Technology Regimes and New Firm Formation

Scott Shane
R.H. Smith School of Business, University of Maryland, College Park, Maryland 20742
sshane@rhsmith.umd.edu

At least since Schumpeter (1934 and 1942), researchers have been interested in identifying the dimensions of technology regimes that facilitate new firm formation as a mode of technology exploitation. Using data on 1,397 patents assigned to the Massachusetts Institute of Technology during the 1980–1996 period, I show that four hypothesized dimensions of the technology regime—the age of the technical field, the tendency of the market toward segmentation, the effectiveness of patents, and the importance of complementary assets in marketing and distribution—influence the likelihood that new technology will be exploited through firm formation.
(*Entrepreneurship; Technology Regimes; Patents*)

Introduction

Under what conditions is new technology exploited through firm formation? For 40 years, researchers have looked to market structure to answer this question (Cohen and Levin 1989, Kamien and Schwartz 1982). For example, researchers have examined the effect of average firm size, capital availability, research and development intensity, and industry concentration on new firm formation. Unfortunately, the results of the effort to explain cross-industry variation in firm formation on the basis of market structure alone are, at best, inconclusive (Cohen and Levin 1989).

Evolutionary economists argue that the failure to explain this variation is the result of a lack of attention to the technological regime (Nelson and Winter 1982, Malerba and Orsenigo 1997), or knowledge system, under which innovation occurs (Winter 1984). Unlike industrial organization economists, who argue that variation in the mode of technology exploitation is a function of firm-level competitive dynamics, evolutionary economists argue that variation in technology life cycles (Utterback and Abernathy 1975, Gort and Klepper 1982) and appropriability conditions (Arrow 1962, Levin et al. 1987, Nelson and Winter 1982) account for at least some of the cross-industry variation in firm formation rates.

However, to date we have relatively little empirical evidence of how specific dimensions of the technology regime enhance or inhibit new firm formation. While evolutionary economists have generally agreed that some industries, but not others, face technological regimes in which new firm formation is relatively common (Acs and Audretsch 1990, Malerba and Orsenigo 1997), they have disagreed about the specific characteristics that facilitate new firm formation (see, for example, the differences between Winter 1984 and Malerba and Orsenigo 1997).

Moreover, efforts to gather evidence in support of the relationship between particular dimensions of technological regimes and rates of firm formation have been limited by three obstacles. First, researchers have found it difficult to observe new technologies that are simultaneously at risk of exploitation by independent entrepreneurs and established firms. However, if researchers examine technologies that already belong to one of these two entities, they cannot test the effect of technology regime characteristics on the propensity for inventions to be exploited through the formation of new companies. If an independent

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entrepreneur or established firm already possesses a new technology, any examination of the effects of the technology regime will be confounded with strategic decisions already made by the entrepreneurs or firm managers.

Second, researchers rarely observe firm formation but instead examine entry into industry. As a result, research on cross-industry variation on the effects of technology regime characteristics on firm formation must infer the effects from empirical investigation of industry entry. However, as Malerba and Orsenigo (1996) explain, firm formation and industry entry are conceptually different. A new entrant may be an established firm that has existed for a long time in another industry. Consequently, empirical findings on industry entry often represent the efforts of established firms to diversify their operations (Caves 1998). Although population ecology research generally overcomes this obstacle by exploring firm formation directly, ecological work examines firms in a single industry. Therefore, it cannot inform researchers about the effects of cross-industry variation in the characteristics of technology regimes on the rate of firm formation.

Third, researchers rarely observe gross firm formation but instead observe firm formation net of exit. Unfortunately, net entry fails to capture the response of actors to technological opportunities in industries with a high degree of entry and exit (Geroski 1995). Although net entry captures variation in the propensity of entrepreneurs to form new firms to exploit opportunities, it confounds this variation with the effect of failure rates. From the examination of net firm formation rates, one does not know if cross-industry variation exists because new firms are more likely to be founded or because newly founded firms are less likely to fail. Only the examination of gross firm formation allows researchers to determine how technology regime conditions influence the likelihood that new technology will be exploited through firm formation.

This study overcomes the three methodological problems outlined above to provide empirical evidence about the relationship between specific dimensions of the technology regime and new firm formation. By exploring data on the 1,397 patents assigned to the Massachusetts Institute of Technology from 1980–1996, the study shows that four dimensions of the technology regime—the age of the technical field, the importance of market segmentation, the effectiveness of patents, and the importance of complementary assets—influence the propensity of new firms to be formed to exploit technology.

The article proceeds as follows. In the next section, I review the literature on the technology regime and develop specific hypotheses for why technology life cycles and appropriability conditions influence the likelihood that an invention will be commercialized through firm formation. In the third section, I describe the dataset and the methods used for analysis. In the fourth section, I summarize the findings. In the final section, I discuss the implications of the results for research on and the practice of entrepreneurship.

Theory Development

In the Schumpeterian (Schumpeter 1934) framework, the invention of a new technology is an exogenous event that creates a disequilibrium in markets. By altering the equilibrium value of resources, a new technology makes it possible to recombine resources in a way that generates a surplus of revenues over costs. In the Schumpeterian context, entrepreneurs are actors who exploit opportunities to recombine resources that result from the invention of new technology.

Entrepreneurs can exploit the technological opportunities that result from exogenous inventions by creating new firms (Schumpeter 1942). In general, an entrepreneur's decision to establish a new firm to exploit a technology is influenced by the effectiveness of a new organization as a mechanism to generate and appropriate entrepreneurial profit (Arrow 1962, Venkataraman 1997). The technological regime in which the new firm's exploitation effort would operate affects the relative advantage or disadvantage of new firms at this activity. On average, potential entrepreneurs will respond to these cost-benefit tradeoffs by establishing new firms when conditions are more favorable to that mode of technology exploitation. Although many other factors, such the attributes of particular inventions, or the characteristics of the people making the commercialization decision, might also influence the choice of the mode of exploitation, the characteristics of technological regimes will have systematic effects on whether or not new firms are formed to exploit inventions.[1]

Technology Life Cycles

Industry life-cycle theories argue that technologies develop along trajectories, which begin with a preparadigmatic phase and end in a paradigmatic phase (Dosi 1982). Moreover, technology development and market competition vary across the stages of the life cycle (Utterback and Abernathy 1975). As a result, the favored mode of organization to exploit a technology shifts over time.

When an entrepreneur founds a new firm in response to the invention of a new technology, he or she does not possess the advantages of learning, scale economies, or complementary assets (or the disadvantages of an existing customer base) that established companies possess. The relative advantages and disadvantages of these assets depend on the age of the technology and the tendency of a market toward segmentation. Technology life-cycle theories hold that new firms are the favored mode of exploitation when technologies are young and when markets are segmented.

Age of the Technology

Technology life-cycle theories argue that industries develop along similar evolutionary paths. When technologies are initially developed, the markets for them are small and few firms compete to operate in them. Through a process of information diffusion, market growth accelerates over time, and new firms enter the industry. Eventually, the market becomes saturated, a shakeout ensues, and many firms exit the industry (Gort and Klepper 1982).

The age of the technical field influences the effectiveness of firm formation as a mode of technology exploitation. Four different arguments have been put forth to explain this life-cycle pattern. First, in the early stages of a new technology, markets are too small to justify investment by large, established firms. Instead, independent entrepreneurs with low opportunity cost tend to exploit new markets. Over time, as markets grow in size, large firms become attracted to them and enter.

Second, at the founding of a technical field, all firms are new to the field, providing no advantage to incumbency. However, as the technology matures, firms that entered first develop learning curve advantages (Nelson 1995). As a result, new firms are at an increasing knowledge disadvantage as a technical field ages.

Third, the maturation of technology changes the basis for competition. As technology matures, product innovation becomes less important, and the reduction of production costs and scale economies become more important (Pavitt and Wald 1971). Therefore, over time, competitive advantage shifts to those things at which established firms are advantaged at the expense of those at which new firms excel.

Fourth, complementary assets are important to competition in many industries. As technologies mature, these assets are brought under the control of established firms to reduce contracting problems. As the industry matures, the tendency of established firms to obtain control over complementary assets makes entry more difficult for new firms (Teece 1987). These arguments lead to the first hypothesis.

Hypothesis H1. *The older a technical field, the lower the likelihood that an invention will be exploited through firm formation.*

Market Segmentation

Technologies vary on the degree to which markets for them can be segmented. For example, Klevorick et al. (1995) found that managers responsible for technology development in paints, screw machinery products, cosmetics, and radio and television ascribed more importance to designing for market segments than did managers responsible for other types of technologies.

[1] Moreover, in the particular setting in which data were collected, the decision-making process also exhibits properties of a garbage can model (Cyert and March 1963). Potential entrepreneurs searching for technologies come together with inventions that have been created (Hsu and Bernstein 1997). In many cases, this process results in single bidders for a given technology and no one seeking to exploit some technologies. Nevertheless, the patterns generated by technology regimes are still observed in this setting.

The degree to which markets lend themselves to segmentation depends largely on customers' willingness to trade off different attributes (e.g., cost, functions, reliability, size). For example, automobile technology lends itself to market segmentation because some automobile customers will prefer lower-cost–lower-performance cars, whereas others will prefer higher-cost–higher-performance cars. In contrast, medical device technologies may not lend themselves as readily to market segmentation because customers will not trade off attributes such as cost and performance.

Life-cycle theories argue that new technologies tend to be exploited first by new firms in small market segments. The lack of performance reliability and high costs mean that new technology will tend to start in small segments where its unique performance advantages are critical (Utterback and Kim 1984). These technologies later spread to mainstream markets after their superiority has been demonstrated in the initial segment (Christiansen and Bower 1996).

When markets are segmented, new firms often enter to exploit inventions. Large, established firms allocate their resources to satisfy the demands of their major customers (Christiansen and Bower 1996). Given the small size of the segments in which the new technology is initially exploited, the application of the new technology to the initial segment does not provide sufficient revenue to justify investment by established companies. Because they focus on mainstream customers, established firms cede niche markets for the new technology to new firms with low opportunity cost. Thus, in segmented markets, new firms can obtain a foothold for a new technology before facing competition from established firms.

When markets are not segmented, however, new firms face immediate competition from established firms. In unsegmented markets, large established firms pursue new technologies immediately because these technologies affect the needs of their major customers (Christiansen and Bower 1996). The interest of major customers means that the new technology provides sufficient potential revenue to justify investment by established companies. As a result, established firms do not cede unsegmented markets to new firms, and new firms cannot obtain a foothold before facing competition from established firms. Consequently, new technologies are more difficult to exploit through the creation of new firms in markets that do not tend toward segmentation than in markets that do. This argument leads to the second hypothesis.

HYPOTHESIS H2. *The more a market tends toward segmentation, the higher the likelihood that an invention will be exploited through firm formation.*

Appropriability

The willingness to exploit an invention depends on the ability to appropriate its value (Arrow 1962). Appropriability is the property of knowledge and the environment in which it operates that allows an invention to be protected against imitation (Dosi 1988). The favored mode of organization to appropriate the returns to the exploitation of new technology depends on the effectiveness of patents and the magnitude of complementary assets in an industry.

Appropriability arguments hold that the propensity of entrepreneurs to exploit new technologies through firm formation is greater when patents are effective and complementary assets are unimportant to the generation of competitive advantage. When an entrepreneur founds a firm in response to the development of a new technology, the new firm typically does not yet possess complementary assets, like a distribution system or specialized manufacturing, which provide a competitive advantage (Teece 1987). The more effectively that entrepreneurs can protect a new technology against appropriation by competitors during the development of the new firm's value chain, the more likely that they will be to form new firms. The ability to protect a new technology against appropriation, in turn, depends on the effectiveness of intellectual property protection and the magnitude of the complementary assets that need to be developed.

Effectiveness of Patents

Mechanisms to prevent imitation include legal rights of protection. Patents are the strongest legal form of protection against imitation because they provide inventors with the right to exclude others from practicing duplicative inventions (Teece 1998). Therefore, legal rights of production depend largely on the effectiveness of patents.

Research has shown that patent effectiveness varies across technologies (Levin et al. 1987). In some fields, patents can be invented around at low cost whereas in others, they provide strong protection for their duration (Teece 1987). In fields in which patent protection is ineffective, new firms have difficulty reaping the benefits of new technology because their new knowledge dissipates quickly to competitors who are often better able to exploit it (Von Hippel 1982).

Effective patent protection increases the likelihood that a new technology will be exploited through the creation of a new firm. First, effective patent protection allows the developer of the new technology to develop the value chain before the knowledge of the new technology dissipates to competitors (Teece 1987). In particular, the possession of a strong patent position provides time to raise money from capital markets (Lerner 1994). Because new firms lack existing cash flow to finance investment, this time window is more important for the efforts of new firms to exploit new technologies than for similar efforts by established firms.

Second, effective patent protection provides the firm with the time to adapt the new technology to market needs. New technologies often turn out to have significant value but are initially commercialized for the wrong market segment or with the wrong design. Strong patent protection allows a firm to come to market with the wrong product but have the time to alter the technology to market needs before competitors can imitate it (Teece 1987). Because new firms lack the information about customer preferences that established firms have developed over time, this time window for adaptation is more important to new firms than to established firms.

Third, effective patent protection allows a new firm to compete on the basis of differentiation rather than on the basis of costs. When patent protection is ineffective, an imitator can copy a first mover's novel design. This ability to copy allows large, established firms to shift competition to manufacturing costs, at which they generally have an advantage over new firms. However, when patent protection is effective, the new firm can offset the imitator's manufacturing cost advantage by maintaining competition on the basis of its superior technology. Consequently, the new firm can avoid competition on the basis of factors at which it is disadvantaged. This argument leads to the third hypothesis.

Hypothesis H3. *The greater the effectiveness of patents in an industry, the higher the likelihood that an invention will be exploited through firm formation.*

Complementary Assets

In many cases, effective legal protection of a new technology is difficult to obtain, and other firms who have better manufacturing or distribution assets can imitate the invention. If the invention can be copied easily and the imitator can provide more or better attributes at a lower price, the imitator will capture the returns that result from the inventor's technology (Teece 1987).

When a technology itself is difficult to protect, the firm must develop alternative barriers to imitation to appropriate the value of the invention (Teece 1998). Teece (1987) has explained that these alternative barriers can be created if the invention is used along with complementary assets, such as specialized manufacturing, a distribution system, or after-sales support. These complementary assets cannot be easily imitated because they result from a process of learning-by-doing that involves the interaction of people from different parts of the organization (Teece 1992). By bundling the invention with these hard-to-imitate complementary assets, the inventor can protect the invention.

Complementary assets are difficult to access through market mechanisms because they are often specialized with the new technology. Specialization creates asset specificity, which makes it important to bring both assets both under the control of a single firm (Williamson 1985). The tendency of established firms to acquire control over complementary assets to mitigate bargaining problems makes it difficult for new firms to contract for these assets in the market place (Teece 1987). Consequently, new firms often must build complementary assets from scratch or incur the cost of establishing strategic alliances or partnerships to obtain them.

The greater the importance of complementary assets in marketing and distribution to competitive advantage in the industry, the lower the likelihood that a new technology will be exploited through firm formation. When complementary assets in marketing and distribution are important to competitive advantage in the industry, existing firms with these assets already in place will be advantaged relative to new firms, who must build these assets from scratch or contract with third parties to obtain them. People will be less willing to found new firms to exploit new technology when complementary assets in marketing and distribution are important to capturing the returns to new technology because they will expect to be less likely to capture the returns from the exploitation of that technology. This argument leads to the fourth hypothesis.

HYPOTHESIS H4. *The more important complementary assets in marketing and distribution are in an industry, the lower the likelihood that an invention will be exploited through firm formation.*

Methodology

Sample

This study explores the incidence of firm formation as the mode of exploitation for the population of 1,397 patents issued to the Massachusetts Institute of Technology between 1980 and 1996 for inventions by members of the MIT community that made material use of university resources.

I examine MIT inventions as my sample for several reasons. First, patented inventions provide a recorded population of inventions that are identified before the mode of exploitation of those inventions is determined. Examination of the mode of exploitation before the exploitation decision has been made reduces the risk of selection bias that will occur if one mode of exploitation is harder to identify than the other. This is typically the case with technology exploitation through firm formation. Because new firms both have higher failure rates than established firms and are less likely to be recorded in publicly available sources, technology exploitation efforts by new firms are more difficult to identify than technology exploitation efforts by established firms. Consequently, examination of the mode of exploitation after the exploitation decision has been made typically results in a selection bias in which efforts by new firms to exploit new technology are undercounted relative to similar efforts by established firms.

Second, to predict firm formation as a mode of invention exploitation, one must identify a population of inventions that are simultaneously at risk of exploitation by both new and established firms. University inventions provide a group of new technologies simultaneously at risk of exploitation through both modes because universities seek to license their technologies to both established firms and independent entrepreneurs. In contrast, inventions developed by established firms and independent entrepreneurs are not simultaneously at risk of exploitation through firm formation and by established firms. Inventions made by established firms are not at risk of exploitation through new firm formation until the established firms have decided not to pursue them (generating a biased sample). Similarly, inventions made by independent entrepreneurs are not at risk of exploitation by established firms until the entrepreneurs decide to license those inventions to other firms (again generating a biased sample). By exploring university inventions, I can examine the mode of technology exploitation absent the biases that would occur from the examination of patents belonging to established firms or independent entrepreneurs (Henderson et al. 1998).

Third, patented inventions are a relatively homogenous group of new technological opportunities because a patent must meet the patent office standard for usefulness, novelty, and value (Malerba and Orsenigo 1996). The universe of all technological opportunities is subject to much greater heterogeneity than the universe of patented inventions because unpatented inventions do not need to meet patent office standards. This heterogeneity increases the probability that unobserved factors influence the firm formation decision. By exploring a pool of patented inventions, I can minimize the variance in unobserved characteristics that are likely to influence the tendency to found firms, and therefore reduce the likelihood of biased estimation in the regression analysis.

Analysis

Ordinary least squares regression is inappropriate for count dependent variables that have large numbers of zero observations and remaining observations taking the form of small positive numbers. Therefore, I employ Poisson regression as the analytical technique for this study. Poisson regression is appropriate to examine the incidence of firm formation from patent data because this statistical technique is designed for maximum likelihood estimation of the number of occurrences of nonnegative counts of events. Moreover, tests of the goodness of fit chi-square indicate that, given the models examined, one can accept that the data are Poisson distributed.

Because I seek to incorporate information on annual changes in some of the covariates, I use pooled cross-sectional time series Poisson regression analysis to examine the number of new firms formed annually to exploit each MIT invention. I examine the data as a series of patent-years and predict the incidence rate of new firm formation per patent-year on the basis of several covariates, which are specified below.

Dependent Variable: Firm Formation

The MIT Technology Licensing Office maintains records of the university's inventions and its licensees, and I was able to use these records to code firm formation. Each patent was observed from its year of issue through 1996. In each year, a patent could be licensed or not. If the patent was licensed, the license could be issued to a nonprofit organization, a venture capital firm, an established firm (of varying size), or a new firm.

I defined firm formation as occurring in a given year if the invention was licensed to a for-profit firm that did not exist as a legal entity in the previous year. Only the initial start-up patents were defined as leading to firm formation. If a start-up returned to MIT to license a patent in a later year, that licensing effort was not defined as new firm formation because the firm already existed as a legal entity in a previous year. Because MIT's licensing agreements do not permit the licensing of future inventions, the assumption that the intellectual property licensed at the founding of the firm represents the set of "start-up" patents seems valid. The 1,397 patents led to 401 firm formation licensing efforts over the observation period.

Readers should note that the MIT data are not biased toward observance of firm formation. Licensing to established firms is actually a much more common occurrence than is licensing to a new firm. The 1,397 patents led to 631 established firm licensing efforts (excluding licenses to venture capital firms and nonprofit organizations) during the observation period. Therefore, this sample provides a relatively conservative setting in which to examine the rate of firm formation.

Yale Measures

No publicly available measures capture three of the dimensions of the technology regime explored in this study (the age of the technology class is the exception). To measure the other three dimensions, I use independent variables developed from the Yale study on industrial research and development, which assembled data on intersectoral differences in Schumpeterian patterns of innovation. Therefore, I summarize briefly the methodology used to collect data for that study.[2] Levin et al. (1987) asked 650 high-level R&D managers from 130 different lines of business to answer questions about technological change in the line of business in which they operated. The respondents were asked to serve as expert observers of their line of business rather than as representatives of their firms and were asked to report central tendencies in the form of a series of Likert scale items that ranged from one to seven. The researchers constructed line of business mean scores for each item on the basis of the average responses of the respondents from each line of business.

I use these line of business mean scores to measure several dimensions of the technology regimes, as described below. To map the Levin et al. (1987) measures to SIC codes, I used the SIC code concordance that they developed. When SIC codes overlapped with more than one industry in Levin et al. (l987), the measures were averaged across those industries.

Using the Yale measures to construct the independent variables has several important advantages for

[2] Further information is available in Levin et al. (1987).

this study. First, unlike many studies that sample entrepreneurs about their choices, the Yale study did not include any respondents from start-up ventures. The tendency of researchers to ask entrepreneurs about their environment is problematic. Because people respond to questions about their environment in ways that are consistent with the actions that they have taken, these self-reports result in ex-post rationalization. Consequently, correlations between the environmental measures and the dependent variables often are artifacts of the data collection process. By using a source of information about the environment that does not depend on entrepreneurs' self-reports, I can mitigate this problem.

Second, the authors of the Yale study took several steps to ensure reliability and validity. The interpretability, reliability, and validity of the measures were established through a pretest with managers from diverse businesses. Moreover, to mitigate sources of intraindustry heterogeneity in the responses to questions, the respondents were asked to identify major innovations in their industry. The respondents generally agreed on those innovations. Furthermore, the value and robustness of these measures has been shown in many subsequent studies (e.g., Cohen and Levinthal 1990, Levin et al. 1985, Klevorick et al. 1995).

Third, the sample of industries in Levin et al. (1987) was representative of sectors in which firms engage in research and development activity, making the sample appropriate for a study that looks at the formation of new firms to exploit university inventions. Moreover, the interindustry differences captured in these data were robust to aggregation to the 25 industries measured by the National Science Foundation, providing further evidence of their representativeness (Levin et al. 1987).

Nevertheless, the use of Yale Survey measures requires making an important assumption about the characteristics of a technology regime. Because the Yale Survey data were gathered at one point in time, this study must assume that the relative level of market segmentation, the degree of patent effectiveness, and the importance of complementary assets in marketing have remained constant across industries between 1980 and 1996. Some evidence supports making this assumption. Cohen and Levin (1989) explain that appropriability conditions are stable, enduring drivers of technical change. Cross-industry differences in such factors as patent strength do not vary significantly over time because they are a function of the underlying nature of technology in different lines of business. For example, biotechnology patents are fundamentally stronger than electrical device patents because the slightest changes in molecular structure can radically change the performance of a biological agent, whereas relatively major changes in the design of an electrical device can be accomplished without changing the functioning of the device. Despite arguments in favor of the time invariance of the three technology regime measures examined with the Yale measures, however, readers are cautioned that their time invariance is an assumption. No empirical evidence has examined the Yale measures' intertemporal stability.

Predictor Variables

Age of the Technical Field. I measure the age of the technical field as the natural log of the number of years since the USPTO established the three-digit patent class.

Market Segmentation. I measure the importance of market segmentation in an industry by using the Levin et al. (1987) item: "designing products for specific market segment" under the heading "to what extent have the following technological activities been engaged in consistently and repeatedly in this line of business?" This item is measured on a Likert scale that ranged from one to seven, with one equal to "of no importance in this line of business" and seven equal to "very important in this line of business."

Effectiveness of Patents. I measure the effectiveness of patents as a mechanism to appropriate the benefits of innovation using a four-item, evenly weighted scale derived from Levin et al. (1987). The first two items were responses to the following question: "In this line of business, how effective is each of the following means of capturing and protecting the competitive advantages of new or improved production processes?" The first item was "patents to prevent competitors from duplicating the process." The second item was "patents to secure royalty income." The third and fourth items were responses to the following question: "In this line of business, how effective is each of the following means of capturing and protecting the competitive advantages of new or improved products?" The third item was "patents to prevent competitors from duplicating the product." The fourth item was "patents to secure royalty income." All four items were measured along a seven-point Likert scale from one equals "not at all effective" to seven equals "very effective." Measured across the 129 lines of business for which the scores were available, this scale had a Cronbach's alpha of 0.78. The use of these items to measure patent effectiveness has been validated by Levin et al. (l987) and Cockburn and Griliches (1988).

Complementary Assets. I measured the importance of complementary assets in marketing and distribution using a two-item, evenly weighted scale derived from Levin et al. (l987). The first item was a response to the following question: "In this line of business, how effective is each of the following means of capturing and protecting the competitive advantages of new or improved production processes?" The item was "superior sales or service efforts." The second item was a response to the following question: "In this line of business, how effective is each of the following means of capturing and protecting the competitive advantages of new or improved products?" The item was "superior sales or service efforts." Both items were measured along a seven-point Likert scale from one equals "not at all effective" to seven equals "very effective." Measured across the 129 lines of business for which the scores were available, this scale had a Cronbach's alpha of 0.65. The use of these items to measure complementary assets has been validated by Levin et al. (1987).

Control Variables

Previous researchers have identified a variety of alternative dimensions of industry that influence the incidence of firm formation. I control for these dimensions to show that the hypothesized effects of the technology regime exist over and above factors identified by previous research.

Capital Availability. Prior research has shown that firm formation is less common when market imperfections make it difficult for entrepreneurs to obtain financing (Cohen and Levin 1989). I measure capital availability as the annual amount of venture capital funding in the industry as a percentage of industry asset size, using data obtained from Securities Data Corporation's venture capital database and various years of the Census of Manufacturers.

Firm Size. Prior research has shown that large average firm size discourages firm formation by raising entry costs (Audretsch 1995). In addition, high levels of firm size provide established firms with the market control necessary to appropriate the benefits of invention (Teece 1992). I measured the average size of firms in the industry as the annual average number of employees per firm, using data from various years of the Census of Manufacturers.

Concentration. Previous research has shown that high levels of industry concentration should discourage firm formation because concentration makes it easier for incumbents to collude and to attack new entrants (Geroski 1995). I measured industry concentration as the annual market share of the four biggest firms in the industry, using data from various years of the Census of Manufacturers.

Research and Development Expenditures. Galbraith (1956) and Scherer (1980) argue that large, established firms in more research and development intensive industries should undertake technology exploitation because large firms can achieve greater economies of scope in R&D. In addition, complementarities between R&D and other activities, such as distribution, provide an advantage to established firms in R&D intensive industries (Cohen and Levin 1989). Finally, because R&D is inherently uncertain, the large, diversified firm has an advantage in R&D intensive industries because it has more market opportunities in which to exploit new knowledge (Nelson 1959). I measured R&D intensity in an industry as research and development expenditures as a percentage of the added value of industry shipments annually, using data obtained from various years of Science and Engineering Indicators and the Census of Manufacturers.

University Share. I measured the share of total patents assigned to universities in the three-digit patent class to which the patent belonged for the year the patent was issued. I control for the university share of inventions because universities are more important to technical advance in some technical fields than in others, and the importance of university inventions is associated with the founding of new companies in the fields in which university technology is more important (Klevorick et al. l995).

Time. I control for the effect of the time of the invention through the use of four dummy variables for the period in which the patent was filed because changes in Federal law and MIT policy over time have changed the incentives for people to exploit university inventions (Henderson et al. 1998). The first dummy variable controls for the period 1980–1983, the second for the period 1984–1986, the third for the period 1987–1989, and the fourth for the period 1990–1996. The omitted period is for patents filed before 1980.

In 1980, Congress passed the Bayh-Dole Act, which gave universities the right to keep income from inventions that resulted from federally funded research, increasing the incentive for universities to license their inventions (Henderson et al. 1998). In 1984, Congress passed Public Law 98-620, which increased the range of inventions from which universities could profit, and the ease with which they could transfer property rights to others, further increasing the incentive for universities to license. In 1987, MIT agreed to take equity in partial lieu of royalties for companies in which a faculty member held equity, reducing the upfront cost to exploit MIT intellectual property. In 1990, MIT allowed inventors taking equity in a company to retain their share of MIT's cash royalties, making it more lucrative for inventors to have their inventions licensed.

Table 1 Descriptive Statistics

Variable	Mean	Std. Dev.	Min	Max
New firms formed to exploit the patent	0.04	0.20	0.00	4.00
Natural log of the age of the technology class	2.65	1.02	0.00	4.57
Market segmentation score	5.27	0.49	4.00	6.50
Patent effectiveness score	3.66	0.68	2.00	4.88
Complementary assets in marketing score	4.38	0.70	2.64	6.00
Venture capital as percent of market	1.67	2.44	0.00	42.19
Average firm size	90.09	29.47	34.16	198.44
4-Firm concentration ratio	36.20	9.70	9.00	72.00
R&D intensity	5.52	3.28	0.30	14.90
University share of patents	3.12	3.60	0.00	54.55
1980–1983	0.21	0.41	0.00	1.00
1984–1986	0.17	0.38	0.00	1.00
1987–1989	0.19	0.40	0.00	1.00
1990–1996	0.15	0.35	0.00	1.00

Results

The descriptive statistics and bivariate correlations for the independent variables are reported in Tables 1 and 2, respectively.

As Table 2 shows, the highest correlation between any two of the independent variables is $r = -0.51$ between R&D intensity and complementary assets. The moderately high correlations shown in the matrix demonstrate that the independent variables are related in ways that we do not yet understand completely. Although these correlations do not create multicollinearity problems that hamper the statistical results, they suggest that none of the factors that predict firm formation are completely independent.

Table 3 predicts the likelihood of firm formation. I provide three models. Model 1 predicts the likelihood of firm formation on the basis of the year of patent filing and the university share of patents issued. Overall this model is significant (chi-square = 181.86, $p < 0.0001$). As Model 1 shows, the time of patent filing has a strong effect on the incidence of firm formation. Patents filed between 1980 and 1983 had a times 1.89 greater incidence of firm formation than patents filed before 1980 ($p < 0.01$). For patents filed between 1984 and 1986, this incidence of firm formation was 2.11 times greater than patents filed before 1980 ($p < 0.0001$). Patents filed between 1987 and 1989, had a 3.74 times greater incidence of firm formation than did patents filed before 1980 ($p < 0.0001$), and patents filed between 1990 and 1996 had a 6.25 greater incidence of firm formation than did patents filed before 1980 ($p < 0.0001$). Thus, the results show a significant and robust pattern of increasing likelihood of firm formation over time. This result is consistent with prior research on entrepreneurship that demonstrates a similar time trend (Gartner and Shane 1995)

Table 2 The Correlation Matrix

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Ln (Class age)	1.00												
2. Segmentation	−0.15	1.00											
3. Patent Effect.	−0.16	−0.05	1.00										
4. Comp. Assets	0.09	0.22	−0.15	1.00									
5. Cap. Availability	0.01	0.27	−0.25	−0.02	1.00								
6. Firm Size	−0.04	−0.03	0.10	0.25	0.03	1.00							
7. Concentration	−0.03	−0.05	−0.41	0.07	0.02	0.30	1.00						
8. R&D Intensity	−0.19	0.18	0.21	−0.51	0.14	0.08	0.26	1.00					
9. University Share	−0.09	−0.09	0.38	−0.16	−0.11	0.09	0.30	0.27	1.00				
10. 1980–1983	0.00	−0.03	0.17	−0.02	−0.04	0.03	−0.11	0.01	0.02	1.00			
11. 1984–1986	0.02	−0.01	0.08	−0.03	0.00	−0.02	−0.08	−0.01	0.03	−0.24	1.00		
12. 1987–1989	−0.05	0.08	−0.05	0.02	0.02	−0.03	0.03	0.03	0.13	−0.26	−0.22	1.00	
13. 1990–1996	−0.02	0.02	−0.13	0.03	0.02	−0.09	0.07	−0.00	0.04	−0.22	−0.19	−0.20	1.00

and qualitative evidence about university technology licensing office activity (AUTM 1996).

In addition, the results show that increases in the university share of patents in the three-digit patent class in which the patent is found increase the incidence of firm formation (IRR = 1.04, $p < 0.0001$). This result is consistent with prior research on technology transfer out of universities, which shows that firm formation is more likely in those fields in which universities are more important to technical advance (Klevorick et al. 1995).

Model 2 adds the industry control variables. The inclusion of these variables generates a good fitting model (chi-square = 193.01, $p < 0.0001$). However, the results are counter to those expected from previous research. In contrast to the predicted effect, research

Table 3 Poisson Regressions Predicting the Incidence of New Firm Formation: 1980–1996

	Model 1		Model 2		Model 3	
Variables	IRR (S.E.)	z	IRR (S.E.)	z	IRR (S.E.)	z
Nonindustry Control Variables						
1980–1993	1.89 (0.39)	3.07***	1.78 (0.37)	2.76**	1.66 (0.35)	2.43*
1984–1986	2.11 (0.45)	3.51****	2.01 (0.43)	3.26***	1.95 (0.42)	3.12**
1987–1989	3.74 (0.71)	6.93****	3.70 (0.71)	6.85****	3.58 (0.69)	6.65****
1990–1996	6.25 (1.15)	9.95****	6.27 (1.16)	9.89****	6.32 (1.18)	9.89****
University Share	1.04 (0.01)	4.99****	1.04 (0.01)	3.81****	1.04 (0.01)	3.54****
Industry Control Variables						
Capital Availability	#		0.99 (0.02)	−0.36	1.00 (0.02)	0.13
Firm Size	#		1.00 (0.00)	−0.45	1.00 (0.00)	−1.30
4-Firm Concentration Ratio	#		0.98 (0.01)	−2.64**	1.00 (0.01)	0.25
R and D Intensity	#		1.04 (0.02)	2.41*	0.96 (0.02)	−1.76t
Technology Regime Variables						
Ln (Age of Technology Class)	#		#		0.71 (0.04)	−6.81****
Market Segmentation	#		#		1.31 (0.17)	2.03*
Effectiveness of Patents	#		#		1.43 (0.16)	3.33***
Complementary Assets	#		#		0.66 (0.09)	−2.92**
N	10759		10759		10759	
−2 LL	3279.38		3268.23		3205.30	
Chi-square of Model	181.86****		193.01****		255.94****	

Key: **** = $p < 0.0001$; *** = $p < 0.001$; ** = $p < 0.01$; * = $p < 0.05$; $t = p < 0.10$; # = not included; two-tailed tests.

and development intensity *increases* the incidence of firm formation (IRR = 1.04, $p < 0.01$) (although this result is not robust to the inclusion of the technology regime variables). Moreover, two other variables that have been argued to influence the likelihood of firm formation, capital availability (IRR = 0.99, $p > 0.87$) and average firm size (IRR = 1.00, $p > 0.67$), have no significant effect on the incidence of firm formation. Furthermore, the effect of the four-firm concentration ratio—which, as expected, reduces the incidence of firm formation (IRR = 0.98, $p < 0.05$)—is not robust to the subsequent inclusion of the technology regime variables.

Model 3 adds the predictor variables. The inclusion of these variables generates a good fitting model (chi-square = 255.94, $p < 0.0001$). Moreover, the results support the four hypotheses. Consistent with hypothesis one, the older the technology class, the lower the incidence of firm formation (IRR = 0.71, $p < 0.0001$). Consistent with hypothesis two, the more that a line of business tends toward market segmentation, the higher the incidence of firm formation (IRR = 1.31, $p < 0.01$). Consistent with hypothesis three, the greater the effectiveness of patents in a line of business, the greater the incidence of firm formation (IRR = 1.43, $p < 0.001$). Consistent with hypothesis four, the greater the importance of complementary assets in marketing and distribution in a line of business, the lower the incidence of firm formation (IRR = 0.66, $p < 0.01$).

Because the results shown in Table 3 clearly indicate that the time period has an effect on firm formation, I sought to determine if the effects of the technological regime variables were the same across all of the time periods examined. I examined a series of interaction effects between each of the four time period variables and each of the four technology regime predictor variables.[3] Given the potential for multicollinearity if more than one interaction between a time period variable and a technology regime predictor is included in the same regression model, I examined each of the 16 interaction effects in a separate regression, controlling for all the other variables in Table 3 Model 3 (except for the other time period variables).

Of the 16 interaction effects, 3 were significant at the $p < 0.10$ level or better. The interaction between the 1987–1989 time period and market segmentation had a significant negative effect on firm formation (IRR = 0.41, $p < 0.0001$), while the main effects for the 1987–1989 time period (IRR = 173.24, $p < 0.0001$), and market segmentation (IRR = 1.52, $p < 0.01$) remained positive and significant. The interaction between the 1984–1986 time period and class age had a significant negative effect on firm formation (IRR = 0.66, $p < 0.01$), while the main effect for the class age variable (IRR = 0.75, $p < 0.0001$) remained negative and significant, and the main effect for the 1984–1986 time period (IRR = 1.93, $p < 0.05$) remained positive and significant. The interaction between the 1990–1996 time period and class age had a significant positive effect on firm formation (IRR = 1.49, $p < 0.0001$), while the main effect for the class age variable (IRR = 0.62, $p < 0.0001$) remained negative and significant, and the main effect for the 1990–1996 time period (IRR = 1.23, $p > 0.10$) lost significance.

The results of this ex-post analysis suggest that the relationships between the technology regime variables and firm formation remain largely constant over the 1980–1996 period, rather than implying that the technology regime evolves over time. Although the fundamental assumption that industry tendencies toward market segmentation, patent effectiveness, and importance of complementary assets in marketing remain untested and could explain the shifts in firm formation over time if they exhibit intertemporal variation, the results are consistent with the explanation that the increasing level of firm formation over time results from factors outside the technology regime framework. Likely candidates include the increased acceptability of entrepreneurial activity among members of the university community, shifting incentives toward and resources for firm formation to exploit university inventions, and a shift in the locus of technology expertise toward university personnel.

[3] I examine interaction effects rather than examining different time periods in different regression models because the number of firm formation events is too low for this analysis to have strong statistical power when the data are divided into separate time periods.

Discussion

By examining data on the population of MIT inventions over the 1980–1996 period and controlling for several dimensions of industry, the time period, and the importance of universities to technical advance in the field, this article shows that four dimensions of the technology regime influence the likelihood that an invention will be exploited through firm formation. Specifically, firm formation is more likely when technical fields are younger, when the market tends toward segmentation, in lines of business in which patents are more effective, and in lines of business in which complementary assets in marketing and distribution are less important.

The design of the study adds confidence to the results. The study examines the effect of different dimensions of the technology regime before the exploitation decision is made, mitigating the problem of sampling on the dependent variable that undermines many studies that attempt to explore this question. It also examines university patents, which allows for the investigation of inventions that are simultaneously at risk of exploitation by new firm formation and by established firm pursuit. In addition, by examining patents from a single university, the study limits the variance in the types of technological opportunities and types of entrepreneurs that exploit them. This reduces the potential for bias from unobserved heterogeneity in the tendency to found firms. Furthermore, the regression analyses account for variation in other dimensions of industries, the importance of universities to the advance of the technical field, and period effects.

Limitations

This study is not without limitations. First, it measures several dimensions of technology regime by using semantic scale scores taken from a relatively small survey of research and development managers. In responding to the survey, the experts' perceptions of the sectoral averages might have been influenced by the firm in which they worked. Moreover, they may have had difficulty accurately responding to Likert scales that lacked universal objective anchors. Although I attempt to mitigate these problems by confirming that the results are robust to measurement of the dimensions of technology regime by both multiple-item scales and single-item measures (not reported here), some of the constructs cannot be measured both ways. Consequently, the dimensions of technology regime are likely measured with error.

Second, the Yale survey was conducted between 1983 and 1984. The one-time nature of this survey requires the covariates taken from the survey to be treated as time invariant. In a review of empirical studies of market structure and innovation, Cohen and Levin (1989) justify this approach, arguing that appropriability conditions are stable and enduring drivers of technical change that are determined by the underlying nature of technology in different lines of business. However, no empirical evidence has examined the intertemporal stability of the Yale measures. Therefore, readers are cautioned that the validity of the findings presented here may be undermined if the attributes of technology sectors captured by these measures are not time invariant.

Third, the comparison of the effects of the technology regime and other dimensions of industry on firm formation is limited by the interrelationships between these factors. As Table 2 shows, significant correlations exist between the dimensions of the technology regime and other dimensions of industry. The existence of these correlations demonstrates the limitations of empirical tests to compete the two perspectives. Because technology regimes and market structure are related in ways that we do not yet understand completely, the explanation of their respective effects on firm formation cannot be generated solely by placing all of the factors linearly on the right-hand side of a regression equation.[4]

Fourth, the study examines only those inventions patented by a single university: MIT. Therefore, the results presented here are conditional on the patentability of an invention, MIT's decision to file for a patent, and the invention's assignment to MIT. If firm formation rates to exploit inventions in fields

[4] This design may suffer from the limitation of unfair comparison. The measures of market structure may be less fine-grained than the measures of technology regime, making the market structure variables appear to be less predictive.

in which patenting is possible are systematically different than those in which patenting is not possible, if firm formation rates for inventions that MIT does not patent are systematically different than those for which MIT patents, or if firm formation rates to exploit inventions patented by MIT are systematically different from those for inventions patented by other entities, then the results presented here may not generalize to other settings. Despite these significant limitations, the study provides empirical evidence that several dimensions of technology regime influence the rate of firm formation. These results suggest the value of further research on this question.

Implications for Research

The central implication of this article is straightforward. The tendency for an invention to be exploited through firm creation varies with the attributes of the technology regime in which it is found. The study provides direct empirical support for the arguments of evolutionary economists that cross-industry variation in technology life cycles (Utterback and Abernathy 1975, Gort and Klepper 1982) and appropriability conditions (Arrow 1962, Levin et al. 1987, Nelson and Winter 1982) influence the likelihood that firm formation will be used as a mode of exploitation of an invention (Winter 1984).

The finding that specific dimensions of the technology regime influence cross-industry variation in the incidence of firm formation as a mode of technology exploitation is important because the failure to explain this variation on the basis of market structure has led many researchers to invoke unique industry effects to explain why some industries, such as computer software, have high rates of firm formation, whereas other industries, such as chemicals, do not. However, the concept of technology regimes provides a more parsimonious and theoretically grounded explanation for between-industry differences in the use of firm formation as a mode of technology exploitation than the invocation of unique industry effects. Because industry dummy variables serve merely as proxies for the characteristics of technological regimes that underlie the industry, researchers can make progress in understanding the nature of Schumpeterian patterns of firm formation by explaining industry differences on the basis of particular industry attributes rather than by the "chemicals" or "software" dummy.

The results also extend existing research on Schumpeterian patterns of firm formation by providing empirical evidence that firm formation rates are influenced by factors other than research and development intensity, capital availability, firm size, and concentration. In particular, the results reconcile two important contradictory findings from prior studies of the relationship of market structure and firm formation. First, the study extends to the domain of new firm formation the argument that the effect of industry concentration on innovative activity is an artifact of unobserved heterogeneity in dimensions of the technology regime (Cohen and Levin 1989). The results here demonstrate that in the absence of controls for the effects of technology regime, industry concentration reduces new firm formation. However, once the technology regime is properly controlled, industry concentration no longer has the predicted effect. This result supports prior research on innovation and technological change, which argues that market structure is not an exogenous driver of innovative activity.

Second, the study reconciles studies that have shown that research and development intensity poses a barrier to new firm formation (Cohen and Levin 1989, Orr 1974, Scherer 1980) with studies that have shown that firm formation is higher in R&D intensive industries (Bound et al. 1984, Cremer and Sirbu 1978, Highfield and Smiley 1987).[5] The coefficient on R&D intensity shown in Model 2 is consistent with studies finding that start-up activity is higher in R&D intensive industries. However, when the effects of technology regimes are included in Model 3, the coefficient on R&D intensity becomes negative. This effect suggests that entrepreneurs found firms because of the opportunities that exist when markets are segmented, patents are effective, complementary assets in marketing are relatively unimportant, and the technical field is young. High levels of R&D intensity are correlated

[5] The author thanks an anonymous reviewer for alerting him to this observation.

with these dimensions of the technology regime but actually inhibit firm formation.

Both of these findings are important because recent reviews have shown that empirical tests of the effects derived from theories of market structure are extremely fragile (Cohen and Levin 1989). Future research could further demonstrate the value of different dimensions of the technology regime by showing that they are less sensitive than the market structure framework to the specification of the sample and the mode of analysis.

The results of this study provide only a small step toward understanding the effects of technology regime characteristics on firm formation. While the results shown here demonstrate that several attributes of the technology regime increase the likelihood that new firm formation will be selected as a mode of technology exploitation, data limitations preclude the examination of whether these factors also influence the rate of technology exploitation by incumbent firms. Because incumbent firms could also respond positively to these factors, perhaps even to a greater degree than new firms, the results shown here cannot determine whether firm formation rates are greater in technological regimes of creative destruction than in technological regimes of creative accumulation. Rather, the results are equally consistent with the proposition that new firm formation is more common under regimes of creative accumulation, as well as the idea that no distinct regime exists at all. Future research is necessary to examine the differential impact of technological regimes on the heterogeneous populations of firms.

Moreover, while the study provides evidence of the tendency of entrepreneurs to exploit new technology through firm formation, it says nothing about the performance of those entrepreneurs. Characteristics of technology regimes may also explain why industries vary in the rate at which new firms replace established firms, the rate at which established firms acquire new firms (Gans and Stern 1998), or the rate at which new firms grow (Acs and Audretsch 1990). Future research could extend the technology regimes framework to explore whether new firms formed to exploit new technology experience different rates of failure, acquisition, and growth when they are in regimes of creative destruction or creative accumulation. In particular, future research could explore which of the specific dimensions of technological regime described here have the largest effects on these rates. Combined with the results of this paper, such research would provide information on how the nature of the technology regime influences the process of creative destruction through effects on rates of firm formation, rates of firm failure, rates of acquisition, and rates of growth.

The results presented here are important to several strands of scholarly research. They are important to entrepreneurship research because they identify an oft-overlooked category of factors that influence firm formation. One strand of entrepreneurship research has shown that several attributes of the entrepreneur influence the tendency of firms to be founded to exploit inventions (Roberts 1991). Another school of research has shown that the market structure of an industry influences the entry decision of a potential entrepreneur (Audretsch 1995). A third category of research has shown that the attributes of the specific piece of technology influence the tendency of a new firm to be formed to commercialize the invention (Christiansen and Bower 1996). This study provides evidence of a fourth category of factors that entrepreneurship researchers need to consider in explaining firm formation: the nature of the technology regime.

The results also provide useful implications for research in the field of strategic management. Established firms sometimes face important challenges from new firms formed to exploit new technology. This study provides evidence that several characteristics of the technology regime influence the tendency for entrepreneurs to challenge existing firms. Technology regimes conducive to new firm formation are also ones in which managers of existing firms must pay attention to the threat of competition from firms not yet in existence. Strategic management does not yet provide a good explanation for how firms successfully manage this threat. The results of this study suggest that the technological regime framework provides a useful tool for strategic management scholars interested in identifying the conditions under which new firms are likely to emerge as competitors of established companies.

Normative Implications

The activities adopted by entrepreneurs to exploit new technologies cannot be isolated from the characteristics of the industries in which they operate. Although entrepreneurs may not understand, or even recognize, the industry characteristics that constrain the approaches available to them, some strategies for technology exploitation are more common in certain industries than in others. The results of this study show that the exploitation of technology through firm formation varies across industries as a function of four dimensions of the technology regime. Entrepreneurs can use this information to determine if firm formation is the appropriate organizational arrangement to exploit technological opportunities in their line of business.

The results of this study also have several implications for public policy. In particular, the study suggests intellectual property policy should be assessed at the industry level. Klevorick et al. (1995) explained that intellectual property policies that are beneficial to entrepreneurial activity in one industry might be detrimental in another industry. This study showed that variation in the effectiveness of intellectual property influences firm formation rates. By demonstrating that firm formation is more likely under some appropriability conditions than under others, this study suggests that intellectual property policies that are supportive of entrepreneurship in one industry may be hostile to entrepreneurship in another.

The results also suggest that government policies toward monopoly should be examined at the industry level. The rate at which new firms enter an industry influences the degree of competition in that industry (Caves 1998). If the characteristics of the technology regime influence the likelihood that entrepreneurs will form firms to exploit new technologies, then industries have differential tendency toward monopoly. Consequently, government policy toward monopoly should take into consideration the nature of the technology regime and its implications for firm formation.

Finally, the results suggest that government policy toward income distribution will be influenced by the technology regime. If entrepreneurs are differentially likely to start firms under certain technological regime conditions than under others, then the distribution of wealth generated by technological change will be different across industries. In industries in which firm formation is more common, the wealth generated by new technology will be distributed to independent entrepreneurs and their investors. This argument suggests that government policies toward wealth distribution need to consider the nature of technological change across industries.

Conclusion

This paper showed that four dimensions of the technology regime—the age of the technical field, the tendency of the market toward segmentation, the effectiveness of patents, and the importance of complementary assets in marketing and distribution—influence the tendency for inventions to be exploited through the formation of new firms. The results generate important implications for theories about entrepreneurship. It is hoped that future researchers will consider the influence of the technological regime on new firm formation in their efforts to develop robust explanations for this important phenomenon.

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