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**TECHNOLOGY SOURCING AND OUTPUT OF ESTABLISHED FIRMS IN A REGIME OF ENCOMPASSING TECHNOLOGICAL CHANGE**

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*This paper argues that when the technological basis of an industry is changing, the firm’s approach to technology sourcing plays a critical role in building the capabilities needed to generate new technical outputs. Using survey and archival data from the U.S. pharmaceutical industry during the period 1981–91, we find that different approaches to technology sourcing (internal R&D and external R&D) are related to different types of biotechnology-based output at the end of the period. Internal R&D was positively associated with patent output. Acquisition activity was positively related to number of biotechnology-based products. Greater use of R&D contracts and licenses was associated with stronger reputation for possessing expertise in biotechnology. These findings underscore the importance of taking a multifaceted approach to technology sourcing in order to build the absorptive capacity needed to generate new technical output. Surprisingly, we also found that involvement in joint ventures was negatively related to patent output. This raises interesting questions about the strategic use of joint ventures in a regime of encompassing technological change.* Copyright  2003 John Wiley & Sons, Ltd.

**INTRODUCTION**

Technological responsiveness

exceptions (Mitchell, 1991; Nicholls-Nixon, 1995; Suarez and Utterback, 1995; Garud and Nayyar, 1994; Rosenbloom, 2000), there is a paucity of work that has focused on explaining why some established firms may actually *succeed* in making the transition to a new technology.

It is this interest in explaining the ability of established firms to respond to technological change that motivates the present study. A new technological regime emerges when developments in science or technology fundamentally *change* the nature of the problems being pursued, the material technology employed, and/or the heuristics used to approach the problem (Dosi, 1982, 1988). These ‘encompassing technological changes’ (Nagarajan and Mitchell, 1998) affect the core capabilities needed to remain competitive. Moreover, they have implications for the learning requirements associated with developing new technological capabilities.

is a critical issue

in our ‘new competitive landscape’ (Bettis and Hitt, 1995). The ability of firms to continually

update their technological know-how and capa- bilities is becoming an imperative for competi- tive survival (D’Aveni, 1994; Christensen, 2000; Foster and Kaplan, 2001). Compelling arguments have been advanced to explain why established firms encounter difficulty when the technological basis of an industry changes (Cooper and Schen- del, 1976; Nelson and Winter, 1982; Tushman and Anderson, 1986; Henderson and Clark, 1990; Christensen and Bower, 1996). With few notable

Key words: technology sourcing; absorptive capacity; technological change; biotechnology

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As a result, firms use different approaches to technology sourcing depending on the nature of the technological changes affecting the business. In their study of the medical lithotripsy industry, Nagarajan and Mitchell (1998) found that equity alliances were used in regimes of encompassing technological change, internal R&D dominated when technological change was incremental, and nonequity alliances were prevalent during periods of complementary technological change (i.e., radical changes that had a greater effect on the firm’s complementary activities than on its core resources/capabilities).

While Nagarajan and Mitchell’s work provides a foundation for explaining/predicting how the methods used for technology acquisition vary *across* different regimes of technological change, our study speaks to the question of how technology sourcing practices vary *within* regimes of technological change and how this variation is related to the ability to generate new technical output. Specifically, we argue that an understanding of this relationship lies at the heart of explaining why some established firms are more effective than others at responding to encompassing technological change.

Firms in the pharmaceutical industry faced this situation in the mid 1970s when the emergence of biotechnology fundamentally changed the material technologies and heuristics associated with devel- oping products aimed at the diagnosis, prevention, and/or cure of human (and animal) health-related conditions. Focusing on this emerging technologi- cal regime, we use survey and archival data, cov- ering the period 1981 – 91, to explore how dif- ferences in the technology sourcing strategies of established pharmaceutical firms during this period are related to the firm’s ability to generate techni- cal output based on biotechnology by the end of the period.

Technology sourcing is a multidimensional construct. It refers to the firm’s approach to developing new technological capabilities, both in terms of the use of in-house R&D and through the use of external technology sourcing ‘linkages’ (Auster, 1990) or ‘strategic technology alliances’ (Hagedoorn and Schakenraad, 1994), such as R&D contracts, licenses, joint ventures, minority equity investments, and acquisitions.

Technical output is also multidimensional. In this study, we employ three measures of technical output: the number of patents that the firm

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holds based on new technologies; the number of products, based on the new technologies, that the firm has on the market or under review by regulatory agencies; and the firm’s reputation for possessing expertise in the new technologies.

Building on prior work by Mitchell and Singh (1996), we argue the need for a ‘dual sourcing’ imperative whereby firms utilize both internal and external R&D as a means of developing new technical output. We argue that, together, internal and external R&D build the ‘absorptive capacity’ (Cohen and Levinthal, 1990) that underlies current and future technical output. Absorptive capacity is the ability to identify and assimilate new knowledge that originates from extramural sources (such as spill-overs by competitors or discoveries made in university or government labs) and to exploit this new knowledge by applying it to commercial ends.

Cohen and Levinthal (1990) first introduced the absorptive capacity construct and explored the industry-level conditions that influence the incentive to invest in it. Subsequent work has explored absorptive capacity at the alliance level: Mowery, Oxley, and Silverman (1996) studied the association between the extent of a firm’s absorption of technological capabilities and various characteristics of its relationship with alliance partners, such as: prealliance level of technological overlap, R&D intensity, firm size, and national traits of the alliance partners. Lane and Lubatkin (1998) argue that interorganizational learning is a function of relative absorptive capacity. The ability of one firm to learn from another depends upon the similarity of their knowledge bases, organization structures and compensation policies, and dominant logics.

While this focus on the learning dyad is clearly an important area of research, the present study differs from past work by arguing that the development of absorptive capacity is not just a matter of ‘who’ firms partner with; it is also a matter of ‘how’ they manage their overall strategic approach to technology sourcing (Nicholls-Nixon, 1995). We assert that because technology sourcing practices contribute to the development of absorptive capacity, they have implications for the ability of established firms to generate new output when the technological basis of their industry is changing.

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**INTERNAL R&D AND TECHNICAL OUTPUT**

it increases the prospect that incoming informa- tion will relate to what is already known’ (Cohen and Levinthal, 1990: 131). In turn, we expect that this will have a positive influence on the firm’s ability to generate outputs based on new technical developments.

Internal R&D contributes to technical output because it builds the prior knowledge that is needed in order to identify, assimilate and exploit technological spill-overs from the firm’s external environment (Cohen and Mowery, 1984; Cohen and Levinthal, 1990). Internal R&D produces an intermediate good: firm-specific knowledge, which enables the firm to absorb external technology (Cohen and Mowery, 1984). Rosenberg (1990:

171) asserts that internal R&D is needed because it takes ‘a substantial research capability to understand, interpret and to appraise knowledge that has been placed upon the shelf.’

Building on Cohen and Levinthal’s assertion that investment in internal R&D contributes to absorp- tive capacity, we assert that there will be a positive relationship between investment in internal R&D and output based on new technical developments.

*Hypothesis 1b: In an emerging technological regime, the greater the breadth of the firm’s internal R&D activities, the greater the subse- quent technical output of the firm.*

**EXTERNAL R&D AND TECHNICAL OUTPUT**

Our second assertion is that in emerging techno- logical regimes the *sources* of knowledge used to develop technical outputs become a critical issue. Expanding the breadth of a firm’s internal R&D may help mitigate the uncertainties associated with the emergence of a new regime. However, even with these efforts, it is virtually impossible for any one firm to keep abreast of all the relevant tech- nological advances solely through internal R&D efforts (Horwitch, 1986; Teece, 1988; Contractor and Lorange, 1988; Burgelman and Rosenbloom, 1989). When a new regime emerges, the techno- logical know-how required to compete shifts out- side the firm’s locus of expertise and the firm’s internal stock of technical knowledge becomes less relevant (Teece, 1988). As such, firms must look to external partners to complement their in- house R&D.

Arora and Gambardella (1990) suggest that dif- ferent types of linkages or alliances are used to access different types of knowledge. When basic knowledge is advancing rapidly, nonequity link- ages with universities and minority equity invest- ments in other commercial firms provide an effi- cient way to access basic knowledge and moni- tor technological developments in areas in which the firm is unwilling or unable to develop its own internal capabilities. Alternatively, nonequity agreements with other firms are often used to access products that are ready for commercial- ization. Finally, the acquisition of a firm that already possesses expertise in a new technology may be a speedier means of building internal capabilities than establishing a green-field R&D unit within the firm (notwithstanding potential problems integrating the acquired firm into the par- ent’s existing organizational structure). Literature

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*Hypothesis 1a: In an emerging technological regime, the greater the level of investment in internal R&D, the greater the subsequent tech- nical output of the firm.*

It is important to note that our argument is not simply that a firm that invests more will have more efforts and thus more output. What we wish to emphasize is that internal R&D also impacts the firm’s ability to more efficiently screen, access, and assimilate outside knowledge. In other words, internal R&D builds the absorptive capacity of the firm.

Another basic premise in Cohen and Levinthal’s (1990) construct of absorptive capacity is that firms need to manage the *diversity* of their knowledge structures. While a sufficient level of overlap in knowledge structures is needed to ensure effec- tive communication, the possession of diverse and different knowledge structures enhances the orga- nization’s potential for innovation by providing an opportunity to make novel linkages and asso- ciations. This is especially true in an emerging technological regime where a variety of unproved technologies compete for dominance. Until one or more of these technologies becomes the industry standard, there is a great deal of uncertainty as to which one(s) will prevail (Rosenberg, 1982). Under these circumstances, ‘a diverse background provides a more robust basis for learning because

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based on transaction cost economics and orga- nizational learning perspectives suggests that the form of alliance undertaken by a firm (equity vs. nonequity) depends upon the difficulty of the learn- ing environment and the complexity associated with knowledge development/transfer (Pisano, 1989; Pisano and Teece, 1989; Nagarajan and Mitchell, 1998). Thus, different types of technol- ogy sourcing linkages are appropriate in different situations. Building on this perspective, Steensma and Corley (2000) found that the effectiveness of different types of technology sourcing partner- ships (joint development agreements, licenses, and acquisitions) varies depending upon the attributes of the technology being pursued and degree of technical change and uncertainty in the external environment.

Taken together, this literature suggests that in order to build the absorptive capacity needed to generate new technical outputs, firms need to pur- sue multiple types of technology sourcing linkages since different linkages are used to access/develop different kinds of knowledge.

and exploit knowledge obtained from/developed through these external sources. Rather, our key assertion is that in an established regime internal R&D may be sufficient because a narrower base of knowledge is required than in an emerging regime. When a new technological regime evolves greater knowledge diversity is needed, as reflected by our interest in the breadth of both internal as well as external R&D activities pursued.

Second, the more experience that firms have in structuring and managing each type of alliance, the greater the likelihood that they will be able to ‘make good’ on these relationships. Previous research suggests that experience using specific types of external linkages enhances the firm’s ability to use these linkages effectively (Gulati, 1995; Anand and Khanna, 2000). Prior experience enables the firm to learn how to select a partner, determine what elements of the relationship can be established at the outset, and adapt the relation- ship as technological and environmental conditions change (Lyles, 1988; Hladik, 1988; Lorange and Probst, 1987).

*Hypothesis 2a: In an emerging technological regime, the greater the number of different types of technology sourcing linkages (R&D contracts,*

*Hypothesis 2b: In an emerging technological regime, the greater the number of technology*

*sourcing linkages of each type (R&D contracts, licenses, acquisitions, joint ventures, and minor-*

*licenses, acquisitions, joint ventures and minor- ity equity investments) pursued by the firm, the greater the subsequent technical output of the firm.*

*ity equity investments) that a firm has used, the greater the subsequent technical output of the firm.*

Not only is it important for firms to pursue a variety of different types of technology sourcing linkages, but it is also important to pursue sev- eral linkages of each type. There are two reasons to expect this relationship. First, pursuing multiple alliances of each type hedges the risk associated with focusing on a limited set of opportunities too early in the evolution of the paradigm. Because of the rapid pace of technological change dur- ing a paradigm shift, no single firm can keep abreast of all the relevant technological develop- ments solely through internal research (Friar and Horwitch, 1986). Therefore, by pursuing multiple linkages of each of the types described previously, the firm enhances its ability to identify and seize technological opportunities as they emerge. It is important to note that we are not suggesting that external sources of knowledge take the place of internal R&D. Internal R&D is still critical to the development of the firm’s ability to assimilate

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**METHODS**

**Sample selection**

The U.S. pharmaceutical industry is chosen as the setting for this study. Since the emergence of biotechnology in the mid 1970s, this indus- try has been widely acknowledged as experienc- ing the emergence of a new technological regime (Friar and Horwitch, 1986; Hamilton, 1986; Arora and Gambardella, 1990). Development of capabil- ities in monoclonal antibody production, recombi- nant DNA technology, and bioprocessing held the potential to revolutionize the safety, efficacy, and cost effectiveness of pharmaceutical and diagnostic products.

The sample for this study consists of a sub- set of 26 of the 39 firms listed in *Biotechnology in the U.S. Pharmaceutical Industry* (1992). The

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report contains information on the pharmaceutical companies and their affiliated sites in the United States that have biotechnology products in devel- opment. It includes all U.S.-based pharmaceuti- cal corporations and major U.S.-based subsidiaries of foreign pharmaceutical companies that have diversified into biotechnology. Consistent with the study’s focus on technological responsiveness by established firms, we excluded seven firms from the sample because they were established after the emergence of biotechnology (these firms were formed between 1976 and 1981). We also focused on firms that were similar in size and commit- ment to the pharmaceutical industry as evidenced by their being listed on the *Fortune* 500, the *Busi- ness Week* R&D Scoreboard, or close in size to the firms on either of these two lists. Thus, another six firms were eliminated because they were substan- tially smaller (average revenues of $220 million; average R&D budgets of $13 million). The sam- ple firms were all parent firms or U.S. subsidiaries of foreign parents founded in the late eighteenth or early nineteenth century (the youngest firm in our sample was founded in 1944) with average revenues of $7.4 billion and average R&D expen- ditures of $607 million.

sample firms. Respondents were identified using *Bioscan* (1991) and the *Directory of American Research and Technology* (1991). These reports list the key personnel of firms active in biotechnology. Respondents were chosen on the basis of their title, which reflected responsibility for R&D, in general, or biotechnology in particular.

Surveys were sent to multiple respondents in each of the firms, resulting in a total of 117 poten- tial respondents. Usable responses were obtained from 22 of the 26 firms in the sample (84.61%). Of the 22 firms that responded to the survey, multi- ple responses were received from six of the firms: Two of the firms had four or more respondents; another four firms had two respondents. Telephone conversations and written correspondence received from the respondent suggests that the low num- ber of multiple responses may be attributed to the fact that, in many cases, the respondents worked together to complete a single survey which was then returned on behalf of all respondents. Other times, respondents indicated that they did not have the expertise needed to complete the survey and that they had forwarded the survey on to some- one else. Often, that person was already part of the sample. Finally, even though the cover letters indicated that the survey was being sent to several executives in the firm and that multiple responses were a crucial part of the study, respondents from several of the firms indicated that they would not be returning the survey because someone else from the firm had already done so.

Our approach for dealing with multiple res-

ponses is addressed in the discussion of the two variables derived from the survey data: reputation (dependent variable) and investment in internal R&D (independent variable). It is important to acknowledge the potential for common method bias in this research, since the same survey was used to collect data on both of these variables.

**Data collection**

Secondary sources were used to obtain data on the firm’s technology sourcing activities over the 10-year period from 1981 to 1991 and on their cumulative technical output at the end of this period. These data were obtained from the follow- ing sources: (a) *Biotechnology in the U.S. Phar- maceutical Industry*, (b) the U.S. Department of Commerce Patent and Trademark Office *Patent Bibliographic File* (1981 – 91), and (c) the 1991 Survey report, *Biotechnology Medicines in Devel- opment* .

A survey instrument was used to collect data on the firm’s investment in biotechnology and the reputation of each of the sample firms for pos- sessing biotechnology expertise. The survey instru- ment was designed and implemented according to Dillman’s (1978) Total Design Method for Sur- veys. The survey was pretested on three executives from the pharmaceutical industry and the director of a major nonprofit organization that monitors the activities of firms involved in biotechnology. The survey was administered by mail in the summer of 1992 to multiple respondents in each of the

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**Dependent variables**

When established firms are confronted with the emergence of new technological regime their focus is on developing expertise in the set of techniques that are relevant to that regime. Yet, techniques and knowledge are not ends in themselves. They must be embedded in outputs which lead to commer- cialization. As such, this study uses the following measures of technical output.

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*Biotechnology patents*

For each firm, we counted the cumulative number of biotechnology patents (PAT), that were assigned to the firm during the period 1981 – 91. These data were obtained from the U.S. Department of Com- merce Patent and Trademark Office *Patent Bibli- ographic File*. We defined biotechnology patents in terms of classification 935 (genetic engineering: recombinant DNA technology, hybrid or fused cell technology, and related manipulations of nucleic acids). Thus, we included in our patent count for each firm all of the patents in classification 935 that were assigned to the firm during the period of the study.

Our measure does not include the patent counts associated with companies that were acquired by the focal firm during the period of the study, nor does it include patents that were accessed by the focal firm through licensing agreements. This approach to measuring patents reflects our interest in studying how technology sourcing prac- tices contribute to the firm’s ability to generate *new* technical output. It is inappropriate to include patents accessed through acquisition or licensing agreements, since these reflect purchases of *exist- ing* technology by the focal firm.

that includes products at *all* stages of development, rather than restricting the measure to include only those products that had attained FDA approval for commercialization. In this way, we mitigate the bias toward products that have shorter develop- ment cycles and are quicker to reach commercial- ization. We feel that this broader conceptualiza- tion of products as measures of technical output is appropriate in the present study since our interest is more about the creation of biotechnology-based knowledge than it is about measures of technical success.

It is important to note that products were inclu- ded in the firm’s count only when the firm was named as the developer. If one of our sample firms acquired a company(ies) during the period of the study, the products associated with the acquired company were not included in the sample firm’s product count. Their inclusion would overstate the sample firm’s technical output in biotechnology, since products gained through acquisition repre- sent purchases of technology that already exist. By not including acquired products in our count, we focus attention on the contributions that acquisi- tions make to technical output by providing access to new knowledge, rather than to specific products.

*Reputation*

The firm’s overall reputation for possessing exper- tise in biotechnology (REP) was measured by peer evaluation using the survey instrument. We felt it was necessary to supplement our tangible count- based measures of technical output with another measure that reflected the intangible nature of capability development. This seems particularly relevant at the early stages of a new technolog- ical regime where tangible output is limited. At the time of this study, there were only 14 biotech- nology products on the market and another 132 in various stages of development. Similarly, the cumulative number of genetic engineering phar- maceutical health care patents issued to U.S. firms was only 138 (169 worldwide). Thus, although there was a great deal of research activity focused on biotechnology, there were few tangible out- comes. In developing a measure of a firm’s repu- tation for possessing biotechnology expertise, our intention was to tap into another dimension of technical output, beyond that which is attributable solely to count-based outcome measures, while

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*Biotechnology products*

For each firm, we counted the cumulative number of biotechnology products (PROD) that the firm had on the market, or under review by regulatory agencies, as of 1991. These data were obtained from the 1991 Survey report of *Biotechnology Medicines in Development* published by the Phar- maceutical Manufacturers Association (PMA). Products were included in a firm’s count if (1) they were in any of the three phases of development at the FDA, (2) applications for approval had been submitted or were pending approval at the FDA,

(3) they were in human clinical trials, or (4) they had received final approval by the FDA.

Products as a measure of technical output can be influenced by differences in the firm’s strate- gic focus. For example, firms that emphasized the development of biotechnology-based diagnos- tic kits would attain commercial success more quickly than those who emphasized therapeutics, simply because the FDA development/approval process is less complicated and faster. Thus, we have adopted a robust measure of technical output

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recognizing that respondents would draw upon such information in making their assessments.

Information regarding the strength of the firm’s reputation for possessing expertise in new biotech- nologies was obtained by peer evaluation using the survey instrument. Survey respondents were given a list of firms active in biotechnology. Using a 5-point Likert-type scale they were asked to give their assessment of each firm, in terms of its current level of expertise in human health care

over 18 years’ experience in the pharmaceutical industry. We found the interrater reliability for

all experts to be high (cronbach’s alpha = 0*.*93).

Therefore, we averaged the score for each firm, across all survey respondents, and used the mean score as our measure of reputation for possess- ing expertise in human health care applications of biotechnology (REP).

**Independent variables**

Our hypotheses are concerned with the relationship between the firm’s technology sourcing strategy practices and subsequent technical output. Thus, we measure technical output (the dependent vari- ables) at the end of the study period and examine the relationship to dimensions of the firm’s tech- nology sourcing strategy over the period of the study. Technology sourcing strategy was opera- tionalized as follows.

applications of biotechnology (1 = very low level

of expertise; 5 = very high level of expertise).

In providing their assessments, respondents were asked to consider the following as indicators of the possession of biotechnology expertise: num- ber of patents (both pending and issued) based on biotechnology; number of new drug applica- tions before the FDA; number of products under development or being marketed, which are based on biotechnology; facilities or equipment dedi- cated to biotechnology R&D; number of alliances with other firms involving research, development, and/or commercialization of biotechnology prod- ucts or production processes.

Providing this anchor in the survey question ensures that the respondents have a common frame of reference for evaluating biotechnology exper- tise. This is necessary because technological exper- tise is ‘invisible.’ Therefore, it is assessed by using tangible indicators or symptoms of its possession (Henderson and Cockburn, 1994). The danger of not providing such an anchor is that expertise means different things to different people and it would be unclear whether all respondents shared the meaning or definition of the construct.

Thus, while we acknowledge that the anchors used in our measure of reputation may be con- founded with our measures of products and patents, the results of correlation analysis suggest that a conceptual distinction is supported (intercorrela- tions between our three measures of technical output— patents, products, and reputation — range from 0.30 to 0.38; *p <* 0*.*05). As noted by one of our reviewers, the low values of the correlation coefficients suggest that the dependent variables are tapping into different dimensions of technical output.

Finally, it is important to note that our mea- sure of reputation was derived by averaging the score received for each firm on the 5-point Lik- ert scale described previously. The survey respon- dents were industry experts with an average of

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*Investment in internal R&D*

Level of investment in R&D, or ‘R&D intensity,’ is commonly operationalized as R&D expendi- tures expressed as a percentage of sales (Cohen and Levinthal, 1990; Cohen and Mowery, 1984). Prior studies have not distinguished between inter- nal R&D and external R&D expenditures. Further- more, data on R&D expenditures are not divided into these two categories when it is reported in public sources, such as annual reports and 10-k reports. Therefore, a survey instrument was used to obtain this information.

Our survey question asks respondents to esti- mate how their firm’s biotechnology R&D expen- ditures were allocated between internal R&D and external R&D such that the total allocation adds to 100 percent. Respondents were asked to provide this information for two time periods: 1981 – 85 and 1986 – 91. Internal R&D was defined as bio- technology R&D conducted in-house by the firm, at either the corporate or the divisional level. External R&D was defined as biotechnology R&D conducted for the firm by an alliance partner, such as: a licensing agreement which involved fixed payments and/or royalty payments in return for access to an external firm’s technology; a contract whereby the firm paid an external firm to provide research services; or payments by the firm to fund research being conducted by a joint venture or lim- ited partnership. We further noted that the term

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‘external firm’ is defined to include universities, nonprofit research organizations and private sector firms. It also includes firms in which the respon- dent’s company had an equity interest.

Data on the depth of investment in internal R&D were aggregated over two time periods: 1981 – 85 (INVEST1) and 1986 – 91 (INVEST2). We felt that this approach to operationalization would prevent us from losing responses from participants who may not have been with the firm for the entire period of the study. We chose proportion of invest- ment, rather than a real dollar amount, as our pretest identified concerns about the willingness of survey respondents to provide information on the dollar amount of investments allocated to internal R&D.

There were four cases where multiple responses were received from a single firm: two firms had four respondents and two firms had two respon- dents. There was considerable variability in the content of the responses. For INVEST1 (pro- portion of R&D expenditures allocated to inter- nal R&D during the period 1981 – 85) the aver- age spread between the highest and the lowest response within the multi-respondent firms was

27.5 percent. For INVEST2, the average spread was 23.6 percent. Because of the heterogeneity of the responses, it would be inappropriate to aver- age the results across respondents within the firm. Instead the individual responsible for R&D at the most senior level in the organization was identified and only his/her survey response to this question was included in the analysis.

agents, blood proteins and enzymes, hormones, anti-infectives, and vaccines.

*Type of technology alliances*

Using the report *Biotechnology in the U.S. Phar- maceutical Industry*, the variety of types of link- ages was operationalized by counting how many of five different types of alliances were used by each firm (TYPE) for alliances undertaken during the period 1981 – 91. The five types of alliances considered in our measure are composed of two nonequity forms (research contracts and licenses) and three equity-based modes (acquisitions, minor- ity equity investments, and joint ventures1 ).

The distinction between equity- and nonequity- based modes is common in the literature on strategic alliances (Arora and Gambardella, 1990; Pisano, 1989; Pisano and Teece, 1989; Nagarajan and Mitchell, 1998). Research at the network level of analysis uses the number of different types of linkages in the network to operationalize the diver- sity of the network (Auster, 1990). In this study, the variable TYPE accomplishes the same purpose, but at the level of analysis of the organization set. This involves taking the perspective of a single organization and studying the set of organizations with which the focal firm has direct links for the purpose of acquiring input/resources and dispos- ing of outputs/products and services (Aldrich and Whetten, 1981). Thus, we take the focal firms in our sample and study their collection of technology sourcing linkages or alliances.

*Number of alliances of each type*

The number of alliances of each type was oper- ationalized by taking a count of the number of times that each of the sample firms used the fol- lowing five different types of technology sourcing linkages: research contracts (RDCONT), licenses (LIC), joint ventures (JV), acquisitions (ACQ), and minority equity investments (ME). Because of the nature of our data, it was not possible to explore how the number and types of alliances undertaken by a firm changed over the period of the study. To do this, we would have needed to be able to determine the status of the firm’s alliances, as well as their start and termination dates. Our data were

1 A joint venture is defined as a new venture created by the equity contributions of two or more partners.

*Technological breadth*

Breadth of a firm’s expertise in biotechnology was measured at the end of the study period, by count- ing the number of biotechnologies (BREADTH) that the firm reported using in the report *Biotech-*

*nology in the U.S. Pharmaceutical Industry*.

The

report distinguishes between the following eight

technologies: hybridoma, liposome, protein engi- neering, recombinant DNA, tissue culture, fermen- tation, and large-scale cell culture. Our measure of the breadth of biotechnology expertise is similar to Pisano’s (1990) operationalization of biotechnol- ogy R&D experience. His operationalization was based on a count of the number of R&D projects that firms had completed in six different categories of biotechnology: immune modifiers, anticancer

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Table 1.

Descriptive statistics and variable intercorrelations (one-tailed Spearman correlation coefficients)

Variable

Median

Mean

S.D.

1

2

3

4

5

6

7

8

9

10

11

12

13

14

1

2

3

4

5

6

7

8

9

10

11

12

13

14

15

PAT PROD REP INVEST1 INVEST2

BREADTH TYPE RDCONT LIC

JV ACQ ME

3.50

1.00

3.27

0.70

0.50

6.00

5.00

4.00

4.00

1.50

1.00

3.00

7.19

2.27

3.27

0.64

0.53

5.50

4.56

4.31

3.96

1.50

1.42

3.12

$7.4B 35,543

$607M

11.64

2.76

0.617

0.298

0.244

2.775

0.705

2.811

3.013

1.273

1.238

2.405

$8.4B 30,554

$335M

1.00

0.301† 1.00

0.357∗ 0.384∗

0.502∗

1.00

0.410†

0.023

−0.051

1.00

0.128

−0.212

0.415

∗

1.00

0.163

−0.181

0.176

−0.029

0.038

1.00

0.070

0.074

0.190

0.143

0.178

0.397†

0.170

0.475†

0.014

1.00

0.242

0.308†

0.230

0.636∗∗

0.469∗∗

0.233

0.195

0.477∗

0.182 0.649∗∗

0.314 −0.210

1.00

0.463∗∗

0.114

0.343∗

0.192

0.198

0.049

0.041 −0.142

−0.134

1.00

0.071

0.203

−0.143

−0.014

0.240 0.131

0.341† 0.145

0.237 0.060

0.100

0.204

0.316†

0.398∗

0.271†

0.590∗∗

−0.070

1.00

0.282†

0.045

0.164

0.208

0.155

0.200

0.357∗

0.269

0.204

0.471∗

1.00

0.293†

0.207

0.193

0.314†

−0.069

−0.165

1.00

0.415∗

0.314†

0.469∗

REVENUE $5.28B

−0.232

−0.075

−0.095

−0.020 0.146

0.023 −0.067

1.00

0.951∗∗ 1.00

0.682∗∗ 0.625∗∗

EMPLYS 32,450 RDBUDGET $492M

−0.182

−0.001

−0.222

−0.357† −0.159

0.140 −0.171

0.012

−0.027

0.010

0.440† 0.038

0.103 −0.216

∗∗ *p <* 0*.*01; ∗ *p <* 0*.*05; †*p <* 0*.*10

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not fine grained enough to permit this type of clas- sification.

We checked the sensitivity of our measures to interfirm differences in size by exploring the cor- relations between the variables in our study and three measures of firm size (revenues, number of employees, and total R&D expenditures). Results of correlation analysis (see Table 1) suggest a moderate association between all three size mea- sures and two of the independent variables: breadth of technologies pursued (BREADTH) and number of minority equity investments (ME). Total R&D expenditures (RDBUDGET) as a measure of size was also related to several other independent vari- ables.

We urge caution in interpreting these associa- tions because there is a conceptual ‘leap’ required in making the linkage between firm size and tech- nology sourcing strategy. All of the firms in our study are diversified multinational enterprises. Our study focuses on one aspect of these businesses: human pharmaceutical applications of biotechnol- ogy. The firms that are largest, in terms of absolute measures of size, are not necessarily the largest in terms of absolute investment in this aspect of their business. Nevertheless they do have a greater resource pool from which to draw upon if they elect to do so.

**Method of analysis**

Nonparametric methods were used to analyze the data (Siegel and Castellan, 1988). While paramet- ric methods would have enabled us to more fully utilize the information contained in the data, they also rely on the assumption that the data are gener- ated from a multivariate normal distribution. Our sample size of 26 is insufficient to invoke this assumption. Moreover, when multivariate regres- sion is employed in situations characterized by a small sample size and a relatively large number of independent variables, there are also concerns about the limited degrees of freedom available for (and hence the power of) statistical tests. There- fore, we used nonparametric methods to analyze the data in this small sample study.

Firms were divided into high and low groups based on their scores on each of the three mea- sures of technical output. Analysis of variance was then employed to test for the sources of dif- ference between the two groups, with respect to their ranks on each of the independent variables. Separate analyses were performed to test the rela- tionship between each of the three dependent vari- ables and the set of independent variables. The Wilcoxon –Mann –Whitney test (Wilcoxon test) was used for this purpose. It serves as an alterna- tive to the parametric *t* -test when, as in the present study, the underlying assumptions of that test can- not be validated or when the measurement in the research is weaker than interval scaling.

For each of the three measures of technical out- put, PAT, PROD, and REP, firms were placed in the high technical output group when they scored above the median on that dimension. Otherwise, they were classified as being low-output firms. Given the small sample size, we were concerned with the need to evaluate the robustness of the results. This was accomplished by changing the breakpoint for classifying a firm into the high or low groups. High-output firms were redefined as those that scored above the 66th percentile on any one of the dependent variables. Low-output firms were those which scored below the 33rd percentile. Firms that fell between the two values were omit- ted from the analysis. Thus, the first classification rule incorporated the full sample, while the second rule incorporated a reduced sample.

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**RESULTS**

Overall, we found a pattern of mixed support for our hypotheses. While there is evidence of a positive association between the firm’s technol- ogy sourcing practices and measures of its techni- cal output, these relationships are not consistently strong across all measures of the independent and dependent variables (see Table 2).

Our first hypotheses focused on the firm’s inter- nal R&D activities. Hypothesis 1a predicted a positive relationship between investment in inter- nal biotechnology R&D and technical output. This was supported for the first period of the study (1981 – 85), where the level of investment in inter- nal biotechnology R&D (INVEST1) was positively associated with two out of the three measures of

technical output (PAT, *Z* = −1*.*743, *p <* 0*.*05 and

REP, *Z* = −2*.*259, *p <* 0*.*05). However, we did

not find any support for the relationship between technical output and internal R&D investment (INVEST2) during the second period (1986 – 91). Furthermore, there was no evidence of support for Hypothesis 1b, which predicted a positive

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Table 2. Comparison of firms with different levels of technical output in 1991, in terms of dimensions of technology sourcing strategy over the period 1981–91

Independent variables Description

Variable name and hypothesized relationship to dependent variables

Dependent variables

Technical output (TO) as defined by:

Wilcoxon test based on the full sample

Wilcoxon test based on the reduced sample

Mean rank of independent variable

Mean rank of independent variable

*Z*

*Z*

High TO firms

Low TO firms

High TO firms

Low TO firms

% of R&D expenditures on internal R&D (1981–85)

% of R&D expenditures on internal R&D (1986–91)

Expertise in number biotechnologies (1991)

Number of types of alliances undertaken

(1981–91)

Number of R&D contracts undertaken

(1981–91)

Number of licenses undertaken (1981–91)

Number of joint ventures formed

(1981–91)

Number of acquisitions undertaken

(1981–91)

Number of minority equity investments

(1981–91)

INVEST1 (+)

INVEST2 (+)

BREADTH (+)

TYPE (+)

RDCONT (+)

LIC (+)

JV (+)

ACQ (+)

ME (+)

PAT PROD REP

PAT PROD REP

PAT PROD REP

PAT PROD REP

PAT PROD REP

PAT PROD REP

PAT PROD REP

PAT PROD REP

PAT PROD REP

−1.743∗

11.25 (8)a 9.30 (5) 11.30 (10)

10.50 (9) 0.93 (7) 10.50 (11)

12.81 (13)

15.14 (11)

13.69 (13)

10.13 (8)

11.13 (8) 10.60 (10)

14.19 (13)

14.77 (11)

18.85 (13)

14.46 (13)

13.86 (11)

15.62 (13)

11.54 (13)

14.73 (11)

14.35 (13)

14.19 (13)

16.23 (11)

13.85 (13)

12.96 (13)

14.64 (11)

14.73 (13)

7.00 (9)

8.88 (12)

5.71 (7)

10.50 (11)

10.81 (13)

10.50 (9)

14.19 (13)

12.30 (15)

13.31 (13)

9.00 (10)

8.20 (10)

8.13 (8)

12.81 (13)

12.57 (15)

8.15 (13)

12.54 (13)

13.23 (15)

11.38 (13)

15.46 (13)

12.60 (15)

12.65 (13)

12.81 (13)

11.50 (15)

13.15 (13)

14.04 (13)

12.67 (15)

12.27 (13)

−1.477†

8.30 (5)

6.70 (5)

6.75 (6)

9.25 (6)

6.75 (6)

7.21 (7)

9.72 (9)

9.83 (9)

9.56 (9)

7.75 (6)

8.00 (6)

5.86 (7)

11.28 (9) 9.61 (9)

13.56 (9)

11.61 (9) 9.56 (9)

11.94 (9)

8.89 (9)

9.44 (9)

10.61 (9)

11.28 (9)

10.56 (9) 9.67 (9)

9.89 (9)

9.72 (9)

9.50 (9)

5.21 (7)

6.36 (7)

3.63 (4)

7.17 (9)

8.06 (8)

6.75 (6)

10.25 (10)

8.06 (8)

9.44 (9)

6.36 (7)

5.00 (6)

6.25 (4)

8.85 (10)

8.31 (8)

5.44 (9)

8.55 (10)

8.38 (8)

7.06 (9)

11.00 (10)

8.50 (8)

8.39 (9)

8.85 (10)

7.25 (8)

9.33 (9)

10.10 (10)

8.19 (8)

9.50 (9)

−0.159

−0.164

−2.259∗

−1.614†

0.000

−0.896

−0.321

−0.591

0.000

−0.218

−0.469

−0.207

−0.950

−0.742

−0.130

−0.045

−0.533

−0.788

−1.387†

−1.897∗

−1.174

−0.241

−0.468

−0.949

−0.737

−0.540

−3.617∗∗∗

−3.253∗∗

−0.650

−1.200

−0.211

−0.490

−1.430†

−1.975∗∗

−1.348†

−0.842

−0.722

−0.397

−0.582

−0.920

−0.482

−0.987

−1.625†

−1.393†

−0.241

−0.140

−0.363

−0.083

−0.656

0.637

0.000

−0.830

a Sample size *(n)*; †*p <* 0*.*10; ∗*p <* 0*.*05; ∗∗ *p <* 0*.*01; ∗∗∗ *p <* 0*.*001

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association between breadth of the firm’s biotech- nology R&D activities (BREADTH) and measures of technical output.

Our second hypotheses concerned the relation- ship between the firm’s external R&D activities and measures of technical output. Again, we found mixed support. Consistent with Hypothesis 2a, we found evidence of a relationship between the num- ber of different types of alliances pursued by the firm (TYPE) and one of the three measures of technical output: the number of products based on

measures of alliance activity, we are encouraging respondents to adopt our theory and then testing their responses against this same theory. However in theory, alliance activity is both an input to and an outcome of biotechnology expertise. Firms pursue alliances in order to develop expertise. At the same time, their stock of expertise influences the alliances they pursue. Therefore we feel that it is valid to consider alliance activity in both measures.2

Third, it is important to consider the potential for reverse causality in our results. We assert that the use of different technology sourcing linkages contributes to the development of technical output, as reflected by the firm’s reputation for possessing expertise in biotechnology. However, it is also possible that the firm’s reputation impacts the number of linkages pursued. It may be that as the focal firm develops a reputation for possessing biotechnology expertise, it becomes a target for other firms seeking strategic partners to develop their own expertise. Thus, our results raise the question whether greater reputation means that a firm’s external linkages have made it stronger, or just better known.

biotechnology (PROD, *Z* = −1*.*387, *p <* 0*.*10).

We also found partial support for Hypothesis 2b, which asserted a positive relationship between technical output and the number of technology sourcing linkages of each type utilized by the firm. Reputation for possessing expertise in biotechnol- ogy (REP) was positively associated with the num-

ber of R&D contracts (RDCONT, *Z* = −3*.*617,

*p <* 0*.*001), and licenses (LIC, *Z* = −1*.*430, *p <*

0*.*10) undertaken by the firm. Number of biotech- nology products (PROD) was positively associated

with the firm’s acquisition activity (ACQ, *Z* =

−1*.*625, *p <* 0*.*10). Contrary to our expectations,

number of patents (PAT) was negatively related to

joint venturing (JV, *Z* = −1*.*348, *p <* 0*.*10). The

only measure of technology sourcing activity not related to technical output was number of minority equity investments (ME).

Three issues bear consideration in interpreting our results. First, the reader will note that repu- tation (REP) was the only statistically significant dependent variable for two out of the four rela- tionships (LIC and RDCONT) between technol- ogy sourcing and technical output. It is possible that publicity about strategic alliances impacts the perception of expertise in biotechnology and that the sheer number of a firm’s alliances, and the associated publicity, is the factor that explains the relationship between reputation and both number of licenses and number of R&D contracts. This explanation is mitigated by the fact that respon- dents were asked to consider multiple criteria in assessing reputation for expertise in biotechnol- ogy: consideration of the firm’s patent and product activities were included in the set of criteria. Thus, peer evaluation of reputation is based on a com- prehensive set of anchors.

Second, it is also important to acknowledge that by including consideration of the firm’s alliance activity in our reputation measure, and then exploring the relationship between reputation and

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**DISCUSSION AND CONCLUSIONS**

Overall, the results of hypotheses testing indicate support for the notion that, when firms are faced with the encompassing technological changes asso- ciated with emergence of a new regime, they can enhance their ability to generate new output by pursuing a multifaceted approach to technology sourcing. This is because the firm’s internal and external R&D activities build the absorptive capac- ity that underlies current and future technical out- put. Thus, while Nagarajan and Mitchell’s (1998) work suggests that equity alliances will be the dominant method used to acquire new knowledge in regimes of encompassing technological change, our findings suggest that the ability to generate new output in this context involves both internal

2 Statistically significant correlations were observed between

reputation and number of R&D contracts (*r* = 0*.*65; *p <* 0*.*001)

and number of licenses (*r* = 0*.*35; *p <* 0*.*05). Correlations were

not statistically significant between reputation and types of alliances, number of acquisitions, or number of minority equity investments. Thus, collinearity between reputation and the two independent variables (RDCONT and LIC) must be considered as a factor in finding support for the relationship hypothesized in Hypothesis 2.

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and external R&D investment, as well as involve- ment in a variety of equity and nonequity alliances. Our findings also suggest that while joint ventures are a popular vehicle for technology sourcing and development, their use may be negatively associ- ated with technical output in the early stages of a new regime.

did not find any support for Hypothesis 1b, which predicted a positive association between technical output and number of biotechnologies used by a firm (BREADTH). Lack of support for this hypoth- esis may be a function of the measure used to operationalize the independent variable. We mea- sured BREADTH by taking a count of the absolute number of technologies that our sample firms listed as using. It is possible that the level of aggre- gation at which technologies were counted was insufficient to obtain adequate variance between the sample firms. Although there were eight possi- ble technologies to choose from, this may not be a sufficiently fine-grained classification to assess the breadth of technological expertise. Furthermore, although our count-based measure gives an indi- cation of the *range* of a firm’s technology base, it lacks the power to discriminate between firms, in terms of the strength of expertise within and across technological areas. Finally, the fact that our count of technologies was taken at the end of the period fails to consider the time required to develop expertise in those technologies. As a con- sequence, this measure may overstate the firm’s technological expertise.

**Outputs associated with internal R&D**

Hypothesis 1a predicted a positive association between investment in internal biotechnology R&D and technical output. It is interesting that this relationship was supported only for invest- ments made during the first period of the study (INVEST1) and only for patents (PAT) and reputa- tion (REP) as measures of technical output. There are several explanations for this finding: firms may have changed their strategies for protecting intel- lectual property, over time, by relying less on patenting; it may be that fewer patentable discover- ies were made during the period between 1986 – 91 than between 1981 – 85; the product mixes associ- ated with the first time period may have been more conducive to patenting than those pursued subse- quently. Finally, the relationship between invest- ment in internal R&D and reputation may not have remained significant in the second period because internal biotechnology R&D became more com- mon and, therefore, did not influence the percep- tion of differential expertise in biotechnology.

The fact that the relationship between internal

R&D and the two measures of technical output (PAT and REP) was not consistently strong across both time periods may also be a reflection of the presence of a time lag between investments made in R&D and their outcome. Because there is a long lead time between initiating R&D and generating a patentable discovery, it is possible that invest- ments made in R&D in the second period of the study have not had time to be translated into tan- gible outcomes, such as patents. The existence of a time lag would also explain why we did not find a statistically significant relationship between internal R&D and products (PROD) as measures of technical output in either time period. Product commercialization is a downstream activity which is even further removed from initial R&D invest- ment than patenting.

Whereas we found partial support for the rela-

tionship between investment in internal biotechnol- ogy R&D and technical output (Hypothesis 1a), we

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**Outputs associated with external R&D**

Hypothesis 2a asserted that there would be a pos- itive association between technical output and the variety of different types of technology sourcing linkages used by the firm (TYPE), since different types of linkages are used to access different kinds of knowledge and capabilities. Support for this hypothesis was mixed. Of the three measures of technical output, only the number of new products based on biotechnology (PROD) was positively related to TYPE. This may be a reflection that gen- erating technical output in the form of new biotech- nology products involves accessing and developing a variety of different capabilities. In contrast, tech- nical output in the form of patents (PAT) and rep- utation for possessing expertise in biotechnology (REP) may be associated with a relatively narrower base of knowledge and capabilities.

Alternatively, failure to observe a statistically significant relationship between TYPE and the other two measures of technical output may be an indication that a simple count of the number of different types of alliances employed by the firm does not adequately reflect the scope of knowledge and technical capabilities that the firm is pursu- ing. Because the technologies relevant to the new

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paradigm are dispersed across many different firms and potential partners, having a threshold number of alliances of each type may be more critical than simply ensuring that there is broad representation across the range of different types of alliances.

This conclusion seems to be supported by the results of testing Hypothesis 2b, which asserted that there would be a positive association between technical output and the number of alliances that firms had of each type. Consistent with this hypoth- esis, our results indicate that high-output firms had a greater number of alliances in three out of the five different types: R&D contracts (RDCONT), licenses (LIC), and acquisitions (ACQ). Surpris- ingly, the reverse was true for joint venturing activ- ity. Technical output was actually lower for firms with greater numbers of joint ventures (JV). A significant relationship was not observed between technical output and the number of a firm’s minor- ity equity investments (ME).

Interestingly, the three measures of technical output were not uniformly higher for firms with greater activity in each of the five types of tech- nology sourcing linkages. Rather, we found that different types of technical output are associated with different kinds of technology sourcing rela- tionships. For example, the number of acquisi- tions undertaken by the firm (ACQ) was posi- tively related to products (PROD) as measures of technical output. It is important to note that this measure of technical output includes only those products that were developed by the sample firms: It does *not* include products gained through acqui- sition. This suggests that the relationship between acquisitions (ACQ) and products (PROD) is not simply a function of purchasing technical output. Rather, acquisitions enable the firm to access or develop knowledge that facilitates commercializa- tion of new technology. For example, the acquiring firm may be purchasing technical capabilities in a specific research area, or it may be purchasing knowledge of the product development process.

Thus, whereas acquisitions provide the focal firms with access to knowledge that is needed to generate commercializable products, the use of R&D contracts and licenses represents more of an investment in the development of upstream capabilities which may not be directly related to tangible outcomes, such as patents and products. Established pharmaceutical firms use R&D con- tracts and licenses with new biotechnology firms

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to access specific knowledge or pieces of technol- ogy that serve as inputs to the focal firm’s R&D process. Thus, these relationships are viewed by industry experts as having an impact on the devel- opment of the firm’s expertise in biotechnology, even though they may not be directly related to the development of patentable innovations or com- mercializable products.

Following this line of reasoning, we may not have found support for the relationship between minority equity investments (ME) and technical output because MEs are even further removed from tangible output. Minority equity investments in new biotechnology companies are aimed at creat- ing future options for the firm. They are helpful in identifying promising avenues of technology advancement because they give the focal firm a window on new technology development and pro- vide a vehicle for monitoring technical progress. Thus, even though minority equity investments may contribute to the development of the firm’s absorptive capacity, there is no systematic rela- tionship to technical output in biotechnology.

As noted previously, our findings also raise interesting questions about the use of joint ven- tures in an emerging technical regime. Contrary to our expectations, the number of patents (PAT) was actually lower for firms with higher numbers of joint ventures (JV). Perhaps the negative rela- tionship between patent output and joint venture activity is a reflection that JVs are used to tackle inherently more complex and risky technology development tasks. As a result, firms that engage in more joint ventures have lower patent output because of the longer time frames required for these collaborative ventures to bear results, and/or because these types of relationships have a lower probability of success. This supports Steensma and Corley’s (2000) finding that tightly coupled tech- nology sourcing relationships (joint development agreements) tend to be less effective than loosely coupled relationships (licensing agreements) dur- ing periods of technological change. They argue that this is because the high exit costs associ- ated with their usage makes it difficult to respond quickly when new technologies or developments render the partnership’s efforts obsolete.

Another reason that patent output may be lower for firms with higher levels of joint venture activity is because of difficulties associated with structur- ing and managing a new venture and coordinating with other parent firm(s) to do so. This finding is

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consistent with recent work by Anand and Khanna (2000) which found that there are strong learning effects associated with the use of joint ventures, whereas no such relationship was observed for the use of licensing agreements. It also suggests that perhaps relational capital (Kale, Singh, and Perl- mutter, 2000) is more important or takes longer to build in joint ventures, and until this is accom- plished firms that rely more heavily on joint ven- tures as part of their technology sourcing strategy will take longer to produce tangible output (like patents).

Finally, the lower patent output associated with joint venture usage may be a reflection that these types of technology sourcing alliances have the potential for greater learning asymmetries. While the transaction cost perspective has suggested that tighter coupling between partner firms will mit- igate the potential for opportunism, the learning perspective has argued that there is more than choice of governance mode at play in determin- ing the performance of alliances. According to this perspective, alliance partners can experience differential outcomes because they learn at dif- ferent rates (Hamel, 1991) and/or differ in terms of their relative absorptive capacity (Lane and Lubatkin, 1998). While our data do not permit us to explore these issues further, the negative rela- tionship between joint venture activity and patent output raises interesting opportunities for future research.

In conclusion, our results suggest that in an emerging technological regime, a multifaceted approach to technology sourcing will enhance the responsiveness of established firms. This is because both internal and external sources of R&D underlie the development of the absorptive capac- ity that is needed to generate new technical out- puts. Since joint effects and time lags were not explicitly considered in our empirical work, future studies should incorporate research designs (such as structural equation modeling) to explore com- plementarities between various aspects of technol- ogy sourcing strategy, and temporal associations between technology sourcing activities, develop- ment of absorptive capacity and technical out- put. Furthermore, while this study explored how a firm’s approach to sourcing new technology impacts technical output, we also need to learn more about the administrative mechanisms that are associated with successful integration of externally sourced technology.

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