grained case information from inventors suggest that the broader the scope of patent protection, the greater the impetus to create new firms to exploit inventions. This argument leads to the third hypothesis:

HYPOTHESIS 3. *The broader the scope of the patent, the higher the probability that the invention will be commercialized through the establishment of a new firm.*

Methodology

Sample

This study examines the population of 1,397 patents assigned to the Massachusetts Institute of Technology (MIT) between 1980 and 1996. This population includes all inventions made by faculty, staff, or students of the university that made material use of MIT property during the course of their development.

I focus on patented inventions rather than other entrepreneurial opportunities in this study for several reasons. First, by looking at patents, I can examine the decision to exploit entrepreneurial opportunities in a setting in which I have information both about who discovered the opportunity and the discovery itself. Second, the population of patented inventions is recorded, mitigating selection biases that plague much of the survey and case study work on the commercialization of new technologies, particularly in the context of firm formation. Third, patents have been studied in many contexts other than firm creation, providing comparability of the results to findings about other aspects of technological change.

I examine MIT's inventions from the 1980–1996 period for several reasons: First, universities are not in the business of manufacturing products or providing services (other than education). They do not refrain from patenting to protect new knowledge through trade secrets, refrain from licensing for competitive purposes, collect patents, or cross-license (Henderson et al. 1998). Therefore, one can examine the process of firm creation in response to technical discoveries by universities absent the biases that would occur from the examination of patents belonging to companies. Second, university research is an important source of new knowledge (Winter 1984) that is particularly relevant to economic growth (Caballero and Jaffe 1993, Romer 1990). Therefore, the study of firm creation to exploit university inventions is important in its own right, even if results cannot be generalized to other settings. Third, the post-1980 period follows a change in federal law granting universities the property rights to federally funded inventions. Since federally funded inventions account for roughly 70 percent of all university inventions, this change provided a strong incentive to universities to commercialize their inventions (Henderson et al. 1998). Therefore, the post-1980 period is an important one in which to understand university firm-formation activity.[3]

Analysis

I use event history analysis to examine the probability that each patent results in the formation of a

[3] The selection of MIT over other universities was a matter of convenience. I had access to data on MIT, but not other universities.

new firm. When a patent is issued, a spell begins.[4] The spell continues until a firm is formed. If a patent does not result in firm formation, it is treated as censored. Because each patent is observed until a firm is formed or until the observation period ends, the 1,397 patents generate 9,002 case-year observations. I use Cox regression to analyze the data because I make no claims about the functional form of time dependence. The analysis incorporates both time-varying and time-invariant covariates, which are specified below.

Dependent Variable: Firm Formation

I used the MIT Technology Licensing Office records of its licensees to construct the dependent variable. The MIT records indicate the legal status of the licensee, and therefore the ability to identify its year of incorporation. The dependent variable was coded 1 in the year that the patent was first licensed if the patent was licensed to an (unincorporated) individual or was licensed to a firm that was incorporated after the patent application was submitted. If these conditions were not met in a given year, the patent was coded as 0 in that year.[5]

This coding scheme allowed two types of licensees to be coded as new firms. The first type was an (unincorporated) individual who licensed the patent. The second type was a new firm incorporated to commercialize the MIT invention. Under this coding arrangement, two types of patents are treated as censored: patents granted to MIT, but never licensed, and patents licensed to an already incorporated company (e.g., Sony). Twenty-six percent of the patents were licensed to "new firms" during the period of investigation.

Predictor Variables

Radicalness. Following Rosenkopf and Nerkar (1999), I measure the radicalness of the patent as a time-invariant count of the number of three-digit patent classes in which *previous* patents cited by the given patent are found, but the patent itself is not classified. Citations influence the legal boundaries of the property rights to an invention (Jaffe et al. 1993). Patents are divided into approximately 100,000 nine-digit patent classes, which aggregate to approximately 600 three-digit classes, and which represent distinct technical areas (Jaffe et al. 1997). The assignment of a patent to a particular patent class represents the U.S. Patent and Trademark Office's (USPTO's) assessment that the patent belongs in a particular technical field. Patent examiners also determine what previous inventions must be cited in a patent by searching prior patents. Because patents belong to technical classes and because they cite previous patents, citations to patents in particular technical fields represent the USPTO's assessment that a particular invention builds upon (cites) knowledge in that technical field. When a patent cites previous patents in classes other than the ones it is in, that pattern suggests that the invention builds upon different technical paradigms from the one in which it is applied.

Importance. Following Henderson et al. (1998), I measure the importance of a patent as a time-invariant measure of the total number of citations that the given patent received from *subsequent* patents from patent issue until 1997. The use of a time-invariant measure of citations provides both advantages and disadvantages in the examination of the economic value of patents. A time-invariant measure of citations captures the idea that inventions have a distribution of underlying economic value at the time of invention. It is this underlying economic value to which people respond in making the decision whether or not to found a firm. A time-varying measure of citations would fail to capture this underlying economic value because it would consider all patents as having the same importance (zero) at the time of invention.

However, a time-invariant measure of citations does not treat all patents equally. A patient issued in 1996 has had only one year to be cited, whereas a patent granted in 1980 has had seventeen years to be cited. Although controlling for the technical field and the year of patent filing (or issue) incorporates the effect of time and technology into the measure of

[4] Since MIT has no records of firm formation for patents that were never issued, starting the spells with the filing date would create selection bias.

[5] Patents licensed to nonprofit organizations were treated as non-firm formation patents.

importance, these controls do not allow the researcher to directly measure the relative importance of one patent as compared to another. Therefore, I also examine an alternative specification of importance: the total number of citations that the given patent received from *subsequent* patents from patent issue until 1997, divided by the number of citations received by an average university patent of that age and in that technology field.

Research confirms the construct validity of the importance measures. Patent citations are significantly correlated with the economic value of inventions. Harhoff et al. (1999) found that the higher the estimated private value of an invention, the more the patent was cited by later patents. Hall et al. (1998) found that companies with highly cited patents have higher stock market values, all other things being equal.

Researchers familiar with the journal review process might question the use of citations on the grounds that inventors might cite friends to help them or enemies to describe their work as inadequate or trivial. However, this problem is unlikely to occur with patent citations. Jaffe et al. (1993) explain that gratuitous citations in patent applications are costly to inventors. Patent citations determine the scope of the inventor's monopoly and unnecessary citations limit what the inventor can claim as his or her monopoly right. Moreover, even if the inventor were to include these citations, the patent examiner's job requires the correct citation of previous patents. Hence, the examiner (unlike the editor of an academic journal) has a sworn duty to remove gratuitous citations from the patent before it issues.

Scope. Following Lerner (1994), I measure patent scope as a time-invariant count of the number of international patent classes into which the USPTO assigns a patent. Lerner (1994) explained that because international patent classes are nested, the more classes to which a patent is assigned, the broader is its intellectual property protection. Lerner (1994) provided construct validity for this measure by showing that venture-capital-backed-biotechnology firms with broader patents, as measured by a count of four-digit international patent classes, received higher valuations.[6]

Control Variables

Firm-Founding Experience. I measure firm-founding experience as a time-invariant estimate of the log of the average number of prior MIT firm-founding inventions across the set of inventors on the patent. I control for founding experience because several researchers have demonstrated that the probability of starting a firm increases with entrepreneurial experience (e.g., Evans and Leighton 1989, Carroll and Mosakowski 1987). Prior experience provides knowledge about resources that help to start new firms, entrepreneurial skills, and reputations that help to influence the reallocation of resources to the new venture (Shane and Khurana 1999). This knowledge influences the propensity to found firms because it increases the expectation of the value that would be gained from firm formation.

Patenting Experience. To control for patenting propensity in the examination of the effect of prior firm-founding experience, I also include a time-invariant measure of the log of the average number of prior MIT inventions across the set of inventors on the patent.

Age of the Technology Class. I measure the age of the technology class as the number of years since the three-digit patent class was established by the U.S. Patent and Trademark Office. Research has shown that people are more likely to start new firms to exploit a new technology when the technical field is young (Utterback and Abernathy 1975) because the markets for new technologies are often too small to interest established firms, because established firms possess learning-curve advantages in mature technologies (Nelson 1995), and because the maturation of technology makes capital-intensity, the reduction of production costs, and scale economies important (Pavitt and Wald 1971).

[6] I construct the radicalness measure on the basis of three-digit U.S. patent classes and the patent scope measure on the basis of international patent classes to make the measures comparable to the measures developed by previous authors (e.g., Rosenkopf and Nerkar 1999, Lerner 1994).

R&D Intensity. I measured R&D intensity in an industry as a time-varying estimate of research and development expenditures as a percentage of the value-added of industry shipments in the three-digit SIC code, using the research and development expenditures obtained from various years of Science and Engineering Indicators.[7] Previous researchers have argued that entrepreneurs will be less likely to establish new companies to exploit inventions in R&D intensive industries (Audretsch 1995) because small firms face a scale disadvantage in research and development (Mansfield 1981, Kamien and Schwartz 1975).

Manufacturing Value-Added. I measured the importance of complementary assets in manufacturing by calculating a time-varying estimate of the value-added by manufacture in the industry year, using data from various years of the Census of Manufacturers. Teece (1987, p. 191) explained that "the successful commercialization of an innovation requires that the know-how in question be utilized in conjunction with other capabilities or assets ... such as marketing, competitive manufacturing, and after-sales support." Where complementary assets are important in an industry, entrepreneurs will be less likely to establish firms to commercialize technology.

Importance of Sales or Service. Another measure of the importance of complementary assets in an industry is the importance of superior sales or service as a competitive advantage. I measured the importance of sales or service in the industry as a time-invariant industry average score for the Levin et al. (1987)[8] survey item: "In this line of business superior sales or service efforts are very effective measures of capturing and protecting the competitive advantages of new or improved production processes."

[7] The USPTO does not assign patents to SIC codes. However, the USPTO has developed a concordance which allows the assignment of patents to three-digit SIC codes by reference to the patent's six-digit technology classification. To assign the correct industry variables to the patents, I used the USPTO concordance to identify the SIC code.

[8] Levin et al. (1987) generated line-of-business measures of innovation and appropriability from a survey of R&D managers.

Incumbent Innovation. Some industries have lower rates of new firm formation than others because established firms are the major innovators of new products and processes in those industries (Acs and Audretsch 1990). I measured the rate of incumbent innovation as a time-invariant industry average score for the Levin et al. (1987) survey item: "Firms within this business have been a very important source of contribution to technological progress in this line of business since 1970."

Market Segmentation. New firms often successfully enter markets with new technologies by targeting the niche customers, because large firms allocate resources for innovation to satisfy the demands of their major customers (Christiansen and Bower 1996). Therefore, the ability of new firms to enter industries depends, in part, upon the degree to which markets in those industries are segmented. Using data from the Levin et al. (1987) survey of research and development managers, I measured market segmentation as a time-invariant industry average score for the Levin et al. (1987) survey item: "designing markets for specific market segments" is a very important technological activity for the line of business.

Capital Availability. An important source of capital to start new technology companies is venture capital. To measure the availability of venture capital across industries, I included a time-varying estimate of the amount of venture capital funding as a percentage of industry shipments in the three-digit SIC code, using data obtained from Securities Data Corporation's venture capital database and the Commerce Department's Survey of Manufacturers. I used Securities Data Corporation's concordance between its proprietary industry scheme and SIC codes to map the data by SIC code. I include this control because entrepreneurship is less likely to take the form of new firms when capital market imperfections make it difficult for independent entrepreneurs to secure financing (Cohen and Levin 1989).

Concentration. I measured industry concentration as a time-varying estimate of the market share of the four largest companies in the industry, using data from the Census of Manufacturers: Concentration Ratios. Since values were available only for 2-digit and 4-digit SIC codes, values for three-digit SIC codes were estimated by taking an average of the relevant 4-digit SIC codes. A straight-line interpolation was used to determine the values for noncensus years. High levels of concentration in an industry discourage people from creating new firms because concentration enhances the power of incumbents to attack new entrants and to collude (Geroski 1995).

Firm Size. I measured the size of the firms in the industry as a time-varying estimate of the average number of employees per firm, using data from the Census of Manufacturers. High levels of minimum efficient scale discourage entrepreneurs from creating firms because they raise the cost of entry (Audretsch 1995). Because new firms that enter a market at below minimum efficient scale must operate at a cost disadvantage vis-a-vis established firms, the greater the amount of production that is necessary before a firm reaches minimum efficient scale, the less likely entrepreneurs should be to enter that market (Weiss 1976).

Technical Fields. The patents examined in this study had their primary U.S. patent classification in 188 different three-digit patent classes. Since attempts to control for such a large number of classes creates incidental parameter bias, I control for technical field using the modified version of Scherer's (1965) classification scheme common in many patent studies (Cohen and Levin 1989). I include dummy variables for mechanical inventions, electrical inventions, chemical inventions, and drugs (the other is the omitted field). I include these variables because citation patterns vary across technologies, necessitating the controls to measure importance correctly (Henderson et al. 1998). Moreover, firm-formation rates vary substantially by type of technology.

Time. I control for the year of patent application. Since citation patents vary over time, this control is necessary to measure importance accurately (Henderson et al. 1998). Moreover, changes in federal law and MIT policy have changed the incentives for firm formation over time.

Results

The descriptive statistics are reported in Table 1. Table 2 provides the distribution of firm-formation patents by year of patent issue. This table demonstrates a clear trend towards an increase in firm-formation patents over time.

Table 3 provides the correlation matrix. It shows that the highest correlation between any two of the independent variables is $r = 0.56$ between previous patents and previous start-ups. This level of correlation indicates that problems of multicollinearity are unlikely to be manifest in the data. Moreover, the table also indicates a low correlation between the radicalness, importance, and patent scope measures. This low level of correlation provides support for the argument that these three measures capture independent dimensions of technological opportunity.

Table 4 reports the effects of technology attributes on the likelihood of firm formation. I provide six models. Model 1 predicts the likelihood of firm formation on the basis of technical field and year of patent filing. Overall, this model is significant (Chi-square $= 112.04, p < 0.0001$). As Model 1 shows, the technical field and year of issue have strong effects on the probability of firm formation. Relative to other technologies, chemical technologies ($\text{Exp}(B) = 0.59, p < 0.001$), electrical technologies ($\text{Exp}(B) = 0.40, p < 0.0001$), and mechanical technologies ($\text{Exp}(B) = 0.56, p < 0.05$) are less likely to lead to firm formation, and drug technologies ($\text{Exp}(B) = 1.38, p < 0.05$) are more likely to lead to firm formation. (However, the effects for mechanical technologies and drug technologies are not robust to the inclusion of other variables in the regression equations). Moreover, the year of patent filing ($\text{Exp}(B) = 1.08, p < 0.0001$) shows a significant and robust pattern of increasing probability of firm formation over time.

Model 2 adds the industry-level control variables. Overall, this model is significant (Chi-square $= 135.40, p < 0.0001$). As Model 2 shows, two dimensions of industry have a significant effect on the probability of firm formation. First, the greater the importance of designing for specific market segments, the greater the probability of new firm formation ($\text{Exp}(B) = 1.60, p < 0.01$). This result is consistent with

Table 1 Descriptive Statistics ($N = 9002$)

Variable	Mean	S.D.	Min	Max
Technology Opportunity				
Radicalness	3.56	3.83	0.00	41.00
Importance	6.82	9.82	0.00	117.00
Patent Scope	1.30	0.62	1.00	6.00
Industry				
Venture Capital (percent of market value)	0.02	0.02	0.00	0.04
Age of Technology Class (years)	22.37	22.87	0.00	96.00
Manufacturing (percent of value added)	51.00	13.00	12.00	66.00
Importance of Sales or Service Efforts	4.98	0.48	3.94	6.25
R&D Intensity (percent of sales)	5.38	3.22	0.30	14.90
Four Firm Concentration Ratio	36.47	9.77	9.00	72.00
Average Firm Size	90.84	29.61	34.16	198.44
Importance of Market Segmentation	5.25	0.50	4.00	6.50
Incumbent Innovation	6.17	0.50	4.00	7.00
Inventor Attributes				
Log Previous Patents	0.66	0.37	0.00	1.60
Log Founding Experience	0.09	0.22	0.00	1.34
Technical Field				
Chemical Invention	0.35	0.48	0.00	1.00
Electrical Invention	0.36	0.48	0.00	1.00
Mechanical Invention	0.05	0.22	0.00	1.00
Drug Invention	0.14	0.35	0.00	1.00
Other Invention	0.09	0.29	0.00	1.00
Time				
Year Filed	1983.67	5.02	1974.00	1995.00

prior research which argues that new entrants displace incumbent firms by entering market segments with radical technologies and then expanding to the mainstream once they have established a foothold (Christiansen and Bower 1996). (However, the effect for market segmentation is not robust to the inclusion of other variables in the regression equations).[9] Second, the greater the average firm size in the industry, the greater the probability of firm formation ($\text{Exp}(B) = 0.99, p < 0.05$). This result is counter to expectations from prior research, which suggests that new firm formation should be more likely in industries in which the average size of firms is smaller.

Model 3 adds the individual-level control variables. Overall, this model is significant (Chi-square $= 299.70, p < 0.0001$). As Model 3 shows, the log of the number of previous new firm patents belonging to the inventors at the time of founding increases the probability of new firm formation ($\text{Exp}(B) = 6.19, p < 0.0001$), even after controlling for the log of the total number of patents belonging to the inventors at the time of founding. These results suggest that career experience of the inventors influences the decision to exploit a technological opportunity through the formation of a firm. Consequently, accurate measurement of the effect of technological

[9] The lack of robust effects for several industry variables should be interpreted with caution. First, to create industry variables, the USPTO patent concordance was applied. Since the concordance is inexact, the lack of effects could result from inexact classification of patents to industry. Second, the construction of the industry variables required some averaging of data across fields and years which might have mitigated the industry effects. Third, the industry variables are measured at a relatively high level of aggregation. Fourth, the technology field dummy variables may be capturing industry effects.

Table 2 The Distribution of Start-up Patents By Year of Patent Issue

Year	Number of Start-up Patents
1980	13
1981	14
1982	13
1983	14
1984	15
1985	9
1986	12
1987	13
1988	17
1989	31
1990	29
1991	26
1992	35
1993	32
1994	28
1995	25
1996	38

attributes on firm formation requires controlling for inventor attributes.

Model 4 adds the three predictor variables to the regression equation. Overall, this model is significant (Chi-square = 330.16, $p < 0.0001$). Specifically, the results show strong support for the three hypotheses. More important inventions ($\text{Exp}(B) = 1.02, p < 0.0001$) are more likely to be commercialized through the creation of new firms (Hypothesis 1). More radical patents ($\text{Exp}(B) = 1.03, p < 0.01$) are more likely to be commercialized through the creation of new firms (Hypothesis 2). Patents with broader scope ($\text{Exp}(B) = 1.18, p < 0.05$) are more likely to be commercialized through the creation of new firms (Hypothesis 3).

Model 5 tests the alternative specification of the importance measure. It examines the relative importance of the patent—the deviation from the average for university patents in the same technological field and of the same age.[10] Overall, this model is significant (Chi-square = 251.91, $p < 0.0001$). Moreover, the effect of the relative importance measure is substantively the same as that of the original importance measure ($\text{Exp}(B) = 1.03, p < 0.0001$), indicating that the original importance measure is robust. Finally, the use of the relative importance measure does not change the significance or magnitude of the coefficients for radicalness ($\text{Exp}(B) = 1.04, p < 0.01$) or patent scope ($\text{Exp}(B) = 1.26, p < 0.05$) in any substantive way.

Model 6 predicts firm formation on the basis of technological opportunity alone, without controlling for the time-varying covariates that measure industry characteristics. Since this model predicts firm formation on the basis of time-invariant measures only, I examine a time-invariant Cox regression, with 1,397 spells—one for each of the patents. Overall, this model is significant (Chi-square = 436.17, $p < 0.0001$). Moreover, the results are substantively the same as the results for the time-varying Cox regressions that control for industry attributes. Patent importance ($\text{Exp}(B) = 1.02, p < 0.0001$), patent scope ($\text{Exp}(B) = 1.16, p < 0.05$), and radicalness ($\text{Exp}(B) = 1.03, p < 0.01$) all increase the likelihood of firm formation.

Some researchers might argue that the radicalness of an invention should have a curvilinear relationship with the probability of firm formation. Initially, the argument goes, the probability that an invention will be commercialized through firm formation increases as radicalness rises, but beyond a certain level, it decreases. In unreported regressions, I tested for this curvilinear relationship. However, the results supported the linear relationship reported here.

Researchers might also argue that people will be more likely to forms firms to exploit radical patents only if the inventions have significant economic value. In unreported regressions, I also tested the interaction between radicalness and importance. However, the results did not support the interaction hypothesis.

Finally, researchers might argue that the correct measure of time to predict firm formation is the year of patent issue rather than the year of patent filing because patents are granted to new companies only after issue. I tested this alternative specification of time. I found substantively the same results as I found for the date of patent filing, indicating that the time measure is robust.

[10] The number of case-years for this regression is 8,420 because the relative importance measure cannot be calculated for all of the patents.

Table 3 Bivariate Correlations For The Independent Variables ($N = 9002$)

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1. Radicalness	1.00																		
2. Importance	0.04	1.00																	
3. Patent Scope	0.03	0.05	1.00																
4. Year Filed	0.32	−0.23	−0.00	1.00															
5. Previous Patents	0.06	0.05	−0.04	0.17	1.00														
6. Founding Experience	0.02	−0.05	−0.05	0.19	0.56	1.00													
7. Manufacturing	0.04	−0.01	0.02	0.09	0.03	0.07	1.00												
8. Sales/Service	−0.04	−0.03	−0.09	0.01	−0.02	−0.05	−0.25	1.00											
9. Class Age	−0.08	−0.10	−0.06	−0.03	−0.14	−0.12	−0.05	0.14	1.00										
10. Venture Capital	0.13	0.02	0.01	0.02	0.04	−0.01	0.00	−0.08	0.04	1.00									
11. R&D Intensity	0.06	0.01	0.15	0.03	0.05	0.13	0.20	−0.45	−0.21	0.16	1.00								
12. Concentration	−0.02	−0.00	−0.06	0.03	−0.10	−0.07	−0.05	0.11	−0.03	0.02	0.26	1.00							
13. Firm Size	−0.15	−0.02	−0.00	−0.11	0.10	0.03	−0.16	0.28	−0.03	0.02	0.05	0.28	1.00						
14. Segmentation	0.15	0.14	−0.01	0.08	0.05	0.07	0.10	0.19	−0.07	0.29	0.24	−0.00	0.02	1.00					
15. Incumbent Innov.	−0.05	−0.01	0.12	0.03	0.20	0.15	0.01	−0.17	−0.25	−0.09	0.47	0.07	0.32	−0.00	1.00				
16. Chemical	0.11	0.06	0.13	0.01	0.10	−0.08	−0.03	−0.02	−0.03	0.00	−0.28	−0.28	−0.03	0.02	−0.18	1.00			
17. Electrical	−0.01	0.03	−0.14	0.10	−0.13	−0.07	−0.07	0.22	0.11	0.09	0.13	0.45	0.09	0.11	−0.02	−0.56	1.00		
18. Mechanical	−0.02	−0.05	−0.03	−0.10	−0.14	−0.06	0.02	−0.01	0.17	−0.06	−0.20	−0.10	−0.27	−0.15	−0.24	−0.18	−0.18	1.00	
19. Drugs	−0.15	−0.09	0.13	−0.08	0.16	0.21	0.02	−0.25	−0.18	−0.12	0.37	−0.17	0.13	−0.14	0.53	−0.30	−0.30	−0.10	1.00

Discussion

This article examined the effect of technological opportunities on the probability that they would be commercialized through the creation of new firms. Using a unique dataset which examines the population of inventions assigned to the Massachusetts Institute of Technology during the 1980–1996 period, I have shown that three dimensions of technological opportunity influence the probability of firm formation. Controlling for who invented the technology, the characteristics of the industry, the time period when the technological development took place, and the nature of the technology, more important inventions, more radical inventions, and inventions with a broader scope of patent protection were more likely to be commercialized through the creation of new firms.

Limitations

This study is not without limitations. First, it uses proxy variables to measure several of the constructs. Although previous research and field interviews supported the construct validity of the measures used, future research could corroborate the findings of this study by demonstrating similar results through the use of alternative measures.

Second, the results of this study may not be generalizable outside the context of university inventions. While I have no a priori reason to expect that the results here would fail to apply to other settings, the empirical examination looked only at one setting. Consequently, future research is necessary to demonstrate the generalizability of the results.

Third, sampling solely from the Massachusetts Institute of Technology during the 1980–1996 period might generate results that cannot be generalized to other universities at other points in time. Location advantages, ties to the venture capital community, and intellectual leadership in many technical fields might enhance the rate at which MIT inventions lead to firm formation.[11] Therefore, the results of this study

[11] However, some rough estimates suggest that the Massachusetts Institute of Technology is representative of the population of universities in terms of start-up activity. The USPTO calculates that between 1980 and 1996, U.S. colleges and universities were issued 17,647 patents, of which MIT received 1,397, or 7.92 percent. The Association of University Technology Managers (AUTM 1996) estimates that between 1980 and 1996, 1,444 new companies were founded to exploit patented inventions to which U.S. universities and colleges were assignees. During that same period, MIT reported to AUTM that 105 new companies were founded to exploit patented inventions to which MIT was the assignee. Thus, MIT

Table 4 Cox Regressions Predicting New Firm Formation: 1980–1996

Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	Hazard Ratio	Hazard Ratio	Hazard Ratio	Hazard Ratio	Hazard Ratio	Hazard Ratio
Technical Field						
Chemical	0.59***	0.59**	0.70*	0.66*	0.65*	0.67*
Electrical	0.40****	0.40****	0.46****	0.50****	0.55*	0.55***
Mechanical	0.56*	0.57†	0.71	0.73	0.51	0.91
Drugs	1.38*	1.47†	1.00	1.15	1.15	1.09
Time						
Year Filed	1.08****	1.08****	1.06****	1.06****	1.05**	1.07****
Industry						
Age of Technology Class (years)	#	0.99	1.00	1.00	1.00	#
Average Firm Size	#	0.99*	0.99*	0.99†	0.99*	#
4-Firm Concentration Ratio (%)	#	1.01	1.01†	1.01†	1.01	#
Venture Capital (% of market)	#	0.96	0.97	0.96	0.95	#
R&D Intensity (% of sales)	#	1.02	1.01	1.00	1.01	#
Manufacturing Share of Value-added	#	1.03	0.65	0.69	0.64	#
Importance of Sales or Service	#	1.08	0.97	0.95	1.05	#
Incumbent Innovation	#	1.09	1.03	1.02	0.94	#
Market Segmentation	#	1.60***	1.37*	1.26	1.17	#
Inventor Attributes						
Log Number of Previous Patents	#	#	1.24	1.03	1.25	1.00
Log Founding Experience	#	#	6.19****	9.19****	7.76****	8.02****
Technology Opportunity						
Radicalness	#	#	#	1.03**	1.04**	1.03**
Importance	#	#	#	1.02****	1.03****	1.02****
Patent Scope	#	#	#	1.18*	1.26*	1.16*
N	9002	9002	9002	9002	8420	1397
Log Likelihood	−2497.33	−2479.14	−2396.99	−2381.47	−1718.44	4782.92
Chi-square	112.04****	135.40****	299.70****	330.16****	251.91****	436.17****

Key: **** = $p < 0.0001$; *** = $p < 0.001$; ** = $p < 0.01$; * = $p < 0.05$; † = $p < 0.10$; # = not included; two-tailed tests. 9,002 case-years and 364 events.

should not be generalized to other universities until future research shows their validity in other university settings.

Fourth, this study cannot determine if the inventions were developed to allow inventors to found firms or the founding of firms resulted from the development of the inventions. Therefore, the findings presented here cannot resolve the debate over whether the existence of technological opportunities leads to firm creation or the need to create firms leads to the creation of technological opportunities.

represents 7.29 percent of the new companies founded to exploit inventions to which U.S. universities and colleges were assignees, in line with its proportion of university inventions.

Implications for Research

The major implication of this study is straightforward. The probability that an invention will be commercialized through the creation of a new firm varies with the nature of the technological opportunity discovered. This finding enhances the literature on firm formation by adding the nature of the technological discovery to previous findings about the effect of industry and individual attributes.

The specific findings also have implications for related and future research. This study provides empirical evidence that technologically more important inventions are more likely to be commercialized through the creation of new firms. This finding is important because previous research has shown that patent importance influences several aspects of technology commercialization and economic growth, but has not considered the possibility that patent importance would also influence the decision to establish a new company. In particular, previous research has explored the relationship between patent importance and knowledge spillovers (Jaffe et al. 1993) and between knowledge spillovers and economic growth (Romer 1990). The fact that more important technological discoveries are more likely to be exploited through the creation of new firms suggests that students of technological change should examine the relationship between firm creation, knowledge spillovers, and economic growth. While this relationship is precisely the core of Schumpeter's (1934) explanation for a capitalist system, the subsequent empirical and theoretical literature is resoundingly silent on this central question.

In addition, inventions are more likely to be commercialized through the creation of new organizations when the scope of patent rights is broader, enabling the inventor to protect the development against imitation from a broader range of competing technologies. This result demonstrates that inventors are influenced by the breadth of intellectual property protection in making the decision of whether or not to start a firm to commercialize their inventions. This finding is important because it extends research about the effect of patent scope (Lerner 1994) to a broader context than biotechnology and to broader questions about firm formation than just venture capital financing.

Finally, the finding that inventions are more likely to be commercialized through the creation of new firms when the inventions are technologically more radical extends the work of strategic management researchers (Tushman and Anderson 1986) and students of technological change (Henderson 1993). These researchers have argued that new entrants are more likely than incumbents to commercialize radical technologies. This study shows that the radicalness of technology also influences the decisions of independent entrepreneurs to create new companies. While previous research suggested the plausibility of this argument, this study provides the first empirical evidence to support it.

The results also provide support for the position of applied entrepreneurship researchers, who have argued that firm formation from technlogical change cannot be accurately explained without consideration of the individuals who possess decision rights over inventions (Roberts 1991). These researchers have argued that one of the reasons for poor results for theories of new firm entry has been the failure to incorporate individual-level heterogenity into theories of technological change and industry entry. The results of this study provide support for a recent strand of individual-level research on entrepreneurship. Career experience influences the propensity to use firm formation as a mechanism to commercialize a new technology (Shane and Khurana 1999, Carroll and Mosakowski 1987). These results suggest that future empirical research on technical change should incorporate the role of the entrepreneur.

Normative Implications

This study examined firm formation in the context of university technologies and provides some useful implications for the management of that process. First, universities earn revenues from the commercialization of technology and therefore adopt policies to enhance it. Many university policies regarding start-up organizations differ from those regarding established organizations. For example, some universities are willing to take equity positions in start-up organizations to commercialize university inventions; and licensing officers play an important role in brokering relationships between faculty entrepreneurs and the venture capital community (Shane and Cable 1998). Consequently, knowledge of which inventions are more likely to be commercialized through the creation of new organizations may prove useful in determining university policies toward firm formation.

Second, from a management science perspective, an understanding of which inventions are commercialized through the creation of new firms is also important to potential entrepreneurs. The creation of a new firm to commercialize a university invention is a costly exercise that requires significant investment of time and capital. Consequently, an understanding of which technology opportunities are most often commercialized through firm creation is useful to university researchers who have to make a decision about how to commercialize their inventions.

Conclusion

This paper showed that three attributes of technology—importance, radicalness, and patent scope—influence the probability that an invention will be exploited through the creation of a new firm. This finding generates several important implications for development of theory about, and the practice of, entrepreneurship. Hopefully, future researchers will consider the attributes of technological opportunities presented here to generate a robust explanation for technology entrepreneurship.

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