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Executive Forum: University technology transfer to entrepreneurial companies

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Abstract

This article discusses four dimensions of university–entrepreneurial firm collaboration—(1) industry-sponsored contract research, (2) consulting, (3) technology licensing and (4) technology development and commercialization—of which practitioners involved in university–private sector technology interaction need to be aware. The article identifies specific findings in each of the four areas and suggests important avenues for future work.

Keywords: Entrepreneurship; Technology transfer; Universities

1. Executive summary

University research and technology transfer to entrepreneurial companies is important and increasing. However, no single document summarizes the ways in which university technology interactions with entrepreneurial firms differ from those with large, established organizations. This article reviews and summarizes the findings of existing research on this topic with the goal of presenting this information in a form useful to practitioners in those two domains.

The article focuses on four dimensions of university–entrepreneurial firm collaboration: (1) industry-sponsored contract research, (2) consulting, (3) technology licensing and (4)

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technology development and commercialization. These four topics were selected because practitioners on both sides of the interaction consider them both important to understand and fundamentally different for entrepreneurial firms as compared to large, established firms.

To date, observers have identified six different ways in which university–entrepreneurial firm interaction may differ from university–large firm interaction in contract research.

1. Entrepreneurial companies are less likely than established companies to engage in contract research.
2. Entrepreneurial companies are less likely than established firms to participate in research consortia.
3. Entrepreneurial companies prefer customized arrangements for contract research with universities.
4. Entrepreneurial companies rely heavily on government-funded research rather than on industry-sponsored research.
5. Contract research from entrepreneurial companies is more geographically localized than contract research from large firms.
6. Contract research from entrepreneurial companies is often contingent on the right to license exclusively.

To date, observers have identified four different ways in which university–entrepreneurial firm interaction may differ from university–large firm interaction in consulting.

1. Consulting arrangements with entrepreneurial firms require more intense involvement by faculty than consulting arrangements with large firms.
2. Consulting arrangements with entrepreneurial companies impose greater questions of conflict of interest than do consulting arrangements with large firms.
3. Consulting arrangements with entrepreneurial companies are more likely to be the result of personal ties than consulting arrangements with large firms.
4. Consulting arrangements with entrepreneurial companies often exist to transfer technology out of the university.

To date, observers have identified eight different ways in which university–entrepreneurial firm interaction may differ from university–large firm interaction in technology licensing.

1. Technology licensing by entrepreneurial firms depends on complementary mechanisms to provide financing.
2. Technology licensing by entrepreneurial firms depends on mechanisms to lower royalty payments.
3. Technology licensing by entrepreneurial firms depends on mechanisms to capitalize patent costs in the form of equity investments.
4. Technology licensing by entrepreneurial firms depends on technology licensing office expertise in firm creation.
5. Technology licensing by entrepreneurial firms depends on providing licensees with strong intellectual property protection.

6. Technology licensing by entrepreneurial firms depends on access to technology families.
7. Entrepreneurial firms license different types of technology than do large firms.
8. Entrepreneurial firms license inventions from different inventors than do large firms.

To date, observers have identified three major findings about how university–entrepreneurial firm interaction over technology development may differ from university–large firm interaction over technology development.

1. Science and technology parks have a larger influence on university–industry interaction for entrepreneurial firms than for large firms.
2. Subsidy programs have a larger influence on university–industry interaction for entrepreneurial firms than for large firms.
3. Buffering institutions have a greater effect on entrepreneurial companies than on large companies.

The review of publications on university–entrepreneurial firm interaction also indicated several areas in which relatively little is known, suggesting the following recommendations for future research to shed light on these topics:

1. Examine the differences between entrepreneurial companies generated by universities and entrepreneurial companies seeking university assistance.
2. Examine the differences between different types of entrepreneurial companies.
3. Examine the differences across industries.
4. Examine the differences across types of universities.
5. Examine the differences across the stage of development.
6. Examine one-time and repeat firms.

2. Introduction

University research and technology transfer is important to entrepreneurial companies. In some areas, like biotechnology, university research has led to the development of completely new industries with strong academic ties. In other areas, university research and technology transfer has been linked to the needs of local industry.[1] For example, Purdue University (the boilermakers) contributed significantly to the development of locomotive technology, the University of Oklahoma was a valuable participant in the development of the petroleum industry and the University of Akron was a major contributor to polymer science (Rosenberg and Nelson, 1994).

[1] Since entrepreneurial companies tend to be more locally constrained than large companies, the specific expertise of local universities is more important to entrepreneurial companies than to large companies. For example, Tornatzky et al. (1999) report that 83% of start-up companies built around university inventions are located in the same area as the university.

Moreover, the interactions between entrepreneurial companies and research universities are increasing. Since the passage of the Bayh-Dole Act in 1980, universities have experienced tremendous growth in the number of companies forming around academic inventions, particularly in biotechnology (Brooks and Randazze, 1998) and software (Cohen et al., 1998).[2] They have also seen significant increases in contract research sponsored by industry, patenting and technology licensing. Perhaps, more importantly, an increasing portion of this interaction is taking place with younger and smaller firms.

Despite the importance of university technology interactions to entrepreneurial firms, no single document summarizes received wisdom on this topic. In particular, the entrepreneurs leading these firms and the university technology transfer offices with which they interact are largely unaware of the particular ways in which university technology interactions with entrepreneurial firms differ from those with large, established organizations. This article reviews and summarizes the findings of existing research on this topic with the goal of presenting this information in a form useful to practitioners in those two domains.

3. Scope

This article is directed to practitioners interested in understanding the nature of cooperative university–entrepreneurial firm interactions in research and technology transfer. It reviews the current state of knowledge about these interactions and provides recommendations for future investigation on this topic. The primary goal of the article is to highlight the differences in the interaction between universities and entrepreneurial firms from the interaction between universities and large firms. An understanding of these differences will help university officials and entrepreneurs to develop better practices for university–entrepreneurial firm interactions.

The article focuses *only* on those dimensions of entrepreneurial company interaction with universities that differ from those of large companies. The many dimensions on which entrepreneurial companies interact with universities in the same way as large companies are not reported here.

For the purpose of this article, interaction with universities is defined as activities that involve research, technology transfer or technology development. Applied and basic science, engineering and mathematics are examined but social science and business school collaborations with industry are not explored.

The article focuses on four dimensions of university–entrepreneurial firm collaboration: (1) industry-sponsored contract research, (2) consulting, (3) technology licensing and (4) technology development and commercialization. These four topics were selected because practitioners on both sides of the interaction consider them to be both important to understand and fundamentally different for entrepreneurial firms as compared to large, established firms.

[2] For example, Shane (2001a) shows that the probability that patents assigned to the Massachusetts Institute of Technology are licensed to start-up companies has increased over the period 1980–1996.

By focusing on these topics, this article provides a comprehensive summary of the areas that practitioners involved in university–private sector technology interaction need to be aware of to understand the differences as they affect entrepreneurial firms.

Although this article summarizes university–entrepreneurial firm collaboration in general, it identifies specific differences (if reported) between the biomedical, agricultural and information technologies. In addition, the article summarizes differences (if reported) between Research I and II and Doctoral I and II universities.

The methodology used to create this article consisted of a review of existing published and unpublished academic articles, government reports and nonprofit organization white papers. No original research was conducted to produce this article.

4. Findings

Researchers have suggested a variety of ways in which universities interact with the private sector over technology (Cohen et al., 1998; Rosenberg and Nelson, 1994). Although much of the discussion of university–private sector interaction is the same for all firms, researchers have identified several factors that differ when the private sector firm is an entrepreneurial organization. These differences can be categorized along four dimensions of university–entrepreneurial firm interaction: (1) industry-sponsored contract research, (2) consulting, (3) licensing of technology and (4) university involvement in technology development and commercialization. In this section, I discuss the findings in each category, beginning with contract research.

4.1. Contract research

To date, observers have identified six different ways in which university–entrepreneurial firm interaction may differ from university–large firm interaction in contract research.

1. *Entrepreneurial companies are less likely than established companies to engage in contract research.* The proportion of contract research funded by entrepreneurial companies at research universities is minuscule. Government agencies provide 70% of funding, and foundations and large firms fund most of the remainder.

Several explanations have been given for the limited involvement of entrepreneurial firms in contract research. First, entrepreneurial firms are less likely than large firms to monitor technological developments from other sources (Woolgar, 1998). Second, entrepreneurial firms are more likely to be involved in the application of existing technical knowledge (development) than in research. Third, faculty favor contract research with large, established firms because interaction with these firms generates greater research and teaching benefits (Lee, 1999).[3]

[3] This situation may not hold true for entrepreneurial firms in biotechnology. Firms are more likely to set up links with universities in industries with greater R&D intensity. Therefore, in biotechnology, entrepreneurial firms may be willing to conduct contract research at universities.

2. *Entrepreneurial companies are less likely than established firms to participate in research consortia.* Fewer than 10% of member companies in university–industry research consortia are small businesses, and start-up companies rarely emerge from university-based consortia (Tornatzky et al., 1999).

Several explanations have been given for the limited involvement of entrepreneurial firms in research consortia. First, to avoid property rights problems, consortia focus on relatively fundamental research at earlier stages of the innovation process (Tornatzky et al., 1999). However, entrepreneurial firms often cannot afford the luxury of such long-term thinking, given their relatively weak cash positions. Second, research consortia do not eliminate the need for R&D programs, which facilitate knowledge transfer from the consortia back to the firms. As Mowery (1998, p. 42) explains, "as in other types of R&D collaboration, significant investments by participating firms to support inward transfer and application of the results...were indispensable. Firms that found [them] to be especially beneficial had invested heavily in this relationship, including significant personnel rotation, travel and communications. Along with the small size of their budgets, the costs of these investments made [those] involving small firms difficult to manage." Third, entrepreneurial firms seek exclusive licenses to technologies, making them less likely to invest through consortia, which generally provide nonexclusive licenses to consortium members.

3. *Entrepreneurial companies prefer customized arrangements for contract research with universities.* Research agreements work best when the magnitude of contract research is large, and the sponsors repeat the arrangements over time. In general, entrepreneurial companies do not like these arrangements because they focus on one or two research projects at a time and do not seek help for the same stage of development repeatedly (Tornatzky et al., 1999). As a result, the creation of research agreements with entrepreneurial firms tends to be more labor intensive than for established firms. Consequently, university contract administration offices have a bias toward contracting with large firms.

4. *Entrepreneurial companies rely heavily on government-funded research rather than on industry-sponsored research.* Entrepreneurial firms often seek collaboration with universities to obtain access to government-funded basic research. Therefore, involvement with universities that involves the financing of new research is relatively unappealing to them (Government University Industry Research Roundtable, 1991).

5. *Contract research from entrepreneurial companies is more geographically localized than contract research from large firms.* Lesser travel budgets, combined with a need for deep involvement of firm personnel, make entrepreneurial firms less likely than large firms to contract research at a distance. Since many local universities lack expertise in particular fields, this tendency toward localization makes entrepreneurial companies less likely to become involved with universities. It also leads universities to develop expertise that supports the clusters of new technology firms in their area. Although this pattern exists across all universities, it is particularly prevalent for Carnegie II universities (Mansfield and Lee, 1996).

6. *Contract research from entrepreneurial companies is often contingent on the right to license exclusively.* In general, entrepreneurial firms utilize universities' intellectual capacity and equipment to make proprietary advances. Consequently, they generally require exclusive

rights to any developments from their contract research with universities (Government University Industry Research Roundtable, 1990).

The major explanation for this emphasis on obtaining exclusive rights is that entrepreneurial companies do not want other firms to gain access to their proprietary technology. Entrepreneurial companies are more reliant than large firms on intellectual property protection since they lack the complementary assets in manufacturing and distribution that large firms use to obtain competitive advantage from new technology.

4.2. Consulting

To date, observers have identified four different ways in which university–entrepreneurial firm interaction may differ from university–large firm interaction in consulting.

1. *Consulting arrangements with entrepreneurial firms require more intense involvement by faculty than consulting arrangements with large firms.* Many entrepreneurial companies become involved with universities to commercialize university inventions. When university inventions are licensed, they often require further development by university researchers.[4] Harmon et al. (1997) found that few university inventors leave the university but rather generally help to commercialize the invention on a part-time basis. Moreover, many venture capitalists advise prospective firm founders to remain on campus and develop the early stages of their technology to conserve cash (Etzkowitz, 1998). Furthermore, entrepreneurial companies often undertake subsequent development in universities because they lack R&D labs in which to do further development work.

Because of the importance of university researchers in the development of technology licensed to entrepreneurial companies, personnel practices that allow the company to use the academic research group for technology development is often important to company formation and growth. University policies that limit consulting activities to 1 day/week and limit leaves of absence to academic settings, or for small amounts of time, hinder these arrangements (Tornatzky et al., 1995).

This issue may be particularly important in biotechnology. Zucker et al. (1998) explain that biotechnology companies are often founded by star scientists from leading universities because the special expertise of these scientists in performing new techniques allow them to earn economic rents on their abilities. These scientists keep their university positions but are often deeply involved in entrepreneurial firms as principals, members of the scientific advisory boards or consultants.

2. *Consulting arrangements with entrepreneurial companies impose greater questions of conflict of interest than do consulting arrangements with large firms.* Tornatzky et al. (1995) report that 37% of respondents to their survey about university technology transfer believe that conflict of interest polices, particularly over faculty equity ownership, hinder the involvement of entrepreneurial firms with universities.

[4] For example, Jensen and Thursby (2001) found that only 12% of university inventions were ready for commercial use at the time of license, and manufacturing feasibility was known for only 8%.

Because of their cash constraints, entrepreneurial firms often pay academic researchers with equity. This creates strong incentives for university researchers to act in the best interest of the entrepreneurial firm even if that creates conflicts of interest with the academic's university role. As Blumenthal (1992, p. 3348) explains, "when investigators have financial relationships (usually through consulting or equity holding) with companies that may benefit from their clinical research, the resulting conflicts of interest, real or apparent, are particularly troublesome for academic institutions. The problem lies in the potential damage to the credibility and public reputation of the life sciences that could flow from real or apparent misconduct associated with academia–industry relationships (AIRs) involving research on humans."

This problem is particularly great when the consulting arrangement is designed to facilitate the transfer of a faculty member's invention. As Tornatzky et al. (1999, p. 21) explain, "the faculty inventor—who may be the impetus for the start-up—is likely to take an equity share in the enterprises. Either by university policy or technology management practice, he/she is usually discouraged or prohibited from assuming a role as a principal, director or manager of the company. Similarly, while the inventor will usually be permitted to consult or do contract research for the company, this is usually proscribed by policy and conflict of interest management procedures. Unfortunately, if these restrictions on the subsequent role of the faculty inventor are too onerous and his/her contributions are critical to the success of the new enterprise, their net effect may be to discourage subsequent investment and put the business at risk."

3. *Consulting arrangements with entrepreneurial companies are more likely the result of personal ties than are consulting arrangements with large firms.* Most small companies that use faculty as consultants already have strong ties to universities and know both the university and the particular faculty member well (Tornatzky et al., 1999). Several explanations have been given for a personal approach to consulting. First, large firms often invest in formal programs, like the Massachusetts Institute of Technology Industrial Liaison Program, that provide them with access to all university faculty in return for payment of a flat annual fee. Entrepreneurial firms, however, can rarely afford these fees. Second, by funding research in faculty members' laboratories, large firms obtain access to the consulting expertise of the lead professor and members of his or her research team. Since entrepreneurial firms fund less research, they access less ancillary consulting from contract researchers. Third, large firms often have departments devoted to university technology transfer or university relationships. Lacking these departments, entrepreneurial firms engage in less formal scanning to identify useful expertise at universities than large firms do (Harmon et al., 1997). Since entrepreneurial firms do not engage in formal search, they are more likely to discover the existence of needed expertise through personal and professional relationships.

4. *Consulting arrangements with entrepreneurial companies often exist to transfer technology out of the university.* Large companies often obtain consulting expertise from faculty to assist with cutting-edge technical advances made by their firms. In contrast, entrepreneurial firms often establish consulting arrangements to use faculty as technical advisors on start-ups that make use of their inventions.

4.3. Licensing

To date, observers have identified eight different ways in which university–entrepreneurial firm interaction may differ from university–large firm interaction in technology licensing.

1. *Technology licensing by entrepreneurial firms depends on complementary mechanisms to provide financing.* Large firms can fund the development of technologies licensed from universities on the basis of their internal cash flow. However, entrepreneurial firms often need access to financing to undertake these licenses. Moreover, the technologies transferred to entrepreneurial firms often require greater investment than the technologies transferred to large firms. For example, Pressman et al. (1995) report that, at the Massachusetts Institute of Technology, 77% of investment induced by licenses occurs in entrepreneurial companies, while only 35% of licenses are to those companies.

Several types of complementary mechanisms are used to provide entrepreneurial companies with capital to finance technology licensed from universities. First, as Tornatzky et al. (1995) explains, some universities bring venture capitalists to university campuses (e.g., ARCH venture partners at the University of Chicago) or have venture capital funds (e.g., Washington University). Second, some universities also use their technology transfer offices as brokers to the venture capital community. For example, Shane and Cable (forthcoming) found that the founders of companies to exploit inventions assigned to the Massachusetts Institute of Technology often used the technology licensing office to help them to gain access to venture capitalists and business angels. Third, some universities, like Washington University and the Massachusetts Institute of Technology, invest university endowment in their spin-off companies (Florida and Kenney, 1990). Fourth, some universities have established programs to fund further development of university inventions (e.g., Virginia's Center for Innovative Technology and the Faculty Research Commercialization Program at Georgia Tech) (Tornatzky et al., 1995).

Although the need for complementary mechanisms to obtain financing is important across all technologies, it is greatest in biotechnology, which is extremely capital intensive.[5]

2. *Technology licensing by entrepreneurial firms depends on mechanisms to lower royalty payments.* Licensees of university technologies often face large costs to commercializing the university technology because of the embryonic state of the technology at the time of license. Unlike large firms, entrepreneurial firms often cannot afford the additional cost of royalties on top of these development costs. Therefore, some institutions cap early royalties to help entrepreneurial companies (Government University Industry Research Roundtable, 1990). As Tornatzky et al. (1999, p. 21) explains, "operationally, the university will still license the technology, but the license will have different terms and oversight requirements. For example, the new/small enterprise licensee will be unable to swallow a deal with lots of cash up front or with obligations for early and large minimum royalty payments."

[5] John Preston, the former director of the Technology Licensing Office at the Massachusetts Institute of Technology, estimates that 40 biotechnology companies emerged from inventions at the Massachusetts Institute of Technology in the 5 years from 1985 to 1990. These companies raised over US$70 million in venture capital funds.

3. *Technology licensing by entrepreneurial firms depends on mechanisms to capitalize patent costs in the form of equity investments.* Unlike large firms, entrepreneurial firms cannot afford the cost of patenting university technologies. As Wallmark (1997, p. 137) explains, for large firms, "the average turnover per patent is 10–100 times larger than the corresponding figure for the university spin-off companies. The conclusion is that the patent cost for small companies, which have not yet had time to grow in the marketplace, is large relative to the large companies and creates a severe handicap for emerging new firms." Therefore, some universities like the University of Colorado, Massachusetts Institute of Technology and Columbia University take equity instead of cash as payment for patent costs (Tornatzky et al., 1999). Overall, equity investment is included in approximately 23% of executed licensing agreements, but licenses with equity tend to be to start-ups with enabling technologies (Jensen and Thursby, 2001).[6]

It is important to note that private universities are more likely than public universities to make equity investments in new firms (Lee, 1996).

4. *Technology licensing by entrepreneurial firms depends on technology licensing office expertise in firm creation.* In many cases, university technology licensed to entrepreneurial companies will go to companies at seed or start-up stages of firm development. Therefore, success at this effort will require a licensing office that is staffed with officers who understand the firm creation process. Expertise in business planning, fund raising and marketing is important (Tornatzky et al., 1999).

5. *Technology licensing by entrepreneurial firms depends on providing licensees with strong intellectual property protection.* Entrepreneurial firms generally require exclusive license to a university invention because they often lack other types of competitive advantage. In fact, over 80% of the Massachusetts Institute of Technology's exclusive patent licenses are to entrepreneurial companies (Pressman, 1997).

6. *Technology licensing by entrepreneurial firms depends on access to technology families.* Large firms generally seek university technology to complement their own R&D efforts and rarely make a university invention the basis of their new products or processes. Therefore, large firms often see value in licensing a single university invention. However, entrepreneurial firms often rely on university technologies to create new products and processes, leading them to license whole families of patents (Wallmark, 1997).

It is important to note that the need for technology families should make entrepreneurial companies more likely to license inventions at Carnegie I institutions because university patenting is highly concentrated, with the top 20 universities patenting approximately 70% of all university patents (Henderson et al., 1998).

7. *Entrepreneurial firms license different types of technology than do large firms.* Shane (2001a) found that more heavily cited, more radical and broader scope patents assigned to the Massachusetts Institute of Technology between 1980 and 1996 were more likely to be

[6] This policy is quite controversial at universities. Only 27% of faculty thought that universities should make equity investments in university start-ups, and only 44% felt that start-up assistance should be provided to new technology companies (Lee, 1996).

licensed to start-up companies. More important inventions are licensed to start-ups because greater technical advance is necessary to justify making an investment in a new firm. Radical technologies are more likely to be licensed to start-up firms because these technologies destroy the capabilities of existing firms, because established firms will not invest in technologies that cannibalize their existing investments, and because established firms filter out information about new technologies. Broader scope patents are more likely to be licensed by start-up firms because patents are often the most important asset for new and small firms.

The types of technology licensed by entrepreneurial firms may vary by industry. As Tornatzky et al. (1995, p. 11) found, "certain fields of science and technology were more compatible with start-up businesses. Having a medical school was cited as helpful as well as particular strengths in medical devices, instrumentation and diagnostics. Another area cited was software and allied technologies (e.g., expert systems), perhaps because of the limited capital needs of a new business in this field and negligible barriers to entry, particularly in niche markets. Both were seen as having strong potential for start-up situations." Similarly, Shane (2001b) found that industries that were younger, where markets were more segmented and where patents were more effective, inventions assigned to the Massachusetts Institute of Technology were more likely to be licensed by start-ups.

8. *Entrepreneurial firms license inventions from different inventors than do large firms.* Shane and Khurana (2001) found that those patents assigned to the Massachusetts Institute of Technology between 1980 and 1996 that were invented by people with more start-up experience were more likely to be commercialized through license to a new company. Wallmark (1997) found that spin-off companies were more likely to be started by undergraduate and graduate students, whereas licensing to established companies was more likely for associate and full professors.

However, these differences may vary across industry. In biotechnology, the creation of new companies depends heavily on the presence of star scientists at particular universities (Zucker et al, 1998).

4.4. Technology development

To date, observers have identified three major findings about how university–entrepreneurial firm interaction over technology development may differ from university–large firm interaction over technology development.

1. *Science and technology parks have a larger influence on university–industry interaction for entrepreneurial firms than for large firms.* Academic researchers and industry personnel are more likely to interact when they are colocated (Vedovello 1997). Because entrepreneurial firms are more likely than large firms to locate in science and technology parks (Etzkowitz, 1989), these institutions have a greater effect on the university interaction patterns of entrepreneurial firms than on the patterns of large, established firms.

2. *Subsidy programs have a larger influence on university–industry interaction for entrepreneurial firms than for large firms.* Several universities have developed subsidy programs to enhance the development of their spin-off companies as well as entrepreneurial companies from the surrounding community. These programs include incubators, leased

access to laboratories and equipment and in kind product development assistance (Tornatzky et al., 1995). These subsidy programs increase university–entrepreneurial company interaction by lowering the cost of technology development for cash strapped firms.

It is important to note that support for technology transfer subsidy programs among faculty is stronger in lower-ranked universities than in higher-ranked universities (Lee, 1996).

3. *Buffering institutions have a greater effect on entrepreneurial companies than on large companies.* Many universities have created buffer institutions to transfer the research of faculty to local industry by conducting applied work. Examples include agricultural experiment stations, cooperative extension services and extension programs focused on manufacturing technology, the Applied Physics Laboratory at Johns Hopkins University, the Charles Stark Draper Laboratory at the Massachusetts Institute of Technology, the Jet Propulsion Laboratory at California Institute of Technology and state laboratories in Michigan, Pennsylvania and Colorado (Brooks and Randazze, 1998).

Brooks and Randazze (1998, p. 385) provide the major explanation for why buffer institutions are more important to entrepreneurial firms than to large firms. They write, "Before they are likely to commercialize academic research findings, small firms will often require that academic research findings be pursued further downstream than is typical for university departments. This would require dedicated personnel who might not fit comfortably into the normal academic culture, where they might tend to be regarded as second-class citizens and be evaluated by criteria inappropriate for their real responsibilities. . .[Therefore,] buffer institutions might afford an especially useful way to connect universities with small and medium-sized companies that do not have formally organized R&D departments."

These buffer institutions may be more important in certain industries than in others. Research has shown that they are particularly important in mature industries because firms in these industries can benefit from accessing well-known, prepackaged technologies (Business-Higher Education Forum, 1988).

Moreover, Postlewait et al. (1993, p. 285) explain that extension services are important in agricultural biotechnology because of the tradition of agricultural extension in universities. They explain, "without Extension, the structure of the agricultural biotechnology industry is likely to be noncompetitive since only large agrochemical and seed companies, which already have field research facilities, will be able to widely test and effectively market new products. Collaboration with farm advisors may enable smaller companies to adapt their products and introduce them to different environments. As a case in point, Biosis's introduction of nematodes as pest control agents for soilborne diseases in various berries and vegetables would not have been possible without reliance on the knowledge and research capacity of farm advisors in different locations."

5. Future empirical research

The review of publications on university–entrepreneurial firm interaction also indicated several areas in which relatively little is known. In this section, I make several recommendations for future research to shed light on these topics.

1. *Examine the differences between entrepreneurial companies generated by universities and entrepreneurial companies seeking university assistance.* The review of existing publications suggested that there were two different models of entrepreneurial company interaction with universities. The first model was one in which university faculty (or sometimes other entrepreneurs) identified a university discovery that they sought to commercialize by starting a new company or growing a small company. The second model was one in which an entrepreneur sought assistance from the university to further develop his or her company. Although there was no systematic evidence on this topic, the existing research suggested that some types of university–entrepreneurial firm interaction (e.g., contract research and licensing) may be used predominantly by firms following model one and other types of entrepreneurial firm interaction (e.g., technology development) were used by firms following the second model. Since the best practices for university–entrepreneurial firm interaction may depend on the model of involvement adopted by firms, this topic should be explored empirically.

2. *Examine the differences between different types of entrepreneurial companies.* The review of existing publications did not differentiate between the types of entrepreneurial companies interacting with universities. However, firms started by university faculty are likely to interact with universities in different ways from those started by professional entrepreneurs. In addition, venture capital-backed firms are likely to interact differently from bootstrapped companies. Since the best practices for university–entrepreneurial firm interaction may depend on the nature of the entrepreneurial firm, future research should examine these differences.

3. *Examine the differences across industries.* This article identified a small number of differences in university–entrepreneurial firm interaction across industries. However, these results were far from systematic. Since one would expect that cross-industry variation in the nature of appropriability, the importance of complementary assets, the locus of innovation and capital requirements should influence the nature of university–entrepreneurial firm interaction, future research should explore this issue. Otherwise, any description of best practices for university–entrepreneurial firm interaction may be inaccurate.

4. *Examine the differences across types of universities.* This article identified a few differences across types of universities in university–entrepreneurial firm interaction. However, these observations were insufficient to explain how university type affects this relationship. Before best practices for university–entrepreneurial firm interactions can be identified, a systematic understanding of the fit of these practices to particular types of universities is necessary. For example, state institutions that are barred from making equity investments in licensees of their technology may not find equity investment to be a best practice even if it increases university–entrepreneurial firm interaction across all firms! Three general categories of university type will likely influence best practices: size, funding source and quality. Future research should explore the interaction of these university characteristics on practices for enhancing university–entrepreneurial firm interactions.

5. *Examine the differences across the stage of development.* One area in which no information was found was the effect of the stage of development on university–entrepreneurial firm interaction. It is plausible to assume that such interaction is different when the firm is developing the proof of principle, prototyping, making initial sales or developing a second

generation of products. Since what may prove to be best practice at one stage may be less effective at another stage, future research should explore this important question.

6. *Examine one-time and repeat firms.* No information was found on the differences between one-time interactors and repeat interactors. Before best practice can be identified for university–entrepreneurial firm interaction, researchers must determine if systematic differences exist across these two groups.

6. Conclusions

This article reviewed the state of current knowledge about university–entrepreneurial firm interactions in research and technology transfer. It showed that interactions between universities and entrepreneurial firms are different from interactions between universities and large, established firms. The article summarized the major issues in university–entrepreneurial firm interaction across four dimensions—(1) industry-sponsored contract research, (2) consulting, (3) licensing of technology and (4) university involvement in technology development and commercialization—and made several recommendations for future research.

An understanding of the differences summarized here will help university officials and entrepreneurs develop better university–industry interactions. Universities that recognize the issues elucidated here will know that they need to develop different policies than those in force for large firms for interacting with entrepreneurial companies. For example, universities interested in licensing more technology to entrepreneurial firms might wish to adopt policies that take their payment for those costs in the form of equity rather than cash.

The article also suggests the importance of a change in mindset among universities interested in interacting with entrepreneurial firms. Differences in the nature of the interaction between large, established firms and entrepreneurial firms is broad—encompassing contract research, licensing, consulting and technology development and assistance—and deep—involving a variety of differences in each area. Although policy changes, such as those mentioned above, might facilitate better university interaction with entrepreneurial firms, these policy changes will need to be accompanied by a change in philosophy. The pervasive nature of the differences suggests that simply applying the philosophy toward private sector interaction that has evolved from interactions with large, established firms would be incomplete, and perhaps even problematic, when dealing with entrepreneurial firms.

At a more micro level, the discussion presented here suggests how entrepreneurs and technology transfer officers could identify which universities are most appropriate for entrepreneurial firms, given the approaches in place at specific institutions. For example, entrepreneurs might want to avoid contract research at universities intent on establishing research consortia as a major vehicle for such activity. Astute entrepreneurs can use the information contained in this article to determine whether interaction with the university would be likely to occur in a manner productive to them or if they should avoid investing scarce resources in a relationship not well designed for their interests.

In addition, the discussion presented here provides insight for researchers interested in further guiding practitioners in this domain. Although the article highlights several areas in

which university–entrepreneurial firm interactions differ for large, established firms and entrepreneurial organizations, it also indicates that much more work could be done. More subtle investigation that considers the type of entrepreneurial company, the industry that it is in, the stage of technology development and other factors would provide great value to practitioners in this field.

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