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. In the management literature, of particular interest are the implications of university-industry collaborations for firm innovation performance. A significant body of evidence shows that these collaborations lead to more important firm patents (Cockburn and Henderson, 1998); to patents of higher quality (Cassiman, Veugelers, and Zuniga, 2006); to more products in development and on the market (Zucker et al., 2002); and to a growth of sales from products that are novel to the market (Belderbos, Carree, and Lokshin, 2004).

In this literature, the sources of value creation in university-industry research alliances remain largely an under-explored area. Most of the empirical studies of performance have focused on linking an innovation output to a simple cooperation indicator measuring the presence of university-industry relationships. Surprisingly, very few studies go deeper into examining the outcome of collaboration in relation to the characteristics of the partners (e.g. Cockburn and Henderson, 1998; Zucker, Darby and Armstrong 1998, 2001, 2002). These studies typically proceed by regressing a performance measure on the observed characteristics of firms, scientists, or universities. The underlying logic is that knowing if, or how much individual characteristics of the partners affect the alliance performance can tell us which factors describe the value of a partnership. However, there is a potential problem with this approach that deserves attention. This methodology is valid only under strict conditions: either (1) all potentially relevant characteristics that influence performance are included in the equation and measured without errors, or (2) the alliance formation is a random process. Clearly, the first condition is hardly met in empirical studies. In strategy research, where great emphasis is placed on the strategic i.e. non-random aspect of alliance partner selection, the second condition is equally problematic.

It is the recognition of these strategic considerations leading to partnership formation that motivates this study. Put succinctly, if there are incentives whereby particular types of partners end up in alliances, the typical regressions of performance on partners’ characteristics that do not account for this endogenous sorting process lead to biased estimates and incorrect conclusions. This potential endogeneity problem has been mentioned in the empirical literature (Cockburn and Henderson 1998, Zucker et al. 2002). Still, its theoretical and empirical implications do not seem to have been fully discussed. 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. 1998, 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”- as Zucker et al.(2002) maintain, 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 study attempts to address this gap in the literature. To answer these questions, I propose a theoretical framework that models partnership formation in relation to the sources of value creation in research alliances. I argue that insofar as university-firm research alliances are formed intentionally to capitalize on partners’ knowledge, the innovative output depends on the synergy between the individual capabilities brought to the relationship by both scientists and firms. Accordingly, I draw upon the economic theory of two-sided matching (Becker 1973; Mortensen, 1988; Roth and Sotomayor, 1990), and I analyze the alliance formation as an endogenous matching process, in which partners sort themselves by attributes relevant to innovation. Further, I apply this framework to empirically investigate whether and when attributes such as knowledge breadth and specialization, scientific and technological capabilities are complements or substitutes in knowledge creation.

A MATCHING MODEL OF PARTNERSHIP FORMATION

The theoretical approach taken in this paper builds on the idea that firm-scientist alliances can be viewed as voluntary partnerships among complementary pairs formed under competitive conditions. 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 et al., 2005), start-ups and VC investors (Sorensen, 2007), or inter-firm contracting in supply-chain networks (Ostrovsky, 2004), among others. The argument that research alliances between firms and scientist should be analyzed as a matching process is based on the following three features of alliance formation: 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
theory points out that 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 one hand, the likelihood that an agent teams-up with 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, it is 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. Accordingly, although some partnerships might look “suboptimal” from the perspective of the dyad, they are “optimal” from the perspective of all linkages in the market.

Up to this point, the discussion has informed the endogeneity aspect of partnership formation. In the matching literature, the complementarity and substitutability between the attributes of the partners have been first considered by Becker (1973) in his analysis of the marriage market. 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.* The model implies that complementarity (substitutability) in knowledge creation can be inferred from the observation of the matches by investigating which attributes of scientists and firms are, *ceteris paribus*, positively (negatively) associated. In conclusion, the theoretical framework of matching allows us to examine the dimensions on which scientists and firms complement or substitute each other in innovation.

**HYPOTHESES**

An important question in the literature on university-industry relationships is whether scientific capabilities of academic scientists complement or substitute firms’ scientific capabilities. The absorptive capacity perspective argues that firms seeking to assimilate and exploit external know-how need to develop a strong internal knowledge-base (Cohen and Levinthal, 1990). Scientific capability, or a firm’s stock of scientific knowledge is an important dimension of the overall firm’s absorptive capacity, particularly for firms involved in science-driven discovery (Cockburn, Henderson and Stern, 2000; Fabrizio, 2007). Studies testing the extent to which firms take advantage of academic scientific knowledge have shown that absorptive capacity explains the *propensity* and the *degree* of collaboration with academic scientists (Mowery, 1983; Arora and Gambardella, 1990; Cockburn and Henderson, 1998). While these studies establish that in-house basic research is necessary for utilizing academic knowledge and engaging in direct ties with scientists, the question that I raise is whether firm-scientist alliances are driven by the synergy between scientists and firms with higher scientific capabilities. In other words, within the population of firms that collaborate with the academia, do better scientists work with firms with higher scientific capabilities? Or, do prominent scientists *substitute* for the lack of outstanding scientific capabilities? The later, substitution hypothesis, is consistent with the view that given the high transaction costs inherent to any research alliance, firms will not engage in external collaborations unless external sources are substantially better than what firms could do internally (Hoetker, 2005). It is also consistent with the broad view that
university research is substituting for industrial research (Blank and Stigler, 1957; Rosenberg and Nelson, 1994; David, Hall and Toole, 2000). Thus, I propose to test the following two alternative hypotheses: (H1a) *Ceteris paribus, scientists’ research quality and firms’ scientific capabilities are complements in innovation* versus (H1b) *Ceteris paribus, scientists’ research quality and firms’ scientific capabilities are substitutes in innovation.*

Although there are no a priori reasons to believe that either H1a or H1b is true, I posit that scientists’ academic age acts a moderating factor. Interviews indicate that career concerns are higher for younger scientists than for senior scientists. The reward system in academia provides incentives for scientists to be more preoccupied with building a scientific prestige in the early stages of their career. These constraints and priorities change over the time (Stephan, 1996). At later stages in their academic career, scientists’ are more prone to reap the rewards of their scientific reputation by establishing ties with firms founded with the explicit goal of developing knowledge created in university labs (Stephan and Everhart, 1998). This line of arguments suggests that it is more likely to observe young scientists teaming up with research intensive firms, and senior scientists substituting for firms’ lack of scientific capabilities. Hence: (H2) *Ceteris paribus, there is a complementary relationship between younger scientists’ research quality and firms’ scientific capabilities, and a substitution relationship between senior scientists’ research quality and firms’ scientific capabilities.*

A related question in the literature on technology transfer is whether university-firm collaborations are driven by a division of labor among universities and firms in which universities contribute with new “scientific knowledge”, and firms contribute with “technological knowledge” (Cohen and Levinthal, 1990; Rosenberg and Nelson, 1994). If such a division of labor in innovation exists, we expect to find university scientists of higher research quality to be more productive if they work with firms of higher technological capabilities, and vice-versa. Accordingly, I propose: (H3) *Ceteris paribus, (academic scientists’) research quality and (firms’) technological capabilities are complements in innovation.*

Knowledge attributes represent another set of potential sources of complementarities in research collaborations. Breadth (knowledge diversification) and specialization in a particular field (expertise) are such examples. Specifically, I propose that a narrowly specialized agent will realize greater synergies by joining forces with a more diversified external partner that will think up new approaches and envision new applications based on the agent’s expertise. Likewise, I maintain that an agent with a diversified knowledge base creates value by teaming up with a specialized external collaborator that can fill his particular knowledge “holes”. Accordingly, I propose the following hypothesis: (H4) *Ceteris paribus, knowledge diversification and specialization are complements in innovation.*

**DATA AND METHOD**

To test these research questions, I use a sample of research collaborations between firms and faculty obtained directly from the Grants and Contracts office at one of the top US Medical Schools. The sample consists of 238 firms and 217 scientists, for a total of 455 contracts during the 1998-2005 timeframe. In addition to this primary data source, I use numerous secondary sources to construct the variables necessary to test the model: MicroPatent U.S. patent database, Delphion, Medline, ISI Web of Science, Directory of Corporate Affiliations, and Lexis-Nexis.

**Firm-level variables.** In line with the existing empirical literature, I measure firms’ *scientific capabilities* as the average number of publications over a ten year window before the
collaboration year (DeCarolis and Deeds, 1999; Gittelman and Kogut, 2003). I use the cumulative number of patents over a six year window prior to the collaboration year to capture firms’ technological capabilities (Arora and Gambardella, 1994; Ahuja, 2000). I construct the variable “breadth of a firm’s knowledge base” as an entropy measure of diversification based on the technological distribution of a firm’s patents in the technology domains defined by the inventive IPCR patent classes (Bierly and Chakrabarti, 1996; Miller, Fern and Cardinal, 2007).

**Scientist-level variables.** I measure faculty research quality as the number of publications per career year weighted by the journal quality, as reflected in the ISI Journal Impact Factor. I defined the variable knowledge-diversification as an entropy measure of diversification based on the scientific domains in which academic scientists have been publishing. To identify these scientific domains, I rely on MESH headings, which are the subject terms assigned by the National Library of Medicine to each article published in Medline journals.

**Estimation Method.** The main challenge in estimating complementarities arises directly from the fact that the observed alliances are formed through a matching process, wherein each partner choice decision depends on all other relationships formed in the market. This aspect complicates the estimation, because there are as many endogenous variables as the observed matches. When alliances are treated as independent decisions, as it is done in standard discrete choice models, the likelihood of observing a set of firm-scientist pairs can be factored into a product of low-dimensional integrals representing the likelihoods of each agent’s decision to ally. Conversely, in a matching situation, all error terms must be integrated simultaneously. The standard ML estimation approach requires integrating over thousand dimensions- a procedure that is not possible numerically.

This study takes a radically different route. I use an estimation method that allows us to make inferences about the relevant complementarities in alliance formation without observing and quantifying the alliance performance. This technique is based on a non-parametric maximum score estimator developed by Fox (2007). The estimator requires specification of a production function, but it does not impose a distribution on the error terms. Instead of calculating the probability of match formation, the maximum score estimator relies on the local production maximization condition. This condition asserts that the sum of the value created by any two pairs of observed alliances is greater than the value created if these pairs exchanged their partners. This property builds on the idea that if the observed partner choices are the outcome of a matching process, then the realized matches should generate more value relative to the feasible unrealized pairings.

**RESULTS AND DISCUSSION**

The results of the multivariate analysis show that the value of scientist-firm collaboration is created by a combination of complementarity and substitutability in knowledge type (breadth and specialization), scientific capabilities, and technological capabilities. 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. In Hypothesis 2, I advanced a more nuanced story, in which the strength of complementarity between partners’ research intensity is moderated by scientists’ academic age. I find that indeed, scientists’ life cycle effects are present in university-industry collaborations. In alliances between firms and faculty at the beginning and middle of their career, the scientific capabilities of the partners reinforce each other. Conversely, senior
scientists’ experience and research prominence substitute for the lack of scientific knowledge of the lesser science-intensive firms.

Further, the analysis shows that scientists with higher research quality and firms with lower technological capabilities tend to select each other. This is a counter-intuitive result, as a positive relationship between research quality and technological capabilities was proposed in H3. As an alternative explanation, I examine whether firms’ technological capabilities create complementarities with a different attribute of faculty expertise: faculty capacity to generate commercially-oriented innovations (captured by the number of patents filed before the collaboration). However, the analysis indicates strong substitution between firms’ and scientists’ patenting activity: ceteris paribus, the lower the firm’s 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 productive 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 on their own. Presumably, these firms are more likely to exploit scientists’ inventions than firms with an intensive patenting activity. Thus, in addition to the complementarity in research intensity found in H1 & H2, 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.

Lastly, as proposed in H4, the type of knowledge the partners possess is important in alliance formation. The combination of knowledge breadth and specialization generates more value than other combinations of knowledge-type. This result is consistent with the idea that firm-scientist alliances are generally motivated by exploration purpose, rather than local search. Specialized firms and scientists go outside looking for new combinations of their existing knowledge base and match with partners of larger knowledge horizons. Equally, knowledge–diversified agents create more value by teaming-up with specialists that fill knowledge holes with their targeted expertise.

Conclusions. This study provides a theoretical foundation and a methodology for estimating cross-organizational complementarities in knowledge creation. The matching perspective points out that in contexts in which synergistic gains are crucial, competition for partners takes place on attributes relevant to innovation. By identifying the various characteristics that drive the matching of firms and scientists in research alliances, the model explains why certain firm-scientists collaborations are more likely to attain superior performance. It also generates useful insights for firms that seek to attract better partners, particularly “star” faculty.

More generally, the paper argues that the ex-post alliance performance cannot be explained without taking into account the antecedent selection process leading to alliance formation. The paper contributes to the management literature by introducing a model of alliance formation that explicitly addresses the endogeneity problem created by the self-selection of the partners into alliances. The framework developed here has a broad applicability to other business situations in which the researcher anticipates endogenous sorting and strategic intent in partner selection.

REFERENCES AVAILABLE FROM THE AUTHOR