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SCIENCE DIRECT

International Journal of Industrial Organization
21 (2003) 1391–1410

International Journal of Industrial Organization

www.elsevier.com/locate/econbase

When do start-ups that exploit patented academic knowledge survive?☆

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Abstract

Researchers have generally suggested that new technology firms should exploit radical technologies with broad scope patents to compete with established firms, implying that new firms founded to exploit university inventions will be more likely to survive in all industries if they possess these attributes. However, the existing empirical evidence indicates that the effectiveness of these two dimensions of new firm strategy is contingent on the industry environment, specifically industry concentration. In this paper, we explain why this industry-specific relationship should exist and use a unique data set of new technology ventures originating at Massachusetts Institute of Technology to test our arguments.

Keywords: Entrepreneurship; Management of technological innovation and R&D

1. Introduction

Universities have traditionally been considered an important source of new technology (Barker, 1985; Jaffe, 1989; Rosenberg and Nelson, 1994). For example, the Internet originated as an electronic discussion group for a community

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0167-7187/03/$ – see front matter
doi:10.1016/S0167-7187(03)00088-2

of physicists in Switzerland. Similarly, the ideas of nuclear fission and fusion were first discussed at Columbia University. Moreover, in recent years, the role of universities in commercial technology development has become even more important as partnerships with the private sector (Siegel et al., 2002, 2003; Hall et al., 2002) and technology licensing (Thursby and Thursby, 2002), have grown.

One of the most important developments in university technology commercialization in recent years has been the significant rise in the creation of new companies as vehicles to exploit university inventions (DiGregorio and Shane, 2003; Feldman et al., 2003). In fact, many university technologies, from Genentech's use of recombinant DNA to Lycos' Internet search engine, have led to the creation of new technology companies (Zucker et al., 1998).

Despite the high profile of a few of the most successful of these university start-ups, many of them have not been very successful. This article seeks to explain why some new companies founded to commercialize patented university inventions survive when others do not. While many explanations have been offered for the differential survival of university start-ups, including the psychology of the founders (Roberts, 1991), their social ties (Shane and Stuart, 2002), or the university from which they come (Saxenian, 1990), no researchers have examined the effects of the technology exploited by the start-up on its survival.

Several researchers have found that the nature of a firm's technology base influences its survival (Lerner, 1994; Tushman and Anderson, 1986; Henderson, 1993; Utterback, 1994; Christensen and Bower, 1996). However, these researchers have focused on explaining why established firms fail in the face of technological innovation, rather than on explaining why new firms survive entry. For example, Henderson (1993), in a study of the photolithographic industry, found that entrants are more successful than incumbents at exploiting radical new technology, while Tushman and Anderson (1986) found, across a range of industries, that competence-destroying new technologies tend to be exploited by new companies. In their study of the disk drive industry, Christensen and Bower (1996) found that established companies tend to be replaced by new companies when a new technology was not valuable to their mainstream customers. Nevertheless, it is entirely possible that the nature of firm's technology base explains why established companies fail, without offering any explanation for why new companies might survive entry.

While the studies mentioned above do not directly test the factors that influence the survival of new technology firms, they do suggest the following argument: new technology firms are likely to survive if they exploit radical technologies that cannot be imitated in the founding period when a firm's marketing and manufacturing assets are being established, thereby allowing the new firm to undermine the advantages that established firms have in pursuing incremental technologies (Merges and Nelson, 1990; Teece, 1986). Therefore, new firms founded to exploit university inventions should be more likely to survive if they exploit radical technologies with broad scope patents (Shane, 2001).

However, even casual observation of the empirical evidence on the survival of new technology companies suggests that the benefits of these attributes appear to be quite industry-specific. While the exploitation of radical inventions with broad scope patents appears to allow new firms to survive competition with established firms in some industries (Christensen and Bower, 1996; Foster, 1986; Romanelli, 1989), this strategy appears less effective in others (Gans and Stern, 2000; Teece, 1986).

We believe that industry differences in the effectiveness of a new firm strategy to exploit radical technology with broad scope patents can be explained by considering the nature of industry concentration. The survival of a new technology company requires the creation of the marketing and manufacturing assets necessary to exploit the technological opportunity, and the possession of a valuable technology that undermines the advantages of established firms and that can be protected against immediate imitation by others (Gans and Stern, 2003; Venkataraman, 1997). Holding the possession of a radical technology and broad scope patent protection constant, the concentration of an industry inhibits the survival of new firms by making it more difficult for their founders to create the marketing and manufacturing assets necessary to exploit the technological opportunity. As a result, even if the new firm possesses a radical technology that undermines the competence of established firms and broad scope patents that protect the technology, in concentrated industries, firm founders are often unable to create the set of assets necessary to serve customers in a way that allows the firm to survive (Teece, 1986).

We provide support for these arguments by conducting an empirical test of the survival of 128 new technology companies founded between 1980 and 1996 to exploit MIT-assigned inventions. Our results show that new firm survival is enhanced by radical technology and broad scope patent protection only in fragmented industries.

2. Radicalness of technology and industry concentration

The standard explanation for the effectiveness of a new firm strategy to exploit new technology is that the firm will be successful if it exploits a radical technology. Radical technology undermines the advantages that established firms have in making incremental improvements to technology, undermines firm competence, and turns existing customer relationships into liabilities rather than assets (Utterback, 1994; Christensen and Bower, 1996; Tushman and Anderson, 1986). However, this explanation is incomplete, as it does not consider the nature of competition from established firms in the product market. Such competition will determine whether a firm formed for exploiting radical technology will survive entry because the introduction of radical technology by new firms may spur actions by established firms that inhibit the survival of new firms.

To survive, new firms must build an organization and acquire assets that will be used in conjunction with their radical technology. This process is more difficult in concentrated industries than in fragmented industries. Firstly, in concentrated industries, the marketing and manufacturing assets necessary to exploit a technology lie in the hands of a few established firms, which tend to acquire ownership of these assets to mitigate contracting problems (Williamson, 1985; Teece, 1986). Because new firms do not have these assets in place at the time of founding, they need to build them. When the needed assets are controlled by a few large, existing firms, there are fewer parties for the new firms to work with, thereby increasing the difficulty of establishing an agreement with one of them to obtain needed assets. In contrast, in fragmented industries, the assets necessary to exploit the new technology are available from a wide number of industry players, minimizing bargaining problems in efforts to obtain access to these assets (Williamson, 1975).

Secondly, the average size of firms is larger in more concentrated industries, requiring the amount of marketing and manufacturing assets that new firms have to build to be larger in concentrated industries than in fragmented industries (Mansfield, 1981; Kamien and Schwartz, 1975). Consequently, the scale of cooperation necessary with established players is larger in more concentrated industries. Given capital market imperfections, new firms find it difficult to build up these assets on a scale that is cost effective with established players (Audretsch and Mahmood, 1991; Geroski, 1995), undermining their ability to survive.

Thirdly, in concentrated industries, established firms have cost advantages and market power, which allows them to drive out the new competitor (Galbraith, 1956; Kamien and Schwartz, 1975). Not only can they jointly work to deter entry by others (Acs and Audretsch, 1989), large established firms can price their products at a level that makes entry unprofitable for the new firm, hindering its survival.

Fourthly, in fragmented industries, new firm entry does not necessarily impact the efforts of market leaders to serve their customers because the target customers of the new firm can belong to small, established players (Eisenhardt and Schoonhoven, 1990). However, in concentrated industries, the establishment of the new firm impacts the efforts of market leaders to serve their customers because the target customers of new firms belong to large established players. As a result, entry by the new firm is more likely to invoke retaliation by a large established firm (Acs and Audretsch, 1987; Romanelli, 1989). Because the large established firm has the power to compete against the new firm through the exploitation of lower costs or superior sales efforts, the new firm is unable to gain a foothold in the market unchallenged by those who can drive it out of business. As a result, the new firm finds it hard to enter the market successfully and its survival is impaired. Thus,

Hypothesis 1. The relationship between radicalness of technology and the survival of a new venture is moderated by concentration within the industry, i.e. radicalness increases the likelihood of firm survival more in fragmented markets than in concentrated markets.

3. Scope of IP protection and industry concentration

New technology firms begin without any competitive advantages other than that embedded in their new technology itself. Yet, as we indicated above, to survive, new firms must develop manufacturing and marketing assets that are used in conjunction with their new technology. Therefore, to survive, the new firm uses intellectual property protection to defend the new technology against imitation until such time as its marketing and manufacturing assets can be put into place (Teece, 1986). Broad scope patents facilitate this transition because they provide better protection than narrow scope patents. As Merges and Nelson (1990, p. 839) explain, 'the broader the scope, the larger number of competing products and processes that will infringe the patent'.

The use of broad scope patents to defend the new firm against imitation by established firms until the marketing and manufacturing assets can be put in place works well in fragmented markets where it is relatively easy to gain access to marketing and manufacturing assets without challenging market leaders. However, this strategy works poorly in concentrated industries. Firstly, when the industry is concentrated, the scale and scope of operations necessary to compete in the industry are so large that it is not possible for the new firm to raise money from the capital markets and create necessary assets before competitors find ways around the new firm's intellectual property protection (Audretsch and Mahmood, 1991). Secondly, when the industry is concentrated, the large established players could compete with the new technology firm effectively even if the new firm has effective intellectual property protection (Acs and Audretsch, 1987). Leading firms in concentrated markets have cost and market power advantages that allow them a basis of competition that offsets the advantages provided by the new firm's patented technology (Acs and Audretsch, 1989; Galbraith, 1956). Thirdly, when the industry is concentrated, any effort by the new firm to introduce its new technology requires it to target the large established firm's customers. This effort to take customers from the large established firm provokes retaliation from better funded and more connected established firms that invest money and time in undermining the new firm's patent protection through lawsuits and other tactics (Eisenhardt and Schoonhoven, 1990; Romanelli, 1989). Fourthly, when the industry is concentrated, the new firm needs to obtain more assets from the few established firms that dominate the market. These firms are reluctant to work with the new firm as its technology might undermine their market positions. Therefore, even though the new firm has protected intellectual property, it cannot obtain the assets that it needs to compete in the industry (Teece, 1986). As a result, in concentrated industries, new firms need more than effective intellectual property protection to survive and broad patent scope is not a sufficient condition for survival.[1] Hence,

Hypothesis 2. The relationship between the scope of IP protection and the survival of a new venture is moderated by industry concentration, i.e. patent scope increases the likelihood of firm survival more in fragmented markets than in concentrated markets.

4. Research methods

The data used for this paper were collected from the Technology Licensing Office (TLO) of the Massachusetts Institute of Technology. Like many other research universities, MIT often patents commercially useful inventions that are developed by their faculty, staff or students and that emerge from work making material use of MIT resources. The TLO's objective is to commercialize MIT

[1] Readers will note that our arguments about the effect of concentration on the survival of new technology companies do not discuss the incentives of incumbent firms to innovate, even though this is a central focus of the economics of innovation (Baldwin and Scott, 1987). Although a large theoretical literature has debated whether monopolists have a strong (Gilbert and Newberry, 1982) or weak (Reinganum, 1983) incentive to innovate, we do not believe that models of the incentives of established firms to innovate focus on the key factors that influence the survival of university spinoffs in concentrated industries. Firstly, the theoretical literature largely assumes that the key behavioral driver behind industry concentration is its effect on established firms' decisions about whether or not to innovate. However, most of the university spinoffs that we study were founded after established firms, which had invested in the research that led to the new university technologies, had decided not to pursue those technologies themselves. We believe that it is a stretch to argue that the main effect of industry concentration on competition between established firms and start-ups is that established firms have greater incentives to innovate when we observe that many established firms from concentrated industries invest in university research and then pass on innovating the technologies that emerge from research. Secondly, we believe that, if the effect of concentration on the survival of start-ups were through its effect on established firms' incentive to innovate, we would see established firms adopt other behavior consistent with that process. As Gilbert and Newberry (1982) argue, a monopolist has more incentive to innovate than a new entrant because of the threat of entry to its monopoly rent. This argument would suggest that established firms adopt behaviors consistent with deterring start-ups from developing technologies that could potentially undermine the established firms' monopoly rents. However, we do not observe established companies engaging in strategic behaviors consistent with this approach. For instance, we fail to observe established companies in concentrated industries licensing university inventions and then shelving them, as a way to prevent new entrants from exploiting the new technology, even though established firms have a right of first refusal to license inventions that come from research that they fund at universities like MIT. Thirdly, our empirical investigation focuses on the survival of new technology firms, and does not include information about the behavior of established firms. We believe that it is better not to assume that the survival of new firms depends on the innovative behavior of established firms when we have no information about the effect of the start-up firms on the innovative behavior of those firms. Our arguments about the effect of concentration on the survival of new firms would hold even if industry concentration has no effect (either positively or negatively) on the incentives of established firms to innovate.

technology. Both established and start-up companies license MIT technology. Given our research question, we focused only on new ventures and exclude all licensing activity that involved established firms. We gathered information on 128 of the 134 firms that were founded to exploit inventions made at MIT between 1980 and 1996.

The TLO archives describe the contracts between MIT and its licensees, characteristics of the licensed intellectual property, and the start-ups' business plans. In addition, the TLO tracked the sales growth and survival of its licensees. To corroborate, as well as to supplement, the TLO data, we conducted unstructured interviews with company founders and consulted online databases including Lexis/Nexis, Dialog Business Connection and ABI Inform. Finally, we obtained additional information on the venture capital financing of these firms and the industry in general from the Venture Economics and Venture One databases. The objective of the data collection effort was to create detailed profiles of all firms from the time they were founded until the time we stopped our observation or the time of firm failure.

Although MIT-based start-ups clearly do not constitute a representative sample of all technology companies, these data have two advantages relative to other samples of start-up firms. Firstly, our approach avoids excluding the large number of firms that fail at very young ages (before they are recorded in directories), in large part because they are not able to secure external financing. Therefore, there is no sample selection bias with respect to very young firms that do not show up in industry directories. A second advantage of the TLO data is that there are no left-censored observations, i.e. firms are observed from the time of founding. This allows us to analyze firm survival using event history analytical techniques with reliable parameter estimates.

4.1. Method

The event we model in this paper is the failure of a start-up founded to exploit MIT intellectual property. We define a failure as a firm that ceases operations. We treat those companies that enter markets and are acquired by established firms as successes because many new companies established to exploit new technology aspire to acquisition as an exit strategy. We analyze this transition from a going concern to a failed firm, which we define as a bankruptcy or cessation of operations, in terms of the instantaneous transition rate (otherwise known as the 'hazard rate'), r, defined as

$$r_k(t) = \lim_{\Delta t \to 0} \frac{\Pr(t < T < (t + \Delta t), D = k | T > \Delta t)}{\Delta t} \qquad (1)$$

where k represents a failure. The variable T measures the time spent at risk of failure and the probability Pr refers to the likelihood of experiencing a failure during the small interval from t to Δt, conditional on a firm having survived as of time t (Tuma and Hannan, 1984). The waiting time clock in the firm event histories turns on at the time of founding. The transition of a start-up from a going concern to a failure is modeled using the approach discussed in Kalbleisch and Prentice (1980). We created annual spells to update the values of the time changing covariates. Each spell ends in censoring unless an event occurs within the focal firm year observation. We used the Weibull model as it has a simple survivor function that is easy to manipulate and many firm failure studies suggest that failure follows a Weibull distribution. The form that this model takes is:

$$r_k(t) = \exp\left[(-\beta X_i)1/\rho\right] \tag{2}$$

where $r_k(t)$ is the instantaneous hazard function of failure while X_i is the vector of covariates and ρ is the Weibull parameter.

4.2. Predictor covariates

4.2.1. Technological radicalness

Following Rosenkopf and Nerkar (2001), we measure technological radicalness as the count of the number of United States Patent and Trademark Office (USPTO) patent classes cited in prior art of the licensed invention outside of the patent's own class. Past research has shown that this measure captures the degree to which a technology is radical or competence changing in a technical sense (Rosenkopf and Nerkar, 2001; Shane, 2001).

4.2.2. Patent scope

We measure patent scope as a count of the number of International Patent Classification (IPC) classes that a patent is classified into by the USPTO (Lerner, 1994). Because the international patent classification is nested, the count of classes indicates a scale of patent scope (Shane, 2001). Past research has shown that patents with a greater number of IPC classes have more claims, face a greater likelihood of infringement and are more likely to be litigated (Lerner, 1994).

4.2.3. Industry concentration

We include a measure nature of competition as the C4 ratio, i.e. the market share accounted by the top four companies in the 4-digit SIC code where the new company is classified. We examine only the C4 concentration ratio in our analyses because previous researchers have not found significant qualitative or statistical differences between the C4 concentration ratio and a Herfindahl index (see, for example, Scott, 1993). Using data from the Census Bureau, we include the concentration ratio in the year that the firm was founded. Because industry concentration changes slowly over time, we do not expect that a one-time measure of industry concentration will lead to errors in measurement. We use the categorization made by MIT's technology licensing office to assign firms to industries.

4.3. Control covariates

Our focus in this paper is on technological entrepreneurship, a sector that is heavily influenced by a host of factors at the environment, firm, and individual levels of analysis. Hence we include a variety of control covariates.

4.3.1. Technical fields

We control for inventions in the chemical or electrical fields with dummy variables for these fields because the process and rate of new firm development differs across types of technology. By controlling for these technical fields, we can partial out this type of variation from the data.

4.3.2. Biotechnology firms

We use a dummy variable of 1 to control for biotechnology firms because biotechnology spin-offs from universities differ from other university spin-offs in two fundamental ways. Firstly, biotechnology is the only industry in which the locus of technology creation lies in universities, suggesting that the survival patterns of university biotechnology firms might be different from that of other university start-ups. Secondly, biotechnology firms tend to require far more capital to commercialize their technologies than other university spin-offs, and often go public without having products on the market. As a result, the survival patterns for biotechnology firms might be systematically different from the survival patterns of other university spin-offs.

4.3.3. Number of firms in the industry

Our measure of concentration is an indication of the power wielded by the top four firms in the industry. We also want to control for the total number of players in the industry to capture the number of firms competing in the industry. Using data from the Census Bureau, we include a count measure of the firms at 4-digit SIC level in the year that the firm was founded. We use the categorization made by MIT's technology licensing office to assign firms to industries. The variable is skewed and we use a logarithmic transformation.

4.3.4. Venture capital in the industry

Survival of firms is also linked to the availability of resources in the environment. Using data from Securities Data Corporation's venture capital database, we include a variable that counts the total number of firms funded by venture capitalists in the industry in the year that the firm was founded. We use the categorization made by MIT's technology licensing office to assign firms to industries. The variable is skewed and we use a logarithmic transformation.

4.3.5. General purpose

General-purpose technologies should enhance the survival of new firms because these technologies can be used in a variety of applications. As a result, they provide new firms with flexibility that is useful to overcoming technical and market risk (Shane, 2000). We include a dummy variable that takes the value of 1 if MIT records showed that the technology is a general-purpose technology that could be applied in multiple fields.

4.3.6. Entrepreneur is inventor

Agency problems are less likely to cause the failure of a venture if the entrepreneur is also the inventor (Holmstrom, 1989). We include a dummy variable that takes the value of 1 if the person starting the firm is also the inventor.

4.3.7. Prior knowledge of problem solved

Prior experience with technical problems can reduce the likelihood of failure at solving them. In the case of technology ventures, founder experience with the specific technical problem to be solved can reduce the likelihood venture failure. We include a dummy variable that takes a value of 1 if the entrepreneur has prior knowledge of the technical problem that the venture seeks to solve (Shane, 2000).

4.3.8. Inventor is tenured at MIT

An invention patented by a senior faculty member may influence the likelihood of failure of a firm started to exploit it because tenure might increase the risks that the founder is willing to take or his ability to leverage his reputation to obtain resources. We include a dummy variable that takes a value of 1 if the inventor is tenured at MIT and 0 if he or she is not tenured.

4.3.9. Product invention

Product inventions are more likely to fail than process inventions because they need to be accepted by end customers and not just the founding firm (Utterback, 1994). Hence we include a dummy variable that takes a value of 1 if the licensed invention is a product invention.

4.3.10. Exclusive license

New firms are more likely to succeed if they have exclusive access to the intellectual property they are exploiting. Therefore, we also coded a dummy variable, exclusive, which takes the value of 1 if the new venture has an exclusive right to use MIT technology in a particular field of use.

4.3.11. Experience of founding team

We include variables that measure two different types of founder business experience. The first measure (start up experience) counts the number of firms started by the founding team in the past while the second measure (market experience) counts the number of years of industry experience on the founding team. Both measures of experience should reduce the likelihood of failure as prior research has shown that these dimensions of human capital are important to new venture performance (Bates, 1990).

5. Results

The descriptive statistics are reported in Table 1, while Table 2 reports the results from the event history analysis predicting firm survival.

Models 1 and 2 in Table 2 predict the hazard of firm failure as a function of concentration and technological radicalness and patent scope, respectively. These models indicate that overall new technology firms are less likely to fail if they exploit radical technology and have broad scope patents. Model 3 includes the interaction term between technological radicalness and concentration, while model 4 focuses on the interaction between patent scope and concentration. (Due to problems of multicollinearity, we are unable to separate the effects of the two interactions simultaneously.) The results offer support for our two hypotheses that technological radicalness and patent scope reduce new firm failure overall, in the sense of what the effect is without the interactive control for seller concentration. However, technological radicalness and patent scope increase new firm failure in concentrated markets.

Table 1
Descriptive statistics

Variable	Mean	S.D.
Failure	0.031	0.174
Age	4.976	3.668
Biotechnology	0.338	0.473
Chemistry	0.367	0.482
Electronics	0.420	0.494
General purpose	0.198	0.399
Ln (number of firms in industry)	7.782	1.019
Ln (venture capital in industry)	11.357	1.604
Entrepreneur is inventor	0.673	0.470
Prior knowledge of problem solved	0.880	0.325
Inventor is tenured at MIT	0.712	0.453
Product invention	0.664	0.473
Exclusive license	0.817	0.313
Start-up experience on founding team	1.018	2.214
Market experience on founding team	12.234	36.850
Technological radicalness	2.120	1.513
Patent scope	1.438	0.943
Industry concentration (C4)	38.100	9.099

$N = 128$ firms, 834 firm-year spells.

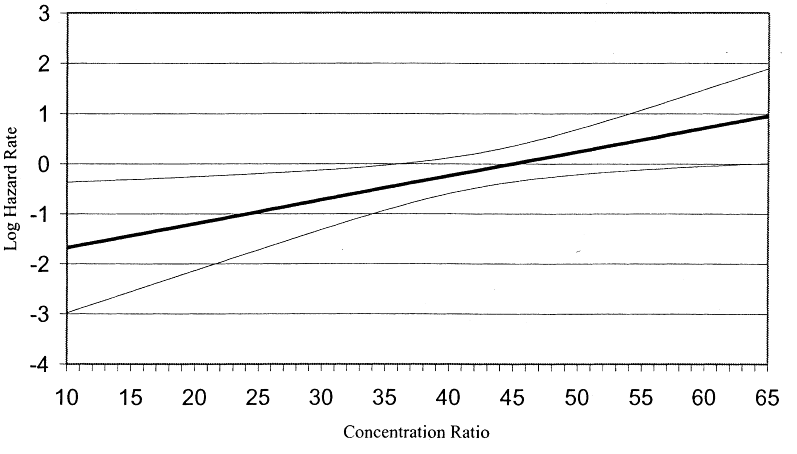
Table 2
Weibull model of failure rates for MIT start-ups

Variable	(1)	(2)	(3)	(4)
Weibull parameter	0.791**	0.817**	0.885**	0.831**
	(0.150)	(0.149)	(0.155)	(0.151)
Biotechnology company	−0.196	0.173	−0.169	0.152
	(1.159)	(1.217)	(0.968)	(1.368)
Chemistry	0.644	0.561	0.351	1.535
	(1.472)	(1.478)	(1.446)	(1.650)
Electronics	1.358	1.569*	1.619*	2.537**
	(0.872)	(0.876)	(0.935)	(0.992)
General purpose	−0.774	−0.628	−1.004	−0.524
	(0.895)	(0.867)	(0.898)	(0.862)
Ln (number of firms in industry)	0.306	0.465	0.341	0.621
	(0.482)	(0.477)	(0.464)	(0.485)
Ln (venture capital in industry)	0.460**	0.412**	0.572**	0.682**
	(0.199)	(0.200)	(0.206)	(0.229)
Entrepreneur is inventor	−1.855**	−1.805**	−1.962**	−1.911**
	(0.570)	(0.577)	(0.572)	(0.570)
Prior knowledge of problem solved	−0.961	−0.879	−1.434**	−0.491
	(0.632)	(0.635)	(0.660)	(0.680)
Inventor is tenured at MIT	0.332	0.248	0.374	0.489
	(0.613)	(0.623)	(0.606)	(0.621)
Product invention	−0.829*	−0.923*	−0.593	−1.200**
	(0.480)	(0.491)	(0.504)	(0.548)
Exclusive license	0.622	0.790	0.489	0.589
	(0.755)	(0.769)	(0.767)	(0.749)
Start-up experience on founding team	0.145	0.194	0.243	0.279*
	(0.146)	(0.152)	(0.155)	(0.160)
Market experience on founding team	−0.043	−0.046	−0.065*	−0.055*
	(0.029)	(0.029)	(0.034)	(0.031)
Industry concentration (C4)	0.061*	0.063*	−0.027	0.048
	(0.033)	(0.033)	(0.049)	(0.032)
Technological radicalness	−0.146		−2.152**	
	(0.194)		(0.860)	
Patent scope		−0.446		−1.619**
		(0.309)		(0.621)
Concentration × radicalness			0.048**	
			(0.020)	
Concentration × patent scope				2.877**
				(1.236)
Log-likelihood	−50.42	−49.69	−47.767	−46.89
LR chi-square	49.27**	50.74**	54.59**	56.34**

Two-sided *t*-tests: $^{*}P<0.10$; $^{**}P<0.05$.

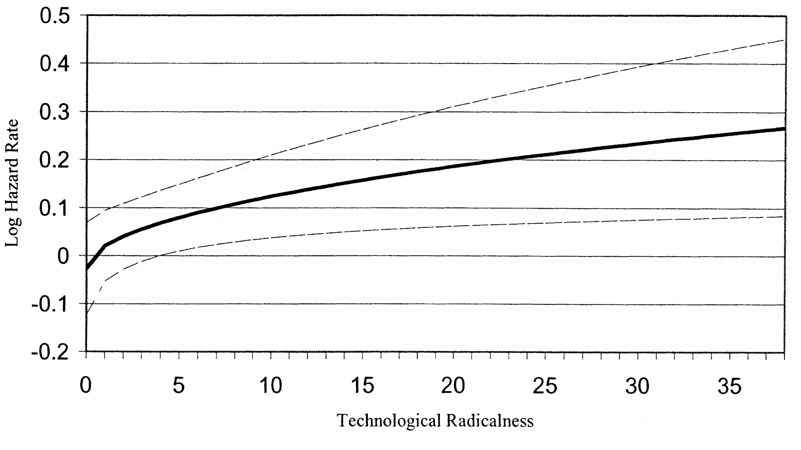
We also show the results for radicalness and concentration graphically in Figs. 1 and 2. These figures demonstrate the interaction effect between concentration and both radicalness and patent scope on firm failure.

Our findings might be explained alternatively if industry concentration proxied



The dark line plots the partial derivative of the ln hazard with respect to Radicalness (-2.152 + 0.048(C4)). The shaded line is the 95 percent confidence interval.

Fig. 1. Conditional effect of technological radicalness on mortality. The dark line plots the partial derivative of the ln hazard with respect to radicalness ($-2.152+0.048$(C4)). The shaded line is the 95% confidence interval.



The dark line plots the partial derivative of the ln hazard with respect to C4 (-0.027 + 0.048(Radicalness)). The shaded line is the 95 percent confidence interval.

Fig. 2. Conditional effect of concentration on mortality. The dark line plots the partial derivative of the ln hazard with respect to C4 ($-0.027+0.048$(Radicalness)). The shaded line is the 95% confidence interval.

Table 3
Alternative A: dominant design

Variable	(1)	(2)	(3)
Industry concentration (C4)	0.081*	−0.005	0.0001
	(0.044)	(0.057)	(0.062)
Technological radicalness	−2.047*	−2.177**	−2.350**
	(1.158)	(0.874)	(1.128)
Concentration × radicalness		0.047**	0.044*
		(0.020)	(0.024)
Dominant design	−1.184	−0.587	−0.683
	(0.746)	(0.712)	(0.813)
Dominant design × radicalness	0.409		0.066
	(0.249)		(0.273)
Log-likelihood	−48.56	−47.43	−47.39
LR chi-square	53.00**	55.26**	55.34**

We control for all of the same variables as are included in Table 2. For ease of exposition, however, we report only the key variables discussed in the focal alternative. The *t*-tests are two-sided: *$P<0.10$; **$P<0.05$.

for unobserved industry characteristics that would also predict the interaction effects we observe. We seek to rule out these alternative explanations. Tables 3–6 report a series of analyses that we conducted to examine alternate explanations that industry concentration proxies for the presence of dominant designs, industry R&D intensity, market growth rates and technological maturity, and that the interaction between radicalness and these factors actually explain the results that we showed in Table 2.

The first alternative explanation is that concentration is proxying for the

Table 4
Alternative B: industry R&D intensity

Variable	(1)	(2)	(3)
Industry concentration (C4)	0.073*	0.074*	−0.009
	(0.038)	(0.038)	(0.051)
Technological radicalness	−0.101	−0.220	−2.159**
	(0.207)	(0.387)	(0.817)
Concentration × radicalness			0.049**
			(0.019)
Industry R&D intensity	−3.926	−8.119	−7.051
	(6.319)	(13.109)	(12.094)
R&D intensity × radicalness		2.032	0.023
		(5.485)	(5.279)
Log-likelihood	−50.23	−50.16	−47.18
LR chi-square	49.66**	49.80**	55.76**

We control for all of the same variables as are included in Table 2. For ease of exposition, however, we report only the key variables discussed in the focal alternative. The *t*-tests are two-sided: *$P<0.10$; **$P<0.05$.

Table 5
Alternative C: market growth rate at founding

Variable	(1)	(2)	(3)
Industry concentration (C4)	0.060*	0.061*	−0.023
	(0.035)	(0.034)	(0.050)
Technological radicalness	−0.144	−0.072	−2.101**
	(0.195)	(0.215)	(0.885)
Concentration × radicalness			0.047**
			(0.020)
Market growth rate	0.185	2.182	0.689
	(1.781)	(3.163)	(3.173)
Market growth × radicalness		−1.424	−0.854
		(1.863)	(1.941)
Log-likelihood	−50.42	−50.14	−47.64
LR chi-square	49.28**	49.84**	54.85**

We control for all of the same variables as are included in Table 2. For ease of exposition, however, we report only the key variables discussed in the focal alternative. The *t*-tests are two-sided: *$P<0.10$; **$P<0.05$.

presence of a dominant design in certain industries because industry concentration is higher in industries that have achieved a dominant design. One might expect that the introduction of a radical technology would not be survival enhancing for a new firm if a dominant design existed in the industry. In Table 3 we include a variable from the Yale Survey on Innovation (Levin et al., 1987) that measures if there was a dominant design in the industry. The results shown in Table 3 indicate that even when the interaction of radicalness and dominant design is measured, we still observe the predicted relationship between radicalness and concentration.

Table 6
Alternative D: technological maturity

Variable	(1)	(2)	(3)
Industry concentration (C4)	0.062*	0.054	−0.017
	(0.033)	(0.034)	(0.047)
Technological exploration	−0.163	−4.937**	−5.904**
	(0.194)	(1.946)	(1.981)
Concentration × radicalness			0.043**
			(0.021)
Age of patent class	−0.666*	−2.511**	−2.394**
	(0.396)	(0.805)	(0.836)
Age of patent class × radicalness		1.127**	0.939**
		(0.457)	(0.456)
Log-likelihood	−49.24	−46.01	−43.95
LR chi-square	51.64**	58.10**	62.20**

We control for all of the same variables as are included in Table 2. For ease of exposition, however, we report only the key variables discussed in the focal alternative. The *t*-tests are two-sided: *$P<0.10$; **$P<0.05$.

The second alternative explanation is that industry concentration is proxying for the level of R&D spending in an industry because more concentrated industries have more R&D spending. One might expect that the introduction of a radical technology would not be survival enhancing for a new firm if established firms had a high level of absorptive capacity or ability to innovate. In Table 4 we include a variable that measures industry R&D intensity and its interaction with radicalness. The results in Table 4 indicate that even when the interaction of radicalness and R&D intensity is measured, we still observe the predicted relationship between radicalness and concentration.

The third alternative explanation is that industry concentration is proxying a lack of market growth because more concentrated industries tend to grow more slowly than less concentrated industries. One might expect that the introduction of a radical technology would not be survival enhancing if the market is growing slowly. Market growth and its interaction with radicalness are included in Table 5. The results in Table 5 indicate that even when the interaction of market growth and radicalness is measured, we still observe the predicted relationship between radicalness and concentration.

The fourth alternative explanation is that industry concentration is proxying the age of the technology because industries with older technologies tend to be more concentrated than industries with younger technologies. One might expect that the introduction of a radical technology would not be survival enhancing if the industry were old. We include the interaction between age of the technology and radicalness in Table 6. The results in Table 6 indicate that even when the interaction of age of the technology and radicalness is measured, we still observe the predicted relationship between radicalness and concentration.

A fifth alternative explanation for our results is that they are an artifact of the Weibull model assumption that the hazard of an event is a smooth function of time. Therefore in unreported regressions, we reanalyze or results with a piecewise exponential model of the form:

$$r_k(t) = \exp\left[\gamma_{\mathrm{p}} + \beta X_i\right]$$

where γ_{p} includes two duration period effects, X_i contains independent variables (some of which vary over time), and β represents the parameters to be estimated. The piecewise specification of duration dependence permits the rate to vary flexibly with duration (in this case firm age) without requiring strong parametric assumptions. The age pieces we include are less than 4 years and more than 4 years old, respectively; the baseline rate is assumed to be constant within each period, but is constrained across periods. The results are qualitatively the same when we use the piecewise exponential model as when we use the Weibull model, suggesting that the results are not explained by the assumptions of the statistical model.

Another challenge to our results is that strategies that lead to a higher probability of failure might also lead to a higher expected payoff. As a result, having radical technology and broad scope patents in fragmented industries might not be beneficial to start-ups because such a technology base would reduce the likelihood of successful outcomes, such as achieving an initial public offering. To rule out this alternative interpretation, we used the same regression model shown in Table 2 to predict the hazard of the new firm achieving either an initial public offering or being acquired by another firm. In unreported regressions, we found that the interaction between concentration and both patent scope and technological radicalness has no statistically significant effect on the hazard of achieving a positive outcome. Thus, we believe that having a radical technology and broad scope patents in a fragmented industry reduces the failure of university spin-offs without influencing their likelihood of achieving a positive outcome.

6. Discussion

This article examined the interaction between radicalness of technology and patent scope and industry concentration on the likelihood of firm failure for university start-up companies. We examine a unique data set of 128 firms founded to commercialize technologies licensed from MIT between 1980 and 1996 and show that technological radicalness and patent scope reduce new firm failure only in the context of fragmented markets.

6.1. Limitations

This study is not without limitations. We measure radicalness as the number of patent classes cited outside of a patent's own patent class. While many scholars have employed this measure of radicalness (e.g. Rosenkopf and Nerkar, 2001; Shane, 2001), researchers might ask whether this construct should be measured differently. For instance, should these measures be normalized by industry? Readers should note that our results are contingent on the construct validity of the radicalness measure.

In addition, we measure patent scope as the number of international patent classes assigned to the patent, consistent with the prior work of Lerner (1994) and Shane (2001). Despite the evidence provided by Lerner (1994) of the construct validity of this measure, researchers might ask if this measure should be normalized by industry. Given this question, we must caution readers that the validity of our results is contingent on the construct validity of the patent scope measure.

A second important limitation concerns the generalizability of our results. Our sample consists of firms that were formed to exploit the intellectual property created by the Massachusetts Institute of Technology. This institution is one of the largest generators of university spin-offs in the United States. Given that some universities are more likely than others to generate spin-offs to exploit their intellectual property (DiGregorio and Shane, 2003), the Massachusetts Institute of Technology might not represent the general population of universities. As a result, the patterns that explain the performance of new companies founded to exploit the Institute's intellectual property might not generalize to new companies founded to exploit the intellectual property of other institutions. While we have no a priori reason to suspect that our results are not generalizable, we also have no evidence to support their generalizability. Therefore, readers should interpret our results with caution.

6.2. Implications

Our results indicate that two dimensions of the strategy of new technology companies founded to exploit university inventions are industry-specific. Previous research has argued that new technology firms will be more likely to survive if they exploit radical technology because the advantages of established companies in exploiting incremental technology require new competitors to exploit competence destroying new technology (Tushman and Anderson, 1986). Our results provide insight into the empirical puzzle engendered by this argument. Why does the exploitation of radical technology only appear to help new firms survive in certain industries? We offer as explanation that a strategy to exploit competence-destroying radical technology as a way for a new firm to compete only works in fragmented industries. In concentrated industries, the exploitation of a radical technology fails to provide an advantage to new companies. Concentrated industry environments hinder efforts of the new firm to build the manufacturing and marketing assets necessary to compete.

Previous research has also argued that new technology firms will perform better if they have broad scope patents because strong intellectual property protection is necessary to protect their technology from imitation while they create the marketing and manufacturing assets necessary to exploit their technologies (Merges and Nelson, 1990). We show that this strategy is also contingent on the entrepreneur founding a company in a fragmented industry. In a concentrated industry, the difficulty of creating these assets makes this strategy problematic.

In sum, we believe that this paper opens a new avenue of inquiry into the ways in which the industry environment in which new university technology start-ups compete interacts with their strategy to influence their survival. While our study only offers insight into one small way in which strategy–environment interaction influences new technology firm survival, we hope that it will spur other researchers to examine this question, rather than simply assuming that a given strategy is effective across all industry environments.

Acknowledgements

We thank Ajay Agrawal and John Scott for helpful comments on an earlier draft of this paper.

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