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MARKETS FOR RESEARCH: A MATCHING APPROACH TO UNIVERSITY-INDUSTRY RESEARCH COLLABORATIONS

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Dissertation Summary submitted to the Ewing Marion Kauffman Foundation.

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This research was funded in part by the Ewing Marion Kauffman Foundation through its Dissertation Fellowship Program. The author gratefully acknowledges the foundation's financial support. The contents of this dissertation and all related working papers are solely the responsibility of the author. This summary is written for a general audience.

February 2009

Abstract: University research-based technological opportunities are often created and exploited through joint corporate and academic entrepreneurship activities such as university-industry research collaborations. This dissertation aims to understand what determines a "good match" between faculty and firms involved these relationships. Firm-faculty collaboration is approached as an endogenous matching process driven by the synergy in knowledge-creation capabilities of the partners. This theoretical model is applied to investigate whether and when attributes such as knowledge breadth and depth, scientific and technological capabilities are complements or substitutes in knowledge creation, and to assess their relative importance in the matching of faculty and firms.

INTRODUCTION

Recent developments in the university-industry relationship suggest that firms do not passively rely on knowledge spillovers generated through published academic research. Increasingly, firms search for new scientific knowledge and technological opportunities through direct corporate entrepreneurship activities, such as licensing of academic inventions and collaborative research (Cohen, Nelson, and Walsh, 2002; Mowery and Shane, 2002; Thursby, Jensen and Thursby, 2001). This trend has attracted considerable academic and policy attention. For the management literature, of particular interest are the implications for firm performance of these collaborations. A significant body of evidence shows that firms establishing direct links with university research increase their innovation performance. Examples of innovation outcomes include more important patents (Cockburn and Henderson, 1998), a faster pace of knowledge exploitation (Fabrizio, 2006), more novel products (Belderbos, Carree and Lokshin, 2004), more products in development and on the market, and a significant increase in firm employment (Zucker, Darby and Armstrong 1998, 2002).

Although previous studies have documented the positive contribution of university-firm alliances to innovation, our understanding of the partners' characteristics which create more value remains unclear. Surprisingly, very few studies go deeper into examining the outcome of collaboration as to capture the characteristics of the partners. Most of the studies include a dummy variable capturing collaboration, and only a handful of large scale empirical studies have information on both scientists and firms. Moreover**,** methodological limitations -- notably endogeneity and measurement problems – restrict our ability to draw strong inferences from the previous studies.

To illustrate, consider the finding that industry alliances with "star" scientists lead to substantially higher firm performance than relationships with any other university scientists (Zucker et al. 2002). A managerial advice derived from this result is that firms aspiring to increase their innovation performance should engage in collaborative research with star scientists. This conclusion raises important questions from a strategy standpoint. Companies may prefer establishing ties with star scientists, but are firms equally attractive to prominent scientists? Could star scientists be equally successful in their research endeavors regardless of which firms they collaborate with? Furthermore, if "success is in the stars" (cf. Zucker et al. 2002), why do university-firm research alliances occur across a whole quality-range of university departments and academic researchers (Mansfield,1995)? Ultimately, all these questions relate to a central issue: *What characteristics of firms and academic scientists reinforce each other to make an alliance more valuable*?

This dissertation addresses this gap in the literature. I argue that one of the reasons for which the existing literature has not answered these questions is because most of the studies have investigated the benefits from collaboration from the perspective of either firms or universities, and have failed to look at them jointly. In this study, I present a theoretical framework that captures the co-determination of value creation and the ability to attract desirable partners under competitive conditions, when both parties' preferences are taken into account. I build on the idea that insofar as university-firm research alliances are formed intentionally to capitalize on partners' knowledge, the innovative output depends on the synergy between the capabilities brought to the relationship by both scientists and firms. Drawing upon the economic theory of two-sided matching (Becker 1973; Roth and Sotomayor, 1990) and the resource-based view (Barney 1986; Lippman and Rumelt, 1982, 2003) I analyze the alliance formation as an endogenous matching process, in which partners sort themselves by attributes relevant for knowledge-creation.

The first part of the dissertation focuses on theory development. It starts by discussing the general theoretical underpinnings of two-sided matching, and it proposes a model of alliance formation rooted in the resource-based view and matching theory. The details of the model are further discussed in the context of university-industry research alliances. The second part of the dissertation focuses on estimating an empirical matching model. Several hypotheses that link the matching theory with the sources of value creation in university-industry alliances are developed. These hypotheses are tested in a unique sample of firm-scientist research collaborations by using a non-parametric matching estimator developed by Fox (2007).

Relative to a baseline set of reinforcing attributes capturing the history of cross-organizational collaboration, this study finds that firm-faculty alliances create more value when partners are complementary in their scientific capabilities, when they substitute each other for lack of patenting skills, and when they complement each other with different types of knowledge (diversified or specialized). In addition, the strength of complementarity between partners' research quality is moderated by scientists' life cycle effects. Although in general, higher-quality academic research is more productive when paired with higher levels of industrial scientific capabilities, faculty with both experience and research prominence substitute for the lack of scientific knowledge of the lesser science-intensive firms. A short presentation of the theoretical framework, data, results and contributions follows.

THEORY

The theoretical approach of this dissertation builds on the idea that firm-scientist alliances can be viewed as *voluntary partnerships among complementary pairs formed under competition for partners*. Classic examples of similar processes include marriages and employment (Mortensen, 1988), as well as the formation of a wide range of business relationships such as those between firms and their IPO underwriters (Fernando, Gatchev, and Spindt, 2005), start-ups and VC investors (Sorensen, 2007), CEO and firms (Tervio, 2008), or inter-firm contracting in supply-chain networks (Ostrovsky, 2008), among others.

The following three features of university-industry alliance formation define the matching process: 1) Firm-scientist alliances are voluntary relationships that form when both parties expect to *mutually benefit* from collaboration. 2) The value of innovation generated through collaboration is determined, at least in expectation, by the *identity* of the scientists and firms involved in a relationship. Thus, *both* firms and scientists have preferences over whom to team-up with. In collaborations intended for scientific discovery, preferences are essentially driven by the belief that joint work with partners of certain type will have a higher probability of generating valuable knowledge. 3) Both firms and scientists are restricted in the number of collaborations they can undertake at a time. Taken together, preferences over potential partners and restrictions in the number of collaborations suggest that in the market for research, agents on each side of the market are rivals in allying with the most "desirable" partner on the other side of the market.

Matching theory explains what happens when all features of alliance formation - voluntary collaboration, two-sided decision making, and competition for better partners are considered in interaction (Becker, 1973; Mortensen, 1988; Roth and Sotomayor, 1990). The decision of two individual agents (firms/scientists) to team-up depends not only upon their preferences, but also on their effective choice set, which is constrained by the decisions made by all other agents in the market. What might be optimal for an agent had he or she been able to choose a partner without any constraints, is very different from what is optimal for the same agent when choices of the other agents are taken into account. On the one hand, the likelihood that an agent teams-up with his or her preferred partner is influenced by the existence of other agents on the same side of the market wishing to ally with the same party. On the other hand, this likelihood is also influenced by the partner's willingness to enter into an

alliance, which is determined by all the other options for collaboration that the partner might have. Thus, dyad-level decisions interact to constrain each other.

Up to this point, the discussion has informed the endogeneity aspect of partnership formation. Complementarity and substitutability between the attributes of the partners have been first considered by Becker (1973) in his analysis of the marriage market. [1] The core proposition established by Becker translates, in our context, into the following prediction: *Ceteris paribus*, *if two inputs (capabilities of a scientist and a firm, respectively) are complements in knowledge creation, in equilibrium, firms and scientists having more of these inputs will work together, leaving firms and scientists with less of these inputs to select each other.* Conversely, if two inputs are substitutes, then firms (respectively, scientists) scoring high on one input will match with scientists (firms) scoring low on the other input, and vice versa. [2]This dissertation applies the assortative matching result to determine which attributes of firms and scientists complement or substitute each other in research alliances.

DATA AND METHOD

Research contracts between firms and scientists are usually treated as confidential information, by both firms and universities. Due to these constraints, prior research has predominantly relied on co-authorship to infer collaboration. However, this approach is a very crude proxy for determining the existence of a research contract between a scientist and a firm. Many contracts do not result in joint co-authorship; often times, and at best, the only paper trail is the acknowledgement of private funding in a footnote. Even this practice has not always been customary. Only recently have journals started to require authors to acknowledge the sources of their financial and material support (Hussain and Smith, 2001). Moreover, joint co-authorship might be the result of informal ties between faculty and scientists working in the industry, and not of formal firm-scientist collaboration (Powell, Koput & Smith-Doerr, 1996). To overcome these problems, I use information on research alliances obtained directly from the Grants and Contracts Office of a U.S. Medical School. This school has been consistently ranked among the top five U.S. Medical Schools and it is part of a private university located on the East Coast.

[1] I use the notions of complementarity and substitution according to the mainstream definition in the economics and management literature. Specifically: 1) *Two attributes are complements in innovation if having **more** of one **raises** the marginal value (or the incremental return) of having **more** of the other. 2) Two attributes are substitutes in innovation if having **more** of one **decreases** the marginal value of having **more** of the other.*

[2] In game-theoretic terms, assortative matching is optimal and stable.

The data set has several attractive features. First, the firm-faculty collaborations in the sample are *formal* research relationships which reflect clear intent towards generating new knowledge and innovation. Second, the data set covers the *full range* of faculty collaboration with the industry over the 1996-2004 timeframe. The sample consists of 238 firms and 217 scientists. Together, they were involved in 455 collaborations. Among firms, 69% collaborated with one scientist only. Larger and older firms are engaged in a greater number of collaborations- a finding that is consistent with the evidence from other studies on university-industry relationships. The company with the highest number of collaborations is located in the same geographical area as the Medical School. This company is large, old, and its publishing and patenting activity are very intense. Of the 217 scientists, 57% collaborated with only one firm. The maximum number of research alliances per faculty is equal to ten, but very few scientists had reached more than six collaborations. Faculty doing both basic and applied work tended to be engaged in more relationships than their colleagues.

Overall, there is a large variation in the sample in terms of firms' and scientists' characteristics. The distribution of firm age indicates that at the time of collaboration, 13% of the firms were start-ups (i.e. age less than 5 years since foundation) and 20% were founded from 5 to 15 years before. The median firm age is 26 years. Among all 238 firms, only 21 had ties with universities at their formation (either their founders were university professors, or these firms were licensing university technology from the inception). While previous studies tend to overstate the relationships that old firms and start-ups have with universities, this evidence suggests that "middle range" firms engage in substantial collaboration. On average, firms in the sample publish more than they patent. This is not surprising, as other studies of biotechnology and pharmaceutical firms have noticed a similar behavior (e.g. Gittelman and Kogut, 2003). Likewise, there is a variation among scientists in terms of academic age and other attributes at the time of collaboration. Scientists in the sample became involved in relationships with companies as soon as four years after graduation. The median and the mean of the scientists' academic age distribution are around 17 years since graduation. The average number of faculty publications is 72, but the number of publications of the top 10% scientists goes beyond 200, with a maximum of 395. On average, scientists in the sample hold two patents, and 40% of collaborations involve a professor with at least one patent.

The empirical analysis is based on a non-parametric estimation developed by Fox (2008). This method estimates the relationship between partners' attributes (complementarity versus substitution) by taking into account that that the observed alliances are formed through a matching process, wherein

each partner choice decision depends on all other partnerships formed in the market. The estimation builds on the idea that if the observed firm-scientist alliances are the equilibrium outcome of a matching process, then the realized matches should generate more value relative to the feasible unrealized pairings (otherwise, partners would have sorted differently and been better off).

RESULTS

The results provide strong support for the idea that the process of alliance formation cannot be studied without a careful consideration of the nature of synergy between the capabilities of the partners. As a starting point, the analysis takes into account the history of university-industry past collaboration and it stipulates a positive relationship between scientists with an interest towards commercial applicability of their research (as reflected by a tendency for collaborating with the industry) and firms exhibiting a propensity to harness academic scientific ideas. Thus, it is implicitly assumed that more value is generated when the intensity of past collaboration is higher. Relative to this baseline relationship, the following patterns are observed.

First, a complementarity relationship exists between scientists' research quality and firms' scientific capabilities. Faculty of better research quality and firms with higher scientific capabilities enjoy higher returns from working together. Previous research has shown that firms endowed with a higher scientific capital are able to build a higher number of partnerships with other firms, and with university scientists in particular (Ahuja, 2000; Arora and Gambardella, 1994; Cockburn and Henderson, 1998). This dissertation points towards a different, strategic effect, in the sense that firms with higher endowments on dimensions relevant to innovation are able to attract university partners of higher research *quality*.

In addition, the strength of complementarity between partners' research quality is moderated by scientists' life cycle effects. Young and mid-career scientists are more preoccupied with building and enhancing their academic career, and for these professors, scientific capabilities of the firms constitute an important consideration in their decision of whom to collaborate with. Senior scientists' incentives are different (Stephan, 1996). In particular, senior scientists with tenured appointments tend to reallocate some of their effort to consulting and other income generating opportunities, such as patenting (Azoulay, Ding and Stuart, 2005), and establishing closer ties with the industry. The empirical analysis in this study indicates that scientific capabilities of the partners reinforce each other in alliances between faculty at the beginning and middle of their career and firms. Conversely, senior scientists' skills and experience act as a substitute for firms of relatively lower scientific capital.

Second, the analysis points towards substitution between firms' and scientists' patenting activity. This relationship suggests that, *ceteris paribus*, the lower the firms' patenting activity the higher the returns from allying with scientists with a good record of generating innovations with commercial applications. Likewise, scientists with a clear interest in commercializing their scientific ideas do not build alliances with partners of high recent patenting activity on their own. Rather, these scientists enjoy higher marginal benefits from partnering with firms with lower patenting activity. Presumably, these firms are more likely to exploit scientists' inventions than firms with an intensive patenting activity. Thus, university-industry alliances seem to be driven by the need to compensate one side's shortage of technological skills (as manifested in patenting activity) by the appropriate choice of a partner on the other side.

Third, firm-scientist alliances generate more value when breadth of knowledge is paired with knowledge specialization. This result is consistent with the idea that firm-scientist alliances are generally motivated by exploration purpose, rather than local search. More specialized firms and scientists look outside for new combinations of their existing knowledge base and match with partners of larger knowledge horizons. Equally, knowledge-diversified actors create more value by teaming-up with specialists, who could fill knowledge holes with their targeted expertise.

CONCLUSIONS

This dissertation makes several contributions to the literature on university-industry knowledge transfer. First, it provides a theoretical foundation and a methodology for estimating the sources of complementarity and substitution among the alliance partners. The theoretical framework advances a model of alliance formation rooted in the resource-based perspective, which builds upon the conceptualization of two-sided markets to take into account the strategic aspects of partner choice. The empirical analysis examines the relative importance of various characteristics that drive the matching of firms and scientists in research alliances. The results indicate that the value of scientist-firm collaboration is created by a combination of complementarity in scientific capabilities and substitutability in knowledge type and technological skills. Had the model not shown a systematic relationship between the attributes of the partners, we would have concluded that only the history of past university-industry collaboration matters in alliance formation. However, the model corroborates the idea that in addition to building on previous university-industry ties, alliance formation is based on the synergy between attributes relevant for knowledge creation.

Second, this dissertation sheds new light on several empirical regularities not yet addressed in the literature on university-industry relationships. This study brings in a distinct perspective on the performance-enhancing effect of affiliation with "star" professors found in other studies. While previous work has emphasized the value-added contribution of the "stars", this study highlights the presence of sorting in the markets for research. Simply stated, it is argued that matching leads to an optimal sorting in the market where "star" scientists team-up with firms with whom they have the strongest compatibility and thus, higher productivity.

More importantly, this dissertation argues that a scientist's "stardom" status is not determined exogenously. On the contrary, it is the subtle interplay between firms' own endowments and the nature of complementarity/substitutability characterizing the "fit" between the alliance partners that shape firms' valuation of scientists. Consider, for example, the role of scientific and technological capabilities in innovation. The analysis shows that scientists that both patents and publish are most valuable to firms with higher scientific capabilities and lower patenting activity (such as young, research-intensive firms), than to established firms that patent on their own. Conversely, scientists with an outstanding contribution to basic research, but without a patenting record, generate more value by allying with firms endowed with both scientific and technological capabilities.

The empirical results of this study generate several broader implications for practice. Successful strategies in Schumpeterian environments depend not only on the appropriability of innovation rents, but also on access to complementary assets. The matching perspective points out that in contexts in which synergistic gains are crucial, the competition for partners takes place on attributes relevant to the innovation process. By identifying the attributes that matter for a cross-boundary research alliance, the model provides useful insights for firms that seek to attract better partners.

Several patterns have emerged. On the subject of scientific and technological capabilities, the model suggests the following interesting relationships. In the biomedical field, many start-ups and young firms might try to tap into new scientific knowledge and innovations generated through university research. With the increase in university patenting, these firms could be tempted to establish alliances with faculty early in the innovation process, so that they could have the first option to license new technologies. This study shows that firms seeking to ally with professors with a greater commercial orientation - as manifested by a good record of patenting activity, need to pay attention to both their own scientific capabilities, and their potential collaborators' scientific capabilities. Indeed, in the

matching process observed at the medical university in this sample, firms lacking a good scientific record might be able to ally with scientists that have patented intensively in the past, but most likely these scientists will be ones with a lower research quality. Thus, in the competition for scientists with a good patenting and publishing record (Pasteurs of the current world), the only chance for firms lacking a patenting record by themselves stands from these firms being able to compensate through higher scientific capabilities. Likewise, the skills of scientists emulating Pasteur's example are in better use when they collaborate with research intensive firms that are just starting to build a technological trajectory. For these scientists, firms' patenting activity is somewhat irrelevant. What matters in alliance formation is that firms possess high scientific capabilities.

A different story can be said about scientists that contribute mainly to basic science (scientists in Bohr's quadrant). All things being equal, firms with higher scientific capability would naturally want to collaborate with better scientists. However, the matching model suggests that prominent scientists doing basic research are more productive in alliances with firms endowed with both high scientific and technological capabilities, rather than with firms of high scientific capabilities but lacking technological skills. Thus, although science-intensive firms might consider they have the relevant skills to establish ties with top faculty, these firms will not be able to attract professors that perform high-quality basic research, unless they also possess high technological capabilities.

Other implications of the model relate to the breadth of knowledge that firms need to take into account when collaborating with faculty. While focused (specialized) firms may want to go outside their organizational borders and establish ties with academic experts in a field (i.e. highly specialized prominent scientists), the empirical matching model suggests that these scientists have a better fit with knowledge-diversified firms. Thus, within the matching logic, firms may want to expand their knowledge-base first, and only then will they be able to compete for academic experts. Nevertheless, narrowly-specialized firms can greatly benefit in this process from the advice of university scientists with experience across multiple knowledge domains.

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