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R&D, ORGANIZATION STRUCTURE, AND THE DEVELOPMENT OF CORPORATE TECHNOLOGICAL KNOWLEDGE

NICHOLAS S. ARGYRES[1]* and BRIAN S. SILVERMAN[2]
[1] *School of Management, Boston University, Boston, Massachusetts, U.S.A.*
[2] *Rotman School of Management, University of Toronto, Toronto, Ontario, Canada*

We explore the link between a firm's organization of research —specifically, its choice to operate a centralized or decentralized R&D structure —and the type of innovation it produces. We propose that by reducing the internal transaction costs associated with R&D coordination across units, centralized R&D will generate innovations that have a larger and broader impact on subsequent technological evolution than will decentralized research. We also propose that, by facilitating more distant ('capabilities-broadening') search, centralized R&D will generate innovations that draw on a wider range of technologies. Our empirical results provide support for our predictions concerning impact, and mixed results for our predictions concerning breadth of search. We also find that control over research budgets complements direct authority relations in contributing to innovative impact. We propose several extensions of this research.

INTRODUCTION

It is by now conventional wisdom that competitive advantage often depends upon the effective development and leveraging of knowledge, particularly technological knowledge (Kogut and Zander, 1992; Teece, 1996; Eisenhardt and Santos, 2000). Consequently, strategy scholars, largely drawing from transaction cost economics, the resource- or capabilities-based view of the firm, or social network theory, have devoted a great deal of attention to exploring the relationship between a firm's organization of its research efforts and the generation and application of such knowledge. Over the last 15 years or so, however, academic research has focused on the *interfirm* organization of R&D activities—specifically, the role of alliances and networks—almost to the exclusion of *intrafirm* organization. The purpose of this paper is to address this imbalance, and to redirect attention toward the influence of a firm's internal organization of research on the nature of its innovative output.

To be sure, there have been efforts in this direction. A nascent literature on the recombination of knowledge shows that a firm's search effort can cross intraorganizational boundaries as well as interorganizational ones (Rosenkopf and Nerkar, 2001), and that particular types of knowledge tend to be better managed through particular sets of relationships among research units (Birkinshaw, Nobel and Ridderstrale, 2002). The international management literature has explored the integration of globally dispersed R&D organizations (Kuemmerle, 1998; Kim, Park and Prescott, 2003), and of knowledge-creating and -using subsidiaries (Gupta and Govindarajan, 1991). Scholars of social networks have examined the flow of knowledge

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*Correspondence to: Nicholas S. Argyres, School of Management, Boston University, 595 Commonwealth Ave., Boston, MA 02215, U.S.A. E-mail: nargyres@bu.edu

among researchers within the firm (Reagans and Zuckerman, 2001; Nerkar and Paruchari, 2002). But with the exception of Argyres (1996), who found that the extent of a firm's divisionalization influences whether the firm generates 'capabilities-deepening' or 'capabilities-broadening' innovation, scholars have devoted relatively little attention to the relationship between internal organization structure and innovation outcomes.[1]

We explore this relationship by examining how the centralization or decentralization of a firm's R&D organization structure and R&D funding authority affects the impact of its innovations, and the breadth of its search for technological solutions. We draw on organizational economics (e.g., Williamson, 1985), studies of innovation (e.g., Cohen and Levinthal, 1990; Henderson and Cockburn, 1994; Trajtenberg, Henderson and Jaffe, 1997), and research on learning and search (Levinthal and March, 1993) to generate our predictions. We argue that by decoupling research effort from the immediate demands of divisions, and by reducing the transaction costs associated with internal R&D coordination, centralized R&D will generate innovations that have a larger impact on future technological developments within and outside the firm, as well as a wider impact across technological domains. We also propose that by facilitating more distant ('capabilities-broadening') search, centralized R&D will generate innovations that draw on previous innovations developed in a wider range of organizations and technological domains. Conversely, decentralized R&D, since it ties research effort directly to specific product-markets and incurs greater transaction costs of interdivisional coordination, produces innovation that has less overall impact, and that influences a narrower range of technological domains. Decentralized R&D also encourages more proximate ('capabilities-deepening') search. We do not assume that more impactful R&D is inherently more profitable, however, and hence we do not argue that one R&D structure is superior for all firms. Rather, as each form promotes a different type of R&D, there are trade-offs between these structures, so firms will seek an efficient match between R&D organization structure and the type of R&D they choose to pursue.

Our study develops hypotheses and tests them on a sample of 71 large, research-intensive corporations engaged in a wide variety of businesses. We explore the relationship between these firms' organization of research and the characteristics of their patented innovations during the early to mid-1990s. We find that firms with centralized R&D organization structures (i.e., corporate-level R&D labs only) and centralized R&D budget authority (i.e., funds coming from corporate headquarters) generate innovations that are significantly different along several dimensions from those generated by firms with decentralized R&D organizations. In particular, firms with centralized R&D organizations generate innovations that have a higher level of impact, and impact upon a broader range of technological areas, than do firms with decentralized R&D organizations. Centralized R&D firms also appear to conduct technological search outside of their organizational boundaries more widely than do decentralized R&D firms. We also find that R&D structure and R&D budget authority appear to work as complementary instruments for influencing the research efforts of a firm. Thus, increases in the degree of corporate-level control of R&D funding are associated with larger increases in innovative impact when R&D decision-making authority is centralized, rather than decentralized. Finally, we find unexpectedly that 'hybrid' R&D structures—that is, firms operating both a centralized corporate research laboratory and decentralized business unit labs—do not generate innovation that is consistently 'intermediate' between that of centralized and decentralized firms. For example, firms that possess a mix of centralized and decentralized R&D labs that is heavily weighted toward the decentralized labs appear to generate innovations with narrower impact, on average, than fully decentralized R&D firms. This may indicate a particular challenge with such 'decentralized hybrid' R&D forms.

The paper proceeds as follows. In the next section, we briefly review the business history and organization theory literature on the intrafirm organization of R&D. In the following section, we integrate this literature with literature on technological change to derive our hypotheses. We then describe our data and methods, and present our

[1] Pitts' (1977) study related the size and existence of a corporate R&D function to the relatedness of a firm's diversification, rather than to its innovation. A set of studies by Hoskisson and colleagues investigated the impact of overall organizational structure and controls on aggregate firm-level research spending (e.g., Hoskisson, Hitt and Hill, 1993) but did not explore their impacts on the directions or outcomes of innovation. These studies also did not investigate the structure of the firm's R&D function itself.

empirical results. We conclude with a discussion of these results and with suggestions for future research.

ORGANIZATION OF R&D WITHIN THE MULTIDIVISIONAL FIRM

The emergence of varied R&D organization structures

In the classic unitary ('U-form') corporation, R&D activity was centralized along with most other functions. As Du Pont pioneered the adoption of the multidivisional ('M-form') structure in the early 1920s, the firm decentralized its research activities to the divisional level (Chandler, 1962). Although Du Pont never entirely eliminated its corporate-level Development and Chemical Departments—the sources of the technologies that supported its initial diversification moves in the prior decade—in 1921 the firm began to allocate virtually all research budget and decision-making authority to division-level R&D groups. What little corporate R&D function remained was essentially required to solicit budgetary funds from the divisions, thus becoming 'entirely dependent on the industrial departments for its survival' (Hounshell and Smith, 1988: 132). The history of Du Pont's organization of R&D illustrates some of the key determinants of R&D organization structure in large multidivisional firms.

Du Pont's decentralization of research was driven by complaints from Du Pont's division-level managers that the Department of Chemicals 'had been unresponsive to the manufacturing and sales needs of Du Pont businesses' (Hounshell and Smith, 1988: 98). Allowing the divisions to have their own chemical departments, these managers argued, would result in the 'avoidance of conflict between the Chemical Department and the management,' and would foster 'better relationships between research and plant personnel' in which scientists would have a more 'intimate and less academic' relationship to the success of the businesses (quoted from managers' memos, in Hounshell and Smith, 1988: 108–109). Du Pont's corporate-level Executive Committee agreed, noting that 'If the Chemical Department continues to function as it has in the past, responsible only to the Executive Committee ... the management of the industrial departments will thereby be deprived of the effective control of the activities of their departments and can at some future time, with unanswerable logic, escape responsibility in case of unsatisfactory performance' (Hounshell and Smith, 1988: 108).

By the late 1920s, however, Du Pont's central Chemical Department staged a comeback under the sponsorship of Chemical Department Director Charles Stine. Stine argued that the Department was 'so completely tied up' with work for the industrial departments that it possessed neither the personnel nor the budget to 'undertake work along any very radically new lines' (Hounshell and Smith, 1988: 135). The Executive Committee was convinced, and dramatically increased corporate funding for the Chemical Department, so that by the end of that decade the Chemical Department was once again 'a vital force in Du Pont's research and development program' (Hounshell and Smith, 1988: 136).[2] Research activity continued at significant levels within the divisions as well. This balanced hybrid structure for research appears to have prevailed at Du Pont for the rest of the century.

As the M-form diffused throughout American business during the middle part of the twentieth century, debates about the appropriate organization of research were no doubt common amongst technology-intensive firms. By the early 1990s, nearly all large firms in the United States had adopted some variation of the M-form (Fligstein, 1990; Teece, 2000). Although little is known about how the organization of research activities evolved within M-form firms, the results of a 1994 survey by the Industrial Research Institute (described in greater detail below) indicate that there exists wider variation in R&D organizational structures than in overall corporate structures.

The organization of research within these large firms typically takes on one of three structures. Examples are shown in Figures 1, 2, and 3. In the centralized structure, there is a single executive in charge of the firm's research activities who reports directly to a corporate-level executive such as the

[2] Even the pro-decentralization divisional managers at Du Pont acknowledged several potential advantages of corporate research, including 'coordination of research, avoidance of duplication of effort, promulgation of results which are of interest to more than one department, and maintenance of a staff of consulting experts on special branches of the science' (Hounshell and Smith, 1988: 108). Thus, their view of decentralized R&D still maintained a role for corporate research, albeit a small, subservient one.

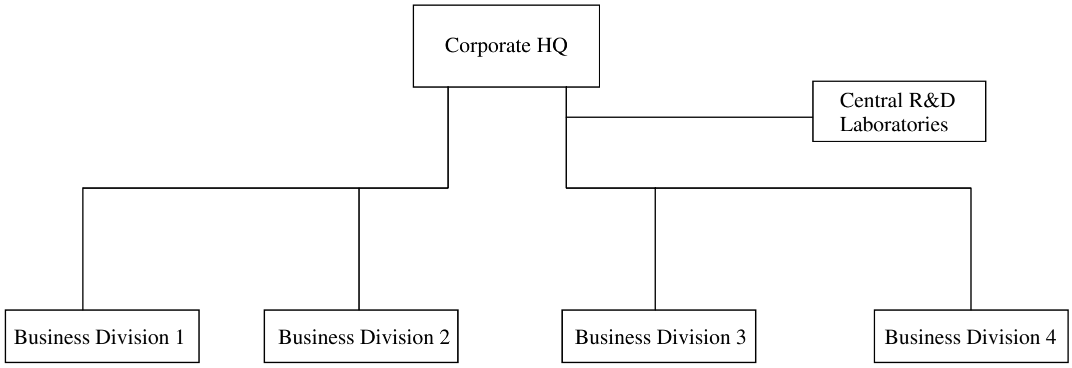

Figure 1. Centralized R&D structure

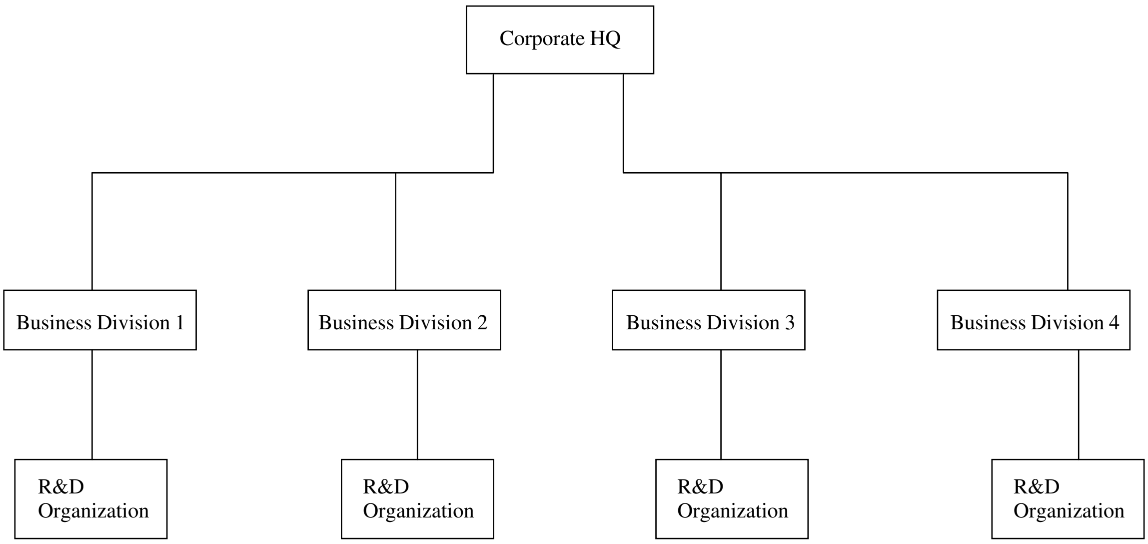

Figure 2. Decentralized R&D structure

CEO or President. In the decentralized structure, research is conducted exclusively within divisions or business units, and R&D directors report to division general managers. In the hybrid structure, research is conducted both within a centralized function whose leader reports to corporate management, and within the firm's divisions or business units. An R&D director at the divisional level reports to his/her division general manager, who in turn reports to corporate management.

Separate from the authority relations in R&D, the Du Pont example highlights the fact that the source of research funding within large firms can be the business units, corporate headquarters, or some combination of the two. In either case, R&D budgets are typically allocated through an annual process in which the senior management of the corporation (or business unit) determine the size of the budget that the R&D function will receive, often based on their assessment of the projects proposed by R&D personnel.

Centralization vs. decentralization

Du Pont's historical record anticipates much of the scholarly analysis of R&D organization. Williamson (1975) argued in favor of decentralization of virtually all functions in the multidivisional (M-form) firm, presumably including R&D (although R&D was not analyzed specifically). Decentralization would be associated with efficiency advantages stemming from improved information processing and reduced scope of managerial opportunism. However, other scholars

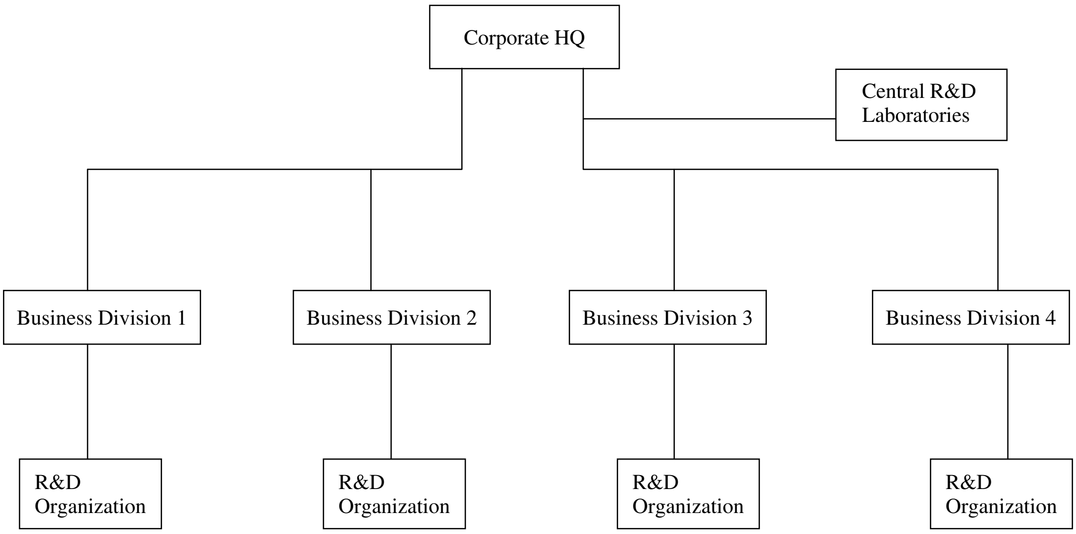

Figure 3. Hybrid R&D structure

have argued that such advantages of decentralization may be outweighed by the inability to achieve economies of scale or scope in R&D. Centralization of certain functions may enable a firm to exploit economies of scale and scope in administration (Galbraith, 1977; Daft, 1989). Such economies may arise in R&D if, for example, laboratory space or support staff time is better utilized when more R&D projects are combined. Relatedly, centralization of certain functions may enable a firm to exploit economies of scale, scope, and spillovers that arise when the outcome from one R&D project reduces the cost of carrying out another project, or delivers benefits to multiple subsequent products or activities (Cohen and Levin, 1989; Henderson and Cockburn, 1996).

To be sure, in the absence of internal transaction costs—i.e., costs associated with exchanges or coordination between units or divisions within the firm—it is not clear why independent R&D units cannot share common space or staff support time harmoniously. Consequently, exploiting economies of administration does not necessarily require that a firm centralize its R&D in terms of authority relationships. Similarly, in the absence of internal transaction costs, it is not clear why the beneficiaries of a particular project cannot use contracts or other agreements to create and share research results efficiently (Teece, 1982). Thus, when internal transaction costs are low, centralized R&D would appear to offer few benefits in achieving scale or scope economies, while it would incur the usual efficiency penalties associated with information processing and managing potential opportunism. When internal transaction costs are high, however, as is often the case when R&D coordination is at issue, then centralized R&D may well provide superior efficiency.

Addressing this issue, Kay (1988) argued that centralized R&D offers the ability to effectively pursue ‘non-specific’ research (that is, research whose fruits are applicable beyond the confines of a specific business unit), whereas decentralized R&D, because it offers the traditional benefits associated with easier measurement and closer relationship to market demand, is more suitable for product-specific research. This is because when scope economies spill across divisional boundaries, as is the case for non-specific research, then centralized governance, by facilitating the efficient creation and transfer of ‘quasi-public’ knowledge across business units (Teece, 1982), enables firms to achieve such economies. Further, for firms seeking to compete on the basis of firm-wide core competencies, active corporate-level involvement in identifying and building core technological competence is necessary to overcome the ‘tyranny of the SBU (strategic business unit)’ (Prahalad and Hamel, 1990).[3]

[3] Relatedly, some scholars have argued that it is the link between a firm’s diversification strategy and its organization structure that affects its performance (e.g., Hoskisson *et al.* 1993).

R&D organization structure and problem selection

As noted above, decentralization of all operating activities has traditionally been associated with efficiency advantages stemming from improved information processing and reduced scope of managerial opportunism (Williamson, 1985). Because divisional managers and employees are better informed about the characteristics of their particular products and marketplaces than are their corporate counterparts, they are better equipped to make decisions that affect their unit (Jensen and Meckling, 1992). This is particularly true where successful innovation depends on close understanding of user needs (Von Hippel, 1988). Hence, decentralization of research decision making—in terms of both reporting relationships and R&D funding decisions—reduces the information and time demands on top management, facilitating the processing of information within the organization (Galbraith, 1977; Williamson, 1975). In addition, as suggested by the history of Du Pont R&D, decentralization of research establishes clear lines of authority and responsibility to the divisional manager, thus reducing the scope for non-cooperation by R&D personnel. It also facilitates the measurement of R&D performance, thereby reducing the scope for opportunism by R&D personnel. Finally, decentralization of research may improve the credibility of corporate-level management's promises not to intervene in the operating affairs of the divisions, thus enhancing incentives of divisional managers (Williamson, 1985). Since a centralized R&D function lacks direct product line responsibility and deprives operating divisions of control over division-related technology developments, it appears to present precisely the type of measurement and incentive problems that the M-form is designed to mitigate.

However, although decentralized research offers advantages in efficiently motivating and measuring research effort related specifically to divisional needs, it is less effective at generating innovation that transcends the business unit (Kay, 1988). It has long been recognized that, because research has public good qualities, the existence of 'spillovers' will lead firms to underinvest in it (Arrow, 1962). Indeed, one of the fundamental challenges of research policy is to develop institutions that internalize these spillovers, either through stronger appropriability mechanisms such as patents (e.g., Kitch, 1977; Klemperer, 1990) or through the encouragement of research consortia (Katz and Ordover, 1990; Grindley, Mowery, and Silverman, 1994).

The firm is, of course, a particularly effective institution for internalizing spillovers across divisions. But this effectiveness depends on the internal organization of the firm. Consider the incentives for a business unit to invest in non-specific research. Although the unit will incur all of the expenses associated with this investment, it is by no means clear that the unit will be able to appropriate the resulting intrafirm rents. A parent might promise to allow the business unit to charge appropriate licensing fees to the other divisions in order to ameliorate the effects of such intrafirm spillovers. In general, however, business unit managers will not have strong reasons to believe such promises. This is the problem of selective intervention (Williamson, 1985): while corporate management may proclaim a commitment not to intervene (in order to sustain high-powered incentives among subordinates), it may have difficulty making such commitments credible.[4]

Alternatively, the corporate parent might address spillovers *ex ante* by 'taxing' other divisions for the non-specific research to be undertaken at a given business unit. However, this runs into classic problems of contracting on research effort (Teece, 1988), in which (1) the divisions are likely to haggle extensively about the value of this research to each of them, and (2) the business unit that undertakes the research, having received the funds, will have an incentive to shade its research efforts away from the non-specific research and towards research that can further its profit center-based objectives. In addition, non-specific research is characterized by fundamental uncertainty, so decentralization of R&D may lead to negotiation and haggling costs as divisions attempt to reach agreement on joint projects *ex ante* (Argyres, 1995). Thus, because of fundamental uncertainty *ex ante*, and the impossibility of securing strong

[4] This credibility problem is exacerbated by the fact that a business unit cannot legally own the patents to any innovations from the research it undertakes, since the parent firm is the ultimate legal owner of all patents produced within the firm—even those that may be assigned to business units when filed at the U.S. Patent and Trademark Office. Although corporate management may promise to give the business unit perpetual ownership over these patents, it cannot credibly commit to never assert the firm's ownership rights over the innovation, or to simply order the unit to share its innovations with other units for free.

intellectual property and decision rights over their innovations *ex post*, divisions within multidivisional firms will tend to underinvest in non-specific research.[5]

With a centralized R&D function and/or significant corporate level funding of R&D, however, these kinds of problems can be at least partially overcome. First, if corporate-level management refrains from delegating R&D funding authority to the divisions, it can use this authority to fund non-specific, spillover-heavy R&D projects that the divisions do not have incentives to fund themselves. Second, by concentrating R&D activity in a single cost center, the firm removes it from the 'high-powered' incentive system faced by divisions within the M-form, in which each division is semi-autonomous, but responsible for its own profitability. Therefore, central R&D researchers will be offered incentives to produce non-specific R&D, although since the contributions of such R&D to firm profitability are more difficult to measure, the financial component of such incentives will be 'lower-powered' (Williamson, 1985; Milgrom and Roberts, 1992). Thus, applying transaction cost logic yields the following basic trade-off: centralized research will favor investment in solving broader, non-specific research challenges (and will feature weaker financial incentives for R&D personnel) while decentralized research will favor investment in solving narrower, business-unit specific research challenges (and financial incentives for R&D personnel can be stronger).

The relative advantages of centralization vs. decentralization of R&D can also be understood in terms of information-processing approaches to organization (Thompson, 1967; Egelhoff, 1991). For example, Thompson (1967) argued that, under norms of rationality, information-processing requirements dictate that reciprocally interdependent activities will be organized within the same organizational unit, whereas sequentially interdependent activities will be organized in different units. Product-specific R&D tends to involve significant reciprocal interdependence, since engineers working more upstream on product enhancements or new products will need to interact frequently with engineers and marketers who are more downstream in the process, and therefore possess more information about manufacturing requirements and user needs. Therefore, an information-processing approach implies that product-specific R&D would tend to be decentralized to the divisional level. Non-specific R&D, on the other hand, arguably bears a more sequentially interdependent relationship with divisional operations. For such R&D, researchers are seeking to go much beyond current product offerings. Therefore, the benefits of interacting frequently with divisional engineers who have specialized information about individual product lines and their customers are arguably lower.

Thus, both information-processing and transaction cost approaches to organizational design are consistent with the idea that centralized R&D organizations will be able to carry out non-specific R&D more efficiently and more effectively than will decentralized R&D organizations. The next step in our argument is to note that non-specific research is more likely to generate innovations with greater and wider technological impact than product-specific research. This is because non-specific research involves the selection of research problems that are more likely to lead to the discovery of fundamental or generalizable knowledge. Nelson (1990: 196) termed such knowledge 'generic,' and described it in the following terms:

> ... technology is not adequately characterized as simply a body of practice. It includes that but it involves, as well, a body of generic understanding about how things work, key variables affecting performance, the nature of major opportunities and currently binding constraints, and promising approaches to pushing these back.

Generic or non-specific knowledge, which encompasses broad principles or understandings, is more likely than product-specific knowledge to produce innovations that affect a large number of future innovations. Put differently, generic knowledge tends to be relevant to more innovations in total than narrower, product-specific knowledge. Thus:

[5] Even if corporate management could resolve this commitment problem, divisions might underinvest in non-specific research for fear that such research could unfavorably alter the allocation of other resources within the firm. Roberts and McEvily (2002) demonstrate that a pharmaceutical firm that introduces a new product in one market will experience market share losses for products in other markets, presumably because scarce resources within the firm are 'cannibalized' from other product lines to support the new product. If the manager of one division in such a firm recognizes that his non-specific R&D may enable another division to launch a product, that manager has lower incentives to invest in such research than does the corporation overall.

Hypothesis 1: The results of more centralized R&D activity will impact a larger number of subsequent innovations than will the results of more decentralized R&D activity.

A second characteristic of generic knowledge is that it is likely to produce innovations that have relevance for technical applications in a broader range of technological areas. Kuznets (1962: 26) described the kinds of breakthroughs that can come from such non-specific research as follows:

> Some inventions, representing as they do a breakthrough in a major field, have a wide technical potential in the sense that they provide a base for numerous technical changes ... the first steam engine, which initiated a whole series of major technical changes and applications ... is vastly different from the innovation of the safety match or pocket lighter. This wide range is for our purposes the major characteristic relevant to the problem of measurement. (Quoted in Trajtenberg *et al.*, 1997: 19)

These arguments, together with those above concerning efficient and effective R&D organization, suggest the following hypothesis:

Hypothesis 2: The results of more centralized R&D activity will have impact on a broader range of subsequent technological innovations than will the results of more decentralized R&D activity.

R&D organization structure and the search process

Recent studies have investigated how international (Almeida, 1996), firm acquisition (Ahuja and Katila, 2001), and component recombination strategies (Fleming, 2001) influence patterns of technological search by firms. Internal R&D organization structures may also influence technological search processes. The search for new technological knowledge is highly path-dependent and constrained by organizational routines (Nelson and Winter, 1982). As a result, firms seeking new knowledge tend to search locally—that is, in areas that are 'close to' the existing knowledge within the firm (Cohen and Levinthal, 1990; Helfat, 1994). In the face of evidence that firms encounter great difficulty in moving beyond local search, scholars have recently begun to emphasize the competitive advantage residing in the ability to do so (Kogut and Zander, 1992; Levinthal and March, 1993; Henderson and Cockburn, 1994). Rosenkopf and Nerkar's (2001) study of patented innovation in the optical disk industry demonstrates that firms can and do go beyond local search. In particular, they find that patented innovations that reflect broader search efforts also have a broader subsequent impact—for example, that patented innovations that cite a wider range of technologies tend to be subsequently cited by patents in a broader range of technologies. This stream of research has not yet focused on the issue of which organization structures support broader or narrower search processes.[6]

We contend that centralized research facilitates non-local search more effectively than does decentralized research. As Kay (1988) argued, because divisional managers and engineers in multidivisional firms are close to the market, they are typically forced to adopt a customer-centric orientation, in which immediate customer needs are weighed heavily in R&D decisions. Consistent with this, Galunic and Eisenhardt (2001) found case evidence that division managers were less likely to pursue opportunities in new markets than were corporate managers. Indeed, recent scholarship has criticized an 'excessive' focus on current customer demands, arguing that such a focus ignores important opportunities to develop more radical technologies that do not serve the immediate needs of current customers (Christensen and Bower, 1996; Jaworski, Kohli, and Sahay, 2000). Technologists and managers in centralized research labs, because they are more insulated from immediate market pressures, will be less constrained by current customer demands and time constraints in searching for new technological solutions. Consequently, they will have more freedom to explore broader research projects—that is, projects with longer time lags and greater technological and demand uncertainty.

Centralized R&D also facilitates non-local search because of the nature of organizational communication. A key component of a firm's absorptive capacity is its being organized so as to recognize the value of new knowledge (Cohen and Levinthal, 1990). Henderson and Clark (1990)

[6] Although Henderson and Cockburn (1994) linked several aspects of R&D decision making to higher research productivity, decision making served only as a proxy for competence in their study. Formal R&D organization structure itself was not a focus of attention.

argued that local groups of product engineers within an organization are repositories of 'component knowledge': knowledge about technical characteristics of the individual components of a larger product. What they called 'architectural knowledge'—that is, knowledge about how components of the systems interact—tends to reside in informal communication channels and 'information filters' shared by local engineering groups. As products develop, these filters and channels deepen, screening out new technological alternatives not previously considered in intergroup communications. Architectural innovation poses particular difficulties, since it involves new interactions between components, and is therefore especially likely to be screened out. An implication is that because researchers in centralized R&D labs are less deeply engaged in local communication channels, they are less subject to the associated information filters, and are therefore more likely to appreciate and explore (broader) architectural innovations.

The breadth of a firm's technological search will be reflected in the extent to which it looks outside its own organizational boundaries for innovations on which to build. For example, some firms tend to build fairly narrowly on their own previous innovations, and do not scan their broader environment very extensively. Other firms conduct more extensive external scanning, searching a broader range of previous innovations developed by other organizations and independent inventors. These observations, together with the arguments above concerning organization, suggest the following hypothesis:

Hypothesis 3: More centralized research activity will encompass broader search efforts in organizational space—that is, will build to a greater extent on innovations developed outside the firm—than will more decentralized research activity.

Another way in which the search for technological knowledge can be broadened or narrowed is by scanning previous innovations from a broader or narrower set of technological areas. Firms that build on innovations from a more diverse range of such areas can be understood as searching more broadly, whereas firms searching fewer, more closely related areas can be understood as searching more narrowly. These observations, together with the arguments above concerning organization, suggest the following hypothesis:

Hypothesis 4: More centralized research activity will encompass broader search efforts in technological space—that is, will build to a greater extent on innovations from diverse technologies—than will more decentralized research activity.

Further, if the foregoing hypotheses are to be believed, then centralized research may also have broader (and possibly greater) impact in part *because* it results from broader search efforts. By searching over a broader range of organizations and technological areas, researchers may be more likely to discover more broadly applicable solutions. In support of this idea, recall that Rosenkopf and Nerkar (2001) found that technological search that spans technological boundaries tends to produce innovations with greater and wider overall impact than narrower search. Thus, it is plausible that the effects stipulated in Hypotheses 1 and 2 are driven to some extent by the effects hypothesized in Hypotheses 3 and 4.

Structure–funding interactions

As noted above, two of the many instruments that firms can use to influence the R&D decisions of their managers and technical staff are: (1) allocating authority by setting reporting relationships, and (2) delegating or retaining control over the funding of internal R&D projects. The arguments above regarding the advantages and disadvantages of centralization vs. decentralization of R&D apply to either instrument of allocating authority, when considered on its own. But how do the two interact when they are used together?

Positive agency (Jensen and Meckling, 1976) and efficiency wage (Akerlof, 1986) theories imply that monitoring and financial incentives are alternate mechanisms for inducing desired employee behavior, and can therefore substitute for each other. In contrast, Holmstrom and Milgrom's (1994) theory of the firm emphasizes that incentives within the firm often operate as a system, providing a complementary syndrome of authority, oversight, and incentives to induce desired employee actions. The basis of this theory is that increasing the incentives for an employee to perform one task can lead the employee to divert attention from other tasks, in the absence of changes in other incentives or controls. A potential implication of this view is that centralization of financial authority may need to be combined with centralized decision authority in order to effectively guide R&D activities.

Do R&D funding and R&D organization structure operate as complementary or substitute instruments for influencing the direction of R&D? In our analysis below, we explore whether marginal differences in the centralization of R&D funding have a greater or lesser effect on R&D outcomes for firms with more or less centralized R&D reporting relationships, and vice versa. If the effects, say, from centralizing R&D funding are large when R&D reporting relationships are already highly centralized, this suggests a complementary relationship (Siggelkow, 2002). On the other hand, if the marginal effects from centralizing R&D funding are larger when R&D reporting relationships are decentralized, this suggests that reporting relationships and budget authority are alternate, or substitute, instruments for influencing a firm's R&D efforts.

Hybrid R&D Structures

Very little systematic data have been collected on the R&D organization structures of large multidivisional firms, and so relatively little is known about how such firms actually organize their R&D functions. The one systematic source of data of which we are aware is a 1994 survey by the Industrial Research Institute, which was followed up by a similar survey in 2001. (These data are described in more detail below.) In the 1994 survey of 120 firms, 27 percent reported a centralized R&D structure, 10 percent reported a decentralized structure, and 63 percent reported a hybrid structure. In the 2001 survey of 85 firms (of which 30 were also represented in the 1994 survey), 31 percent reported a centralized structure, 10 percent reported a decentralized structure, and 59 percent reported a hybrid structure. The preponderance of hybrid structures is striking, because there has been relatively little written about hybrid internal structures in general, much less hybrid R&D structures in particular.

Daft (1989) does contain a brief treatment of general hybrid internal structures, the essence of which is that hybrid organizations may be able to achieve the 'best of both worlds' by combining the advantages and disadvantages of centralized and decentralized structures in terms of coordination, control and information processing, but may suffer the consequence of greater role ambiguity than other structures. Tushman and O'Reilly (1996) introduce the concept of 'ambidextrous organizations': organizations that can simultaneously pursue radical and incremental innovation. While they do not mention hybrid structures, one might be tempted to associate hybrids with ambidextrous organizations, following the logic outlined above that centralized R&D structures better support radical innovation while decentralized R&D structures better support incremental innovation. Tushman and O'Reilly, however, describe ambidextrous organizations as featuring 'massive decentralization of decision-making' (Tushman and O'Reilly, 1996: 26), which would be at odds with the hybrid structure. Given the paucity of theoretical or empirical analyses of hybrid structures, we do not state formal hypotheses with respect to them. However, from the logic outlined above, and from Daft's (1989) discussion, we might expect them to feature intermediate degrees of impact breadth and magnitude, as well as breadth of search.

EMPIRICAL ANALYSIS: SAMPLE AND METHODS

Data

We test our hypotheses in a study of R&D organization and patented innovation among a sample of 71 large, mostly diversified corporations in the mid-1990s. As noted above, the sample was taken from the Industrial Research Institute's (IRI) 1994 survey of R&D executives. Founded in 1938, IRI is a well-established non-profit organization in Washington, DC whose member firms are particularly active in industrial research. IRI sponsors a number of conferences and other educational programs for its member companies, and also produces a large number of R&D-related publications including the journal Research Technology Management. In 1994, IRI conducted a survey to collect information on its members' R&D organization structures. In addition, the survey asked managers to report the fractions of corporate and divisional R&D budgets that come from corporate management, divisional management, and external sources (e.g., contract research).

IRI received usable information from 120 of its approximately 180 members, and ultimately published the survey results in 1995. Few of the surveyed companies consented to printing their names on the published R&D organization charts (which include research funding policies), preferring instead to identify themselves by their primary industry sectors. However, all companies that participated in the survey consented to being identified as participants in the survey. Using clues on the charts, along with supplementary sources such as 10-K filings, annual reports and some historical information included in the 2001 IRI survey, we were able to link more than two-thirds (82) of the charts to specific companies surveyed. While this is in some respects a convenience sample, a difference of means test indicates that the respondents that we were able to identify do not differ from the unidentified respondents in terms of R&D organization forms chosen. (That said, we have no data with which to compare respondents to non-respondents.) After eliminating private firms and some non-U.S. companies for which supplementary data were not available, the sample stood at 71. After identifying the firms in this sample, we used the Directory of American Research and Technology to augment the IRI information about each of our firms' reliance on centralized vs. decentralized R&D efforts.

Although this sample is not large, it is economically and technologically important. The U.S. firms in the sample accounted for over 25 percent of total industrial research spending in the United States in 1994 (National Science Foundation, 1995). Sample firms participated in a wide range of industries, and most were listed in the *Fortune* 500 in 1994 (see Table 1). Further, these data are more comprehensive than any other source of R&D organization structure of which we are aware. Systematic data on R&D organizational structures are not available from alternative sources, and are difficult to obtain due to secrecy concerns. This difficulty is underscored by the fact that even though they presumably joined IRI (at a cost) to learn about R&D management practices, most respondents still were unwilling to identify themselves with a specific R&D organizational chart in the 1994 and 2001 IRI surveys. Thus, the sample contains important information that cannot, as far as we are aware, be found anywhere else, or be collected easily.

We also collected information on each firm's size and R&D expenditures from Compustat. In addition, we collected detailed information on granted patents that these firms and their subsidiaries applied for between January 1, 1992 and December 31, 1996. During this time period, these firms collectively applied for 31,232 patents that were ultimately granted.[7] Finally, we collected detailed information on prior patents that these patents cited, and on the subsequent patents that cited these patents. The sources for the patent data included the U.S. Patent and Trademark Office, Micropatent, and the NBER Patent Citation Data file (Hall, Jaffe, and Trajtenberg, 2001). We used these to construct a variety of citation-based measures, discussed below. Although patent data have drawbacks of their own—not all technological knowledge is patentable, and not all patentable knowledge is patented (Griliches, 1990)—citation analysis has become increasingly widely accepted as a method for identifying the 'paper trail' left by knowledge flows (Jaffe and Trajtenberg, 2002).

Dependent variables: Measures of technological impact and search

This study incorporates several dependent variables that are intended to capture different aspects of breadth of innovation-related search and breadth/level of innovative impact. All are constructed from patent citations to and from the sample patents. All are derived from the stream of research by Hall, Henderson, Jaffe, and Trajtenberg on patent statistics and technology diffusion (see references throughout this section).

Measures of impact

Hypothesis 1 relates the centralization of R&D to the overall impact of a firm's innovations. We use the traditional measure of number of *Citations Received* by a focal patent to proxy for its overall impact (Henderson *et al.*, 1998):

$$\text{Level of Impact} = \text{Citations Received} = t_i$$

[7] We know the organization structure for our sample firms as of 1994. The IRI survey also asks respondents when the organization structure last underwent a 'significant change.' More than 90 percent of the sample firms reported the last significant change as prior to 1992. We therefore arbitrarily set 1992 as the beginning of the 'window' during which we know these firms' R&D organization structure. We arbitrarily set 1996, 2 years after the IRI survey, as the end of this window, on the assumption that any major changes to R&D structure initiated in 1995 would have taken a year to fully implement. The dependent variables are based on the 'average' patent for these 5 years of data. The results are robust to a wide range of alternate cutoffs and window sizes.

Table 1. Industrial sectors of sample firms*

Firm	Sector(s)	Firm	Sector(s)
Adolph Coors	Food, Tobacco and Kindred Products	Gillette	Personal Care
Air Prod.'s & Chemicals	Chemicals and Plastics	BF Goodrich	Chemicals and Plastics
Alcan	Fabricated and Primary Materials	GTE	Electrical Communications
Allegheny Ludlum	Primary and Fabricated Materials	Helene Curtis	Personal Care
Allergan	Pharmaceuticals	Hershey Foods	Food, Tobacco and Kindred Products
ALCOA	Primary and Fabricated Materials	Honeywell	Electrical/Communications/Aerospace/Transportation
Anheuser Busch	Food, Tobacco and Kindred Products	ITW	Manufactured Products
Armco	Primary Materials	International Paper	Building/Forest/Paper Products
Ashland Oil	Petroleum and Energy Related Products	Johnson & Johnson	Personal Care/Pharmaceuticals
Avery Denison	Paper and Plastics	Kennametal	Machinery
Baker Hughes	Petroleum and Energy Related Products	LTV	Primary Materials
Ball Corp.	Packaging	Masco	Fabricated Materials/Building Products
Becton Dickinson	Hospital Products	3M	Chemicals and Plastics/Fabricated Materials/Pharmaceuticals
Bethlehem Steel	Primary Materials	Mobil	Petroleum and Energy Related Products
Bristol-Meyers Squibb	Pharmaceuticals	Monsanto	Chemicals and Plastics/Pharmaceuticals
Briggs & Stratton	Machinery	Occidental Petroleum	Petroleum and Energy Related Products
BHP (Australia)	Petroleum/Primary Materials	Noranda (Canada)	Primary and Fabricated Materials/Petroleum
Cabot	Chemicals and Plastics	Olin	Chemicals and Plastics/Primary Materials
Clorox	Chemicals and Plastics	Owens Corning	Fabricated Materials
Colgate-Palmolive	Personal Care/Household Products	Pepsico	Food, Tobacco and Kindred Products
Corning	Fabricated Materials	Pfizer	Pharmaceuticals
Deere	Machinery	Philip Morris	Food, Tobacco and Kindred Products
Chevron	Petroleum and Energy Related Products	Phillips Petroleum	Petroleum and Energy Related Products
DEC	Electrical/Communications	PPG	Chemicals and Plastics/Fabricated Materials
Du Pont	Chemicals and Plastics/Petroleum Products	Proctor & Gamble	Consumer Products
Eastman Chemical	Chemicals and Plastics	Rockwell	Aerospace/Transportation/Electrical/Machinery
Eastman Kodak	Imaging	Shell Oil	Chemicals and Plastics/Petroleum and Energy Related Products
ECC Int'l	Aerospace/Transportation	Square D	Electrical/Communications
Elf Aquitaine (France)	Chemicals and Plastics/Petroleum/Pharmaceuticals	Tambrands	Personal Care Products
Emerson Electric	Electrical/Communications	Union Camp	Building/Forest/Paper Products
FMC	Chemicals and Plastics/Machinery	USG	Building/Forest/Paper Products
Ford	Aerospace/Transportation	US West	Electrical/Communications
Gencorp	Aerospace/Transportation	Westinghouse	Electrical/Communications
GE	Chemicals/Plastics/Electrical/Communications/Aerospace	Weyerhaeuser	Building/Forest/Paper Products
GM	Aerospace/Transportation	WR Grace	Chemicals and Plastics

* Self-reported in 1994 and 2001 Industrial Research Institute surveys. All firms are U.S. based unless otherwise noted.

where t_i equals the number of citations received for patent i as of December 31, 1999.

One concern with our method is the possibility of truncation bias. It usually takes several years before patents begin to accrue citations. Consequently, our tally of citations will suffer from truncation. This will be particularly pronounced for focal patents that were applied for in the later part of our 1992–96 window, and consequently will affect our results particularly severely if some firms have a greater proportion of their patents in the later part of this window than do others. In unreported models we checked the robustness of our results by confining ourselves to the earlier half of the window, and alternately by including a variable that measured the average application date of each firm's patents, and found no significant difference in results.

Hypothesis 2 relates the centralization of R&D to the breadth of impact of a firm's innovations. To measure the breadth of technological impact, we use what Trajtenberg *et al*. (1997) called their 'generality' measure, although we term it 'breadth of impact.' Construction of this measure entails three steps: (1) identification of all citations made to a focal patent; (2) identification of the technology class to which each of these cited patents is assigned; and (3) calculation of a technological 'diversity' index that is equal to one minus the Herfindahl concentration index of these technology classes: Hence:

$$\text{Breadth of Impact} = 1 - \sum_{j}^{n_i} {t_{ij}}^2$$

where t_{ij} denotes the percentage of citations received by patent i that belong to class j, out of n_i technological categories assigned to patents by the U.S. Office of Patents and Trademarks.[8] Note that the summation will be larger, and consequently one minus the summation will be smaller, the more that these citing patents reside in a single technology class. At the limit, where a focal patent is only cited by patents from a single technology class, the Breadth of Impact measure will equal 0. The intuition behind this measure is that the more diverse the technologies citing a patent, the broader is the impact of that patent.

Measures of search

Hypothesis 3 relates research organization to the organizational breadth of search undertaken by a firm. Following Rosenkopf and Nerkar (2001) and, obliquely, Henderson, Jaffe, and Trajtenberg (1998), we measure the organizational breadth of search as the degree to which a focal patent cites prior art from outside, as opposed to within, the firm. Specifically, the breadth of search is measured for each focal patent as one minus the proportion of citations made by that patent that are 'self-citations'—that is, citations to patents assigned to the same firm that developed the focal patent:

$$\text{Organizational Breadth} = 1 - s_{ik}$$

where s_{ik} denotes the proportion of citations made by patent i that belong to firm k, the owner of patent i.

Hypothesis 4 relates research organization to the technological breadth of search undertaken by a firm. To measure the breadth of technological search conducted by firms, we use what Trajtenberg *et al*. (1997) called an 'originality' measure, although we term it 'technological breadth.' This is constructed analogously to the Breadth of Impact measure, except that it is based on the technology classes of patents cited by the focal patent, rather than those citing it:

$$\text{Technological Breadth} = 1 - \sum_{j}^{n_i} {s_{ij}}^2$$

where s_{ij} denotes the proportion of citations made by patent i that belong to class j, out of n_i technological categories assigned to patents by the U.S. Office of Patents and Trademarks. Again, the summation will be larger, and consequently one minus the summation will be smaller, the more that these cited patents fall in a single technology class. The intuition behind this measure is that the more diverse the technologies cited by a patent, the broader was the search effort underlying that patent.

[8] Hall *et al*. (2001) note that this measure, like all Herfindahl-type measures based on citation counts, often suffers from bias due to the properties of small numbers. For example, a patent that has received a single citation will have by definition a breadth of impact of 0. Bronwyn Hall proposes a method to correct for this bias, which entails multiplying the Breadth of Impact measure by $N/(N-1)$, where $N =$ the number of citations that a focal patent has received (Hall *et al*., 2001: Appendix 2). We apply this correction to our breadth of impact and breadth of search measures.

Independent variables: Measures of R&D organization structure

We operationalize the degree of centralization/decentralization of R&D functions in three ways. Two measures are based on direct authority relations. Using the IRI data, we coded each firm as having a centralized, decentralized, or hybrid structure. (Figures 1–3, discussed above, demonstrate examples of each.) We then refined the hybrid category further by identifying hybrids that were centralized to greater or lesser degrees.[9] The IRI data do not provide information on the degree of centralization of each hybrid—that is, the relative size of each hybrid's corporate and divisional laboratories. We gathered data on the relative sizes of each type of lab for each hybrid from the Directory of American Research and Technology, which contains information on the sizes of the technical staffs of R&D laboratories in the United States. This source provides employee counts, by lab, for some but not all firms, and provides cruder information on the organization of labs for the rest. The lack of employee counts for all firms precludes our creating a continuous measure of R&D centralization. We were able, however, to estimate some lab sizes based on the number of fields of R&D listed for the lab, so as to categorize the hybrids as follows. Hybrids with a ratio of corporate to divisional researchers greater than 1.3 were categorized as 'centralized hybrids;' those whose ratio was below 0.7 were categorized as 'decentralized hybrids' and those with a ratio between 0.7 and 1.3 were identified as 'balanced hybrids.' We selected these cut-offs to correspond to natural breakpoints in the data; our empirical results are robust to small changes in these cut-offs. The centralized hybrids typically possess a relatively large corporate lab located at corporate headquarters, and relatively small divisional labs elsewhere. The decentralized hybrids have large divisional labs—often located within separately incorporated divisions—and a relatively small central lab. These firms generally appear to have grown largely by acquisition. The balanced hybrids appear to have combined growth by internal expansion with growth by acquisition, and possess a relatively large central lab, along with sizable divisional labs as well.[10]

We then created five categorical variables that capture each of the R&D structure types. $Centralized_k$ is set equal to 1 if firm k has a centralized R&D structure, and 0 otherwise. $Decentralized_k$ is set equal to 1 if firm k has a decentralized R&D structure, and 0 otherwise. $Centralized\ Hybrid_k$ is set equal to 1 if firm k has a centralized hybrid R&D structure, and 0 otherwise. $Decentral\ Hybrid_k$ is set equal to 1 if firm k has a decentralized hybrid R&D structure, and 0 otherwise. $Balanced\ Hybrid_k$ is set equal to 1 if firm k has a balanced hybrid R&D structure, and 0 otherwise. In our empirical estimations, we omit the Decentralized variable. Above, we predicted that centralized research would be positively related to each measure of search and impact. We therefore expect the coefficients for $Centralized_k$ to be positive (since $Decentralized_k$ will be the omitted variable). Further, we anticipate that $Centralized\ Hybrid_k$, and $Balanced\ Hybrid_k$, $Decentral\text{-}Hybrid_k$, will also have positive coefficients, and that these variables will display the following relationships with respect to the sizes of their effects on each of the dependent variables:

$$Centralized_k > Centralized\ Hybrid_k > Balanced\ Hybrid_k > Decentral\ Hybrid_k > Decentralized_k$$

In addition to the categorical measures of R&D structure, we also created a centralization scale which increases with overall R&D centralization as follows: 1 = decentralized; 2 = decentralized hybrid; 3 = balanced hybrid; 4 = centralized hybrid; 5 = centralized. Following Hypotheses 1–4, we expect the coefficient for this centralization scale to be positive. Although this measure is clearly not ideal—most obviously, it implicitly assumes that the 'distance' between each adjacent organization form is the same—it has the advantage of ease of interpretation (as compared

[9] Our initial draft of this paper simply relied on the three-category typology of the IRI survey. The unusual results for the Hybrid category—rarely significantly different from the Decentralized category, and when significant usually signed opposite of expectation—led us to develop ways to refine and further explore the Hybrid category. We thank the reviewers and editors for encouraging us to explore this route.

[10] Our measure of hybridization assumes that relative lab size is correlated with other organizational variables that determine the degree of decision-making authority held by various R&D units. For example, larger labs may enjoy more formal authority through committees, and/or more informal influence, than smaller labs.

to the numerous categorical variables described above) in some of the models below.

Our third proxy for centralization of R&D is a variable that measures the degree to which R&D budget authority is centralized. The IRI survey collected information on corporate, business unit, and external funding of R&D for each responding firm. Since external funding was zero for most firms, and less than 6 percent of total funding for the rest, we excluded external funding for the sake of exposition of the empirical results.[12] *Corp Funds*$_k$ is defined as the proportion of firm k's 1994 R&D budget that was provided by corporate HQ, as opposed to being provided directly by the business units. Specifically:[13]

> *Corp Funding*$_k$ = Proportion of firm k's R&D funding that is allocated by corporate HQ ÷ (Proportion of firm k's R&D funding that is allocated by corporate HQ + Proportion of firm k's R&D funding that is allocated by business units)

Given our hypotheses, we expect the coefficient for Corp Funding to be positive.

Control variables

Many other factors may influence the patterns of corporate innovation. However, our 71-firm sample affords limited degrees of freedom. Accordingly, we construct several sets of control variables. We then test which sets of controls have an impact on which measures of impact or search, and include only these sets in our models. Nelson (1959) hypothesized that diversified firms may better appropriate the returns from basic (i.e., nonspecific) R&D. Therefore, more-diversified firms might be expected to conduct higher and broader impact R&D, and to conduct broader search. We therefore constructed a concentric index measure of firm-level diversification (Caves, Porter, and Spence, 1980), *Diversification*$_k$, using SIC information disclosed in 10-K filings. A firm's size may affect either its actual or its perceived technological prowess, which in turn may affect its search efforts and the degree to which other firms cite its patented innovations. Accordingly, we construct *LnSales*$_k$, defined as the natural log of firm k's annual sales. In unreported models we replaced firm sales with firm assets, with no significant changes to our results. Similarly, firm R&D expenditures may affect either actual or perceived technological capability. We therefore construct $LnR\&D_k$, defined as the natural log of firm k's annual R&D expenditure. A firm's prior patenting history may affect its search ability or perceptions of its technological prowess (Podolny, Stuart, and Hannan, 1996). We therefore construct *LnPriorPatents*$_k$, defined as the natural log of the sum of granted patents applied for by firm j during 1987–91. In models of organizational breadth of search, this also controls for the fact that firms with more prior patents have a larger 'risk set' of patents for self-citation.

As discussed above, our sample includes firms in a wide range of industries. We construct a vector of industry fixed effects. Given the degree-of-freedom constraints, we aggregate these industries into four sectors: natural resources (pulp/paper, petroleum, metals); chemicals/pharmaceuticals; industrial products (aircraft; autos; machinery; electrical/ electronics); and consumer products (food; personal care products). These sectors are based upon the industries that the firms self-reported on the IRI survey. In unreported models, we replaced the sector fixed effects with a vector of fixed effects based on aggregations of 2-digit SIC codes, with no significant change to our results. It is also likely that different technologies exhibit different empirical regularities with respect to impact and search of patented innovation. Henderson *et al*. (1998) and Hall *et al*. (2001) assigned each U.S. patent class to one of six technology fields. We aggregate these to three technological fields—drug/chemical patents; electrical/computer patents; and mechanical/other patents—and construct fixed effects for these technology fields. Thus, if a firm applies for 100 patents in the sample time period, and 12 of these patents are in the drug-related technology field and 11 are in the chemical-related technology field, then the firm has a value of 0.23 for Drug/Chemical Patent Share. Table 2 presents descriptive statistics for each variable, and Table 3 provides the correlation matrix. Note that Centralization Scale and Corp Funding are not

[12] We thank an anonymous referee for this suggestion.

[13] The funding proportions for hybrid firms are broken out separately by recipient R&D group. Since we do not know the overall amount of funding going to each group, we used both weighted and unweighted averages of these proportions to calculate Corp Funds for our hybrid firms. (This is not an issue for our centralized or decentralized firms, since the allocation of R&D funds is by definition 100% to one group or the other.) The reported models rely on weighted averages; results are robust to changes to (or absence of) the weights.

Table 2. Descriptive statistics

Variable	Mean	Standard Deviation	Min	Max
Dependent variables				
Level of Impact	2.417	1.321	0.200	8.073
Breadth of Impact	0.247	0.087	0.049	0.555
Organizational Breadth of Search	0.527	0.098	0.156	0.689
Technological Breadth of Search	0.874	0.100	0.589	1.000
Explanatory variables				
Centralization Scale	3.630	1.332	1.000	5.000
Centralization Scale^2	14.854	8.212	1.000	25.000
Decentralized	0.139	0.348	0.000	1.000
Decentralized-Hybrid	0.097	0.298	0.000	1.000
Balanced-Hybrid	0.125	0.333	0.000	1.000
Centralized-Hybrid	0.403	0.494	0.000	1.000
Centralized	0.236	0.428	0.000	1.000
Corp Funding	0.395	0.338	0.000	1.000
Corp Funding * Centralization Scale	1.594	1.545	0.000	5.000
Corp Funding * Centralization Scale^2	6.730	7.340	0.000	25.000
Corp Funding * Decentralized	0.004	0.023	0.000	0.158
Corp Funding * Decentralized-Hybrid	0.025	0.096	0.000	0.620
Corp Funding * Balanced-Hybrid	0.039	0.144	0.000	1.000
Corp Funding * Centralized-Hybrid	0.210	0.310	0.000	1.000
Corp Funding * Centralized	0.117	0.292	0.000	1.000
Technology controls				
Drug/Chemical Patents	0.425	0.315	0.000	1.000
Electrical/Computer Patents	0.153	0.234	0.000	0.942
Sector controls				
Resource products	0.153	0.362	0.000	1.000
Industrial products	0.292	0.458	0.000	1.000
Chemical/Pharmaceutical products	0.375	0.488	0.000	1.000
Firm controls				
LnSales	8.698	1.429	4.148	11.933
LnR&D	4.752	1.669	−0.585	8.859
LnPriorPatents	5.160	1.889	0.000	8.817
Diversification	24.542	20.851	0.000	70.000

particularly highly correlated (0.47). We observe in the data some centralized firms with all R&D funding from corporate HQ, and some centralized firms with all R&D funding from the business units. There exists less variation in funding among decentralized firms—the highest level of Corp Funding for a Decentralized firm is less than 0.16. The correlations involving the Diversification variable are also interesting to note. One might expect that more-diversified firms are more likely to use more decentralized R&D structures. While the correlations are consistent with this idea, they are not particularly high—generally less than ±0.20.

Analyses

Three of our dependent variables are bounded between 0 and 1. We use the two-sided tobit regression technique to estimate models using these variables. Our fourth dependent variable, Level of Impact, is non-negative by definition. We use one-sided tobit estimation for this variable.[14] We use STATA 8.0 for all estimations in this study.[15]

[14] For an individual patent, citations received is a non-negative count variable, and consequently negative binomial models are often employed (Hall *et al*., 2001). When these citations are averaged at the firm level, however, citations received becomes a continuous variable rather than an integer. Hence, negative binomial estimation is not appropriate.

[15] A subtle issue that arises is whether endogeneity between the main independent variables and the dependent variables is a concern in our regressions. Endogeneity concerns arise when an independent variable represents a choice over which the firm has control, and the firm is likely to make its choice so as to optimize its performance relative to the dependent variable.

Table 3. Correlations among dependent and explanatory variables

	1	2	4	3	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1. Level of Impact																							
2. Breadth of Impact	0.48																						
3. Technological Breadth of Search	−0.10	0.05																					
4. Organizational Breadth of Search	−0.05	0.42	−0.13																				
5. Centralization Scale	0.09	−0.12	0.22	−0.13																			
6. Centralization Scale^2	0.09	−0.14	0.26	−0.16	0.98																		
7. Decentralized	−0.05	0.05	−0.08	0.06	−0.74	−0.62																	
8. Decentralized-Hybrid	−0.06	0.01	−0.14	−0.02	−0.39	−0.42	−0.13																
9. Balanced-Hybrid	−0.02	0.13	0.11	0.09	−0.16	−0.24	−0.15	−0.13															
10. Centralized-Hybrid	0.02	−0.01	−0.27	0.12	0.29	0.19	−0.31	−0.27	−0.31														
11. Centralized	0.07	−0.13	0.39	−0.24	0.64	0.76	−0.22	−0.19	−0.22	−0.46													
12. Corp Funding	0.13	0.02	0.04	−0.19	0.47	0.43	−0.42	−0.14	−0.10	0.29	0.17												
13. Corp Funding * Centralization Scale	0.12	−0.00	0.08	−0.21	0.56	0.55	−0.39	−0.24	−0.17	0.24	0.32	0.97											
14. Corp Funding * Centralization Scale^2	0.10	−0.02	0.12	−0.23	0.59	0.60	−0.35	−0.26	−0.21	0.16	0.43	0.91	0.98										
15. Corp Funding * Decentralized	−0.12	−0.02	−0.01	0.11	−0.32	−0.27	0.44	−0.06	−0.06	−0.14	−0.09	−0.13	−0.16	−0.15									
16. Corp Funding * Decentralized-Hybrid	−0.02	0.01	−0.06	−0.09	−0.31	−0.33	−0.10	0.79	−0.10	−0.21	−0.15	0.00	−0.14	−0.19	−0.04								
17. Corp Funding * Balanced-Hybrid	0.02	0.06	0.11	0.03	−0.11	−0.18	−0.11	−0.09	0.72	−0.23	−0.16	0.14	0.02	−0.06	−0.05	−0.07							
18. Corp Funding * Centralized-Hybrid	0.16	0.05	−0.26	0.06	0.24	0.15	−0.26	−0.22	−0.26	0.83	−0.38	0.53	0.45	0.35	−0.11	−0.18	−0.19						
19. Corp Funding * Centralized	−0.01	−0.06	0.28	−0.27	0.46	0.55	−0.16	−0.14	−0.16	−0.33	0.72	0.54	0.67	0.79	−0.07	−0.11	−0.11	−0.28					
20. Drug/Chemical Patents	−0.18	0.03	0.06	−0.09	−0.06	−0.04	−0.04	−0.17	0.03	0.05	−0.09	−0.05	−0.04	−0.04	0.09	−0.24	0.04	0.05	−0.07				
21. Electrical/Computer Patents	0.29	−0.02	−0.07	−0.03	−0.05	−0.10	−0.11	0.28	−0.02	−0.07	−0.02	−0.04	−0.09	−0.11	−0.03	0.31	0.01	−0.08	−0.07	−0.52			
22. Diversification	0.17	0.08	−0.15	0.00	−0.14	−0.15	−0.14	0.17	0.07	−0.14	0.00	−0.14	−0.14	−0.14	0.01	0.00	0.17	−0.20	−0.03	0.21	−0.02		
23. LnSales	0.13	0.06	−0.26	0.14	−0.09	−0.08	−0.05	0.13	0.05	−0.26	0.13	−0.09	−0.08	−0.04	0.14	0.18	−0.00	−0.31	0.15	−0.08	0.18	0.34	
24. LnR&D	0.22	0.11	−0.17	−0.06	−0.08	−0.10	−0.09	0.21	0.11	−0.16	−0.05	−0.07	−0.10	−0.09	0.15	0.25	0.04	−0.24	0.04	0.04	0.23	0.25	0.83

Discussion of results

Impact

Table 4 reports estimates for our analyses of the level and breadth of a firm's innovative impact. Model 1a includes basic control variables, and introduces one measure of the centralization of R&D decision authority, Centralization Scale. Models 2a and 3a check for non-linearities in the centralization–impact relationship by replacing Centralization Scale with a vector of categorical measures for centralization of R&D (Model 2a), or by adding a square term for Centralization Scale (Model 3a). Model 4a removes all measures of R&D decision authority and introduces our measure of the centralization of R&D funding, Corp Funding. Models 5a and 6a include Corp Funding and measures of decision authority, as well as the attendant interaction terms. We describe each of the model's results in turn.

In Model 1a, the coefficient for Centralization Scale is significant and positive. Consistent with Hypothesis 1, increased centralization of R&D decision-making authority is associated with increased level of impact of a firm's innovation. Holding all other variables at their means, a firm that shifts from a fully decentralized to a fully centralized R&D organization structure would experience a 30 percent increase in the citation rate of its patented innovations, from 2 to roughly 2.6 citations per patent.

In Model 2a, we replace Centralization Scale with the categorical variables denoting varying degrees of R&D centralization (Decentralized is the omitted category) to further explore this effect. In this model, the coefficient for Centralized is positive and significant. This is also consistent with Hypothesis 1, in that innovations developed by firms with fully centralized R&D structures display greater technological impact than those developed by firms with fully decentralized R&D structures. That said, it is interesting that the coefficients for the three hybrid structures are neither statistically significant nor all positive relative to the omitted Decentralized category, as one might expect if centralization–decentralization effects operated linearly.

To explore this non-linearity further, and to conserve on our limited degrees of freedom, in Model 3a we replace the categorical variables with Centralization Scale and its square term, Centralization Scale^2. The coefficients for Centralization Scale and Centralization Scale^2 are negative and positive. (Although only the square term is insignificant, a likelihood ratio test indicates that this model offers significantly better fit than the purely linear estimation in Model 1a.) These coefficients indicate a U-shaped relationship between centralization of decision authority and level of innovative impact. This relationship reaches its minimum point when Centralization Scale = 2.2, which is just past the Decentralized-Hybrid form. Thus, although greater R&D centralization is associated with greater innovative impact for the majority of the observable range of data, purely decentralized firms will exhibit greater innovative impact than those hybrid firms that are only slightly more centralized in R&D authority. In sum, then, we find evidence in Models 1a–3a that centralized R&D decision authority is associated with greater technological impact than decentralized authority, but that this relationship is more nuanced than a purely linear conception would suggest.

In Model 4a, we remove all decision authority variables and introduce our measure of R&D funding authority, Corp Funding. The coefficient for Corp Funding is significant and positive. Consistent with Hypothesis 1, centralization of R&D funding is positively associated with increased impact of a firm's innovations.[16] Holding all other variables at their mean, a firm that shifted Corp Funding from the sample mean (about 0.39) to one standard deviation above the sample mean

Thus, studies that relate a strategy or structure choice to performance are typically plagued by endogeneity issues (Hamilton and Nickerson, 2001). In this study, the firm has control over its choice of R&D organization. However, we presume that the firm chooses so as to optimize the bottom-line profits associated with its R&D. Our dependent variables—impact and search—are not theoretically correlated with firm financial performance. Indeed, Trajtenberg *et al*. (1997) assume that technological impact is *inversely* related to appropriability of financial returns to R&D investment, a greater number of citations implies more free use of an invention by others. Further, Henderson and Cockburn (1994) note that their demonstration of a relationship between pharmaceutical company policies and citation rates of patents should not be interpreted to imply a positive relationship between these policies and firm profits. Accordingly, we do not attempt to draw normative conclusions about the general superiority of one R&D structure over another. We seek only to test for statistical associations between R&D structures and innovation behavior that, theory predicts, should be efficiently matched. We thank Iain Cockburn and Adam Jaffe for their comments on this issue.

[16] In unreported models, we also include the square of Corp Funds to check for non-linearities in this relationship. There was no significant non-linearity.

Table 4. Estimations of the effect of R&D organization on level and breadth of impact

	Level of impact (1a)	Level of impact (2a)	Level of impact (3a)	Level of impact (4a)	Level of impact (5a)	Level of impact (6a)	Breadth of impact (1b)	Breadth of impact (2b)	Breadth of impact (3b)	Breadth of impact (4b)	Breadth of impact (5b)	Breadth of impact (6b)
Centralization Scale	0.155*		−0.469			−1.362**	0.002		−0.050*			−0.056
	(0.096)		(0.504)			(0.707)	(0.007)		(0.038)			(0.052)
Centralization Scale^2			0.107*			0.249**			0.008*			0.008
			(0.083)			(0.120)			(0.006)			(0.009)
Decentral-Hybrid		−0.205			−0.569			−0.063**			−0.061	
		(0.552)			(0.750)			(0.038)			(0.056)	
Balanced-Hybrid		0.130			−0.351			−0.051*			−0.051	
		(0.484)			(0.621)			(0.035)			(0.050)	
Centralized-Hybrid		0.085			−1.039**			−0.019			−0.048	
		(0.388)			(0.546)			(0.031)			(0.043)	
Centralized		0.688**			0.663*			0.052*			0.016	
		(0.420)			(0.506)			(0.031)			(0.041)	
Corporate Funding				0.504*	−8.326*	−4.637				0.025	−0.260	−0.456*
				(0.378)	(5.929)	(4.862)				(0.031)	(0.456)	(0.310)
Corp Funding * Centralization Scale						3.427*						0.228*
						(2.599)						(0.174)
Corp Funding * Centralization Scale^2						−0.509*						−0.025
						(0.344)						(0.024)
Corp Funding * Decentral-Hybrid					8.438*						0.229	
					(6.241)						(0.482)	
Corp Funding * Balanced-Hybrid					8.908*						0.234	
					(6.061)						(0.465)	
Corp Funding * Centralized-Hybrid					10.016**						0.304	
					(5.991)						(0.457)	
Corp Funding * Centralized					7.994*						0.319	
					(5.944)						(0.461)	
Drug/Chemical Patents	1.958***	1.865***	1.867***	1.973***	1.798***	1.775***	0.079*	0.074	0.087*	0.081*	0.078*	0.081*
	(0.509)	(0.511)	(0.508)	(0.513)	(0.487)	(0.503)	(0.045)	(0.045)	(0.045)	(0.045)	(0.045)	(0.045)
Electrical/Computer Patents	2.673***	2.719***	2.696***	2.737***	2.633***	2.687***	0.110**	0.116**	0.107**	0.119**	0.130**	0.127**
	(0.663)	(0.660)	(0.656)	(0.668)	(0.634)	(0.651)	(0.053)	(0.052)	(0.053)	(0.054)	(0.053)	(0.052)
Diversification	−0.015**	−0.014**	−0.013**	−0.015**	−0.013*	−0.013*	0.000	0.001*	0.001*	0.001*	0.001*	0.001*
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Significant firm characteristics and sector controls	Included	Included	Included	Included	Included	Included	Included	Included	Included	Included	Included	Included
Constant	2.892***	3.707***	3.979***	3.006***	3.739***	4.664***	0.138***	0.168***	0.193***	0.131***	0.163***	0.214***
	(1.083)	(1.157)	(1.388)	(1.078)	(1.108)	(1.416)	(0.043)	(0.040)	(0.058)	(0.040)	(0.044)	(0.070)
χ^2	31.8	34.0	33.3	31.0	42.0	36.8	13.9	18.0	15.8	14.5	20.6	20.0

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$; one-tailed test for hypothesized variables; two-tailed test for control variable (about 0.72) would experience a 9 percent increase in the impact of its patented innovations, from 2.05 to roughly 2.2 citations per patent.

Model 5a reintroduces the categorical variables for decision authority and also introduces interaction effects between Corp Funding and each categorical variable. A likelihood ratio test indicates that Model 5a is a significant improvement over Models 2a and 4a. In this model, the coefficients for all main effects except for Centralized are negative, although not all of them are statistically significant. At the same time, the coefficients for all interaction effects are positive and significant. This indicates that centralized funding and centralized decision making are complementary instruments for managing R&D—increased centralization of R&D funding in a fully decentralized organization will actually decrease the level of impact of that organization's patented innovations, while increased centralization of R&D funding for hybrid organizations will be associated with increased impact (thanks to the large positive interaction terms). Further, this effect becomes increasingly pronounced as hybrid forms become increasingly centralized: whereas a Decentralized-Hybrid firm will experience a 2 percent increase in level of innovative impact as it moves from all business unit funding to all corporate HQ funding, a Balanced-Hybrid firm will experience a 9 percent increase and a Centralized-Hybrid firm will experience a 27 percent increase in innovative impact. Finally, the main effect for Centralization retains its significance, and its interaction term, although significant, just barely offsets the negative main effect for Corp Funding. Thus, although not affected by changes in corporate funding, a fully Centralized firm's innovation continues to have greater impact than that of less centralized forms. We return to this finding below.

The prevalence of categorical variables and their attendant interaction terms make the interpretation of Model 5a somewhat problematic, and also strain the available degrees of freedom given our sample size. Consequently, Model 6a replaces the categorical variables with Centralization Scale and Centralization Scale^2, and includes interaction terms with Corp Funding. The likelihood ratio test indicates that Model 6a is a significant improvement over Models 3a and 4a. In this model, the coefficients for Centralization Scale and Centralization Scale^2 are again negative and positive, and both are significant. The main effect for Corp Funding now has an insignificant coefficient, but the interaction effects have significant coefficients. Again, these effects imply a complementary relationship—increased centralization of R&D funding will increase innovative impact when coupled with more centralized R&D decision authority, although this is tempered at high levels of Centralization Scale by the negative coefficient on Corp Funding * Centralization Scale^2.

Figure 4 graphically illustrates the implications of these main and interaction effects on the level of impact of a firm's innovation. Figure 4 compares the influence of centralized decision authority on the level of innovative impact for a firm whose R&D is entirely funded by business units to that of a firm whose R&D is funded by corporate HQ to varying degrees. A multiplier of greater than 1 indicates that the level of innovative impact is increased relative to a firm with purely decentralized decision authority, by a factor equal to the multiplier. As Figure 4 shows, increasing the centralization of decision authority nearly always increases the level of impact that a firm's innovation will have. However, the impact of more centralized decision authority varies with the budget authority of the firm. A firm in which the business units handle the bulk of R&D funding has a dramatically lower multiplier for increasingly centralized decision authority than does a firm in which corporate HQ handles the bulk of R&D funding allocation. Thus, the more that corporate HQ controls the budget authority instrument (allocation of R&D funding) the greater the influence that centralization of the decision authority instrument will have on a firm's innovative impact.

In sum, increased centralization of R&D decision authority—at least at higher levels of centralization—is positively associated with increased innovative impact. Increased centralization of R&D funding has a more complicated relationship with level of innovative impact. Centralization of R&D funding authority is positively related to innovative impact in models that exclude R&D decision authority measures, but when controlling for decision authority funding authority affects innovative impact primarily through its interaction with decision authority. The two instruments for influencing R&D activity appear to work as complements, in the sense that the more centralized one instrument is, the more that increases in the centralization of the other will increase the level of a firm's innovative impact.

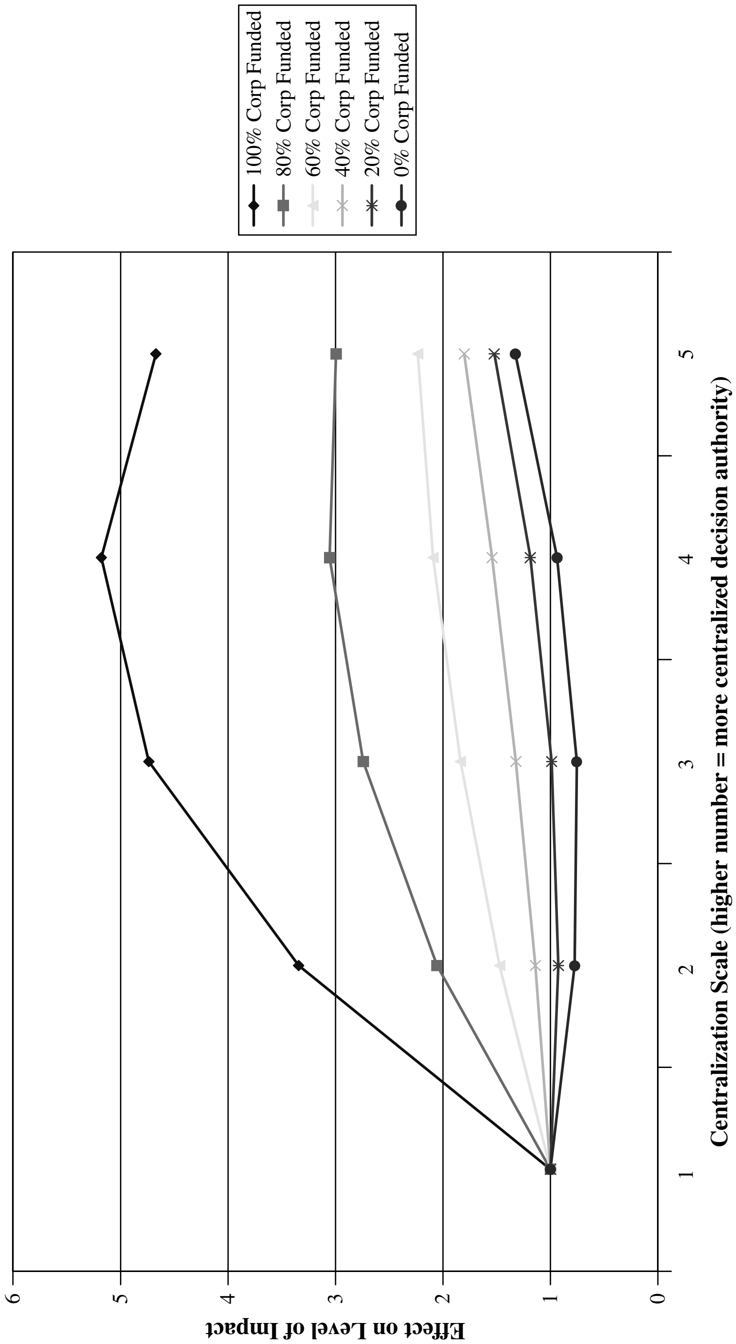

Figure 4. Multiplier effects of decision authority and budget authority on level of impact (cites received)

Models 1b through 6b replicate the above analysis for the breadth of innovative impact exhibited by a firm. The results are similar to those for level of impact, albeit somewhat weaker. In Model 1b, the coefficient for Centralization Scale is insignificant. In Model 2b, the categorical variable Centralization again has a positive, significant coefficient. Now, however, the coefficients for Decentral-Hybrid and Balanced-Hybrid are negative and significant, indicating a deeper nonlinearity in the relationship between centralization of decision authority and breadth of impact than existed for level of impact. In Model 3b, the coefficients for Centralization Scale and Centralization Scale^2 are again negative and positive. Corp Funding is not associated with breadth of impact in Model 4b, and none of the main effects or interaction terms has a significant coefficient in Model 5b. In Model 6b, the coefficient for Corp Funding is negative and significant, and the coefficient for the interaction term Corp Funding * Centralization Scale is positive and significant (although the coefficients for the Centralization Scale and Centralization Scale^2 main effects are insignificant). Again, a fully Decentralized firm that moves from SBU R&D funding to Corporate HQ funding will experience a significant decrease in the breadth of its innovative impact, yet for firms with more centralized R&D organizations an increase in centralization of funding will lead to increases in breadth of impact. Overall, these results are consistent with Hypothesis 2.

Figure 5 graphically illustrates the effects of decision authority and funding authority on the breadth of impact of a firm's innovation. Much like Figure 4, Figure 5 demonstrates that increasing the centralization of decision authority nearly always increases the breadth of innovative impact, and that this effect is magnified as a firm's budget authority is increasingly centralized. A firm in which the business units handle the bulk of R&D funding has a dramatically lower multiplier for increasingly centralized decision authority than does a firm in which corporate HQ handles the bulk of R&D funding allocation. Thus, the more that corporate HQ controls the budget authority instrument (allocation of R&D funding) the greater the influence that the decision authority instrument (centralization of the R&D function) will have on the breadth of a firm's innovative impact.

Search

Table 5 reports estimates for our analysis of the technological and organizational breadth of a firm's innovative search. Models 1c through 6c replicate the above analysis for organizational breadth, and Models 1d through 6d replicate the above analysis for technological breadth.

Models 1c through 6c present estimates for our analysis of the organizational breadth of a firm's innovative search. In Model 1c, the coefficient for Centralization Scale is positive and significant, as predicted. A Centralized firm will cite innovation developed of its organizational boundaries more heavily than will a Decentralized firm. In Model 2c, the coefficient for Centralized is positive and significant, as is the coefficient for Balanced-Hybrid. In Model 3c, the coefficients for Centralization Scale and Centralization Scale^2 are negative and positive, respectively, indicating a U-shaped relationship between centralization of decision authority and organizational breadth of search. This relationship reaches its minimum point when Centralization Scale = 2.5, which is between the Decentralized-Hybrid and the Balanced-Hybrid forms. Thus, the results in these models provide support for Hypothesis 3, as centralized R&D organizations conduct search that looks outside the firm's boundaries to a significantly greater extent than do decentralized R&D organizations, although the same nonlinearity regarding Decentralized-Hybrids remains.

The coefficient for Corp Funding is insignificant in Model 4c. In Model 5c, Centralization remains positively associated with organizational breadth of search, although no other main effect or interaction term has a significant coefficient. In Model 6c, the coefficient for Corp Funding becomes significant and positive, although for hybrid and centralized firms this effect is negated by the significant negative coefficient from the Corp Funding * Centralization Scale interaction term. The results in Models 1c–6c thus provide some support for Hypothesis 3, particularly regarding the centralization of R&D decision authority.

In Models 1d through 6d, virtually none of the hypothesized variables exhibits a significant association with technological breadth. All in all, these models do not provide support for Hypothesis 4.

Overall, then, our results for the differential impact of centralized research efforts are relatively strong (Hypotheses 1 and 2), whereas we

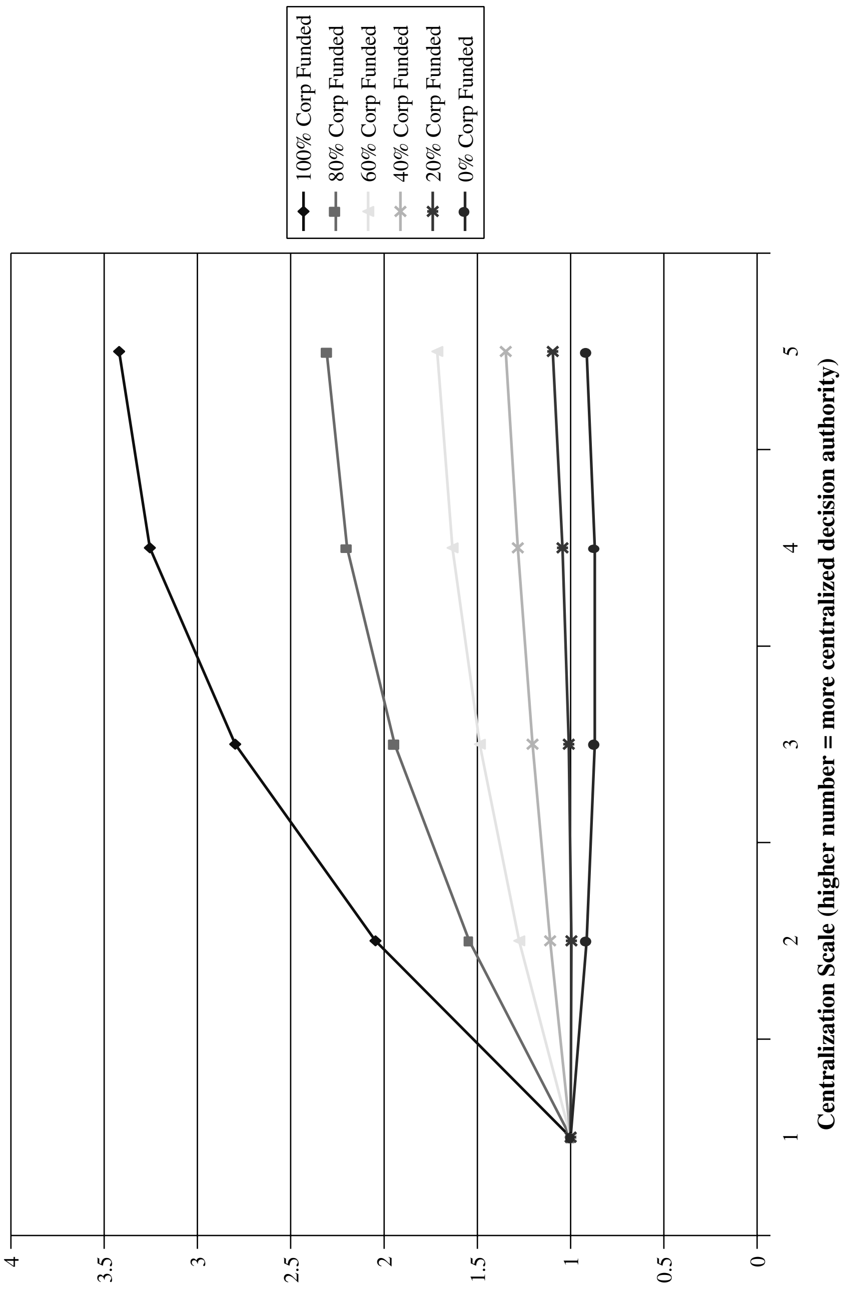

Figure 5. Multiplier effects of decision authority and budget authority on breadth of impact

Table 5. Estimations of the effect of R&D organization on breadth of search

	Org. breadth (1c)	Org. breadth (2c)	Org. breadth (3c)	Org. breadth (4c)	Org. breadth (5c)	Orl. breadth (6c)	Technol. breadth (1d)	Technol. breadth (2d)	Technol. breadth (3d)	Technol. breadth (4d)	Technol. breadth (5d)	Technol. breadth (6d)
Centralization Scale	0.015**		−0.055*			−0.016	−0.002		0.004			0.059
	(0.008)		(0.043)			(0.058)	(0.007)		(0.038)			(0.051)
Centralization Scale^2			0.012**			0.007			−0.001			−0.011*
			(0.007)			(0.010)			(0.006)			(0.009)
DecentralHybrid		−0.005			−0.012			−0.034			−0.003	
		(0.044)			(0.061)			(0.039)			(0.056)	
Balanced-Hybrid		0.061*			0.035			−0.015			0.001	
		(0.038)			(0.050)			(0.036)			(0.047)	
Centralized-Hybrid		−0.009			0.036			−0.004			0.049	
		(0.032)			(0.044)			(0.031)			(0.043)	
Centralized		0.090***			0.106***			−0.026			−0.051	
		(0.034)			(0.043)			(0.032)			(0.041)	
Corporate Funding				0.007	0.305	0.891**				−0.019	0.096	−0.169
				(0.032)	(0.475)	(0.397)				(0.031)	(0.454)	(0.308)
Corp Funding * Centralization Scale						−0.468**						−0.003
						(0.211)						(0.170)
Corp Funding * Centralization Scale^2						0.058**						0.009
						(0.028)						(0.023)
Corp. Funding * Decentral-Hybrid					−0.206						−0.191	
					(0.498)						(0.480)	
Corp. Funding * Balanced-Hybrid					−0.183						−0.144	
					(0.488)						(0.463)	
Corp. Funding * Centralized-Hybrid					−0.371						−0.193	
					(0.480)						(0.456)	
Corp. Funding * Centralized					−0.314						−0.036	
					(0.476)						(460)	
Drug/Chemical Patents	0.000	−0.006	−0.010	−0.004	−0.002	0.003	0.081*	0.071*	0.080*	0.079*	0.066	0.076*
	(0.043)	(0.040)	(0.042)	(0.044)	(0.039)	(0.041)	(0.043)	(0.043)	(0.043)	(0.043)	(0.042)	(0.043)
Electrical/ Computer Patents	0.103*	0.100*	0.100*	0.094	0.098*	0.090	0.027	0.036	0.028	0.021	0.027	0.024
	(0.058)	(0.053)	(0.057)	(0.059)	(0.052)	(0.055)	(0.052)	(0.052)	(0.052)	(0.054)	(0.052)	(0.053)
Diversification	0.000	−0.000	0.000	−000	−0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Significant firm characteristics and sector controls	Included	Included	Included	Included	Included	Included	Included	Included	Included	Included	Included	Included
Constant	0.818***	0.919***	0.943***	0.857***	0.919***	0.907***	0.384***	0.390***	0.376***	0.387***	0.390***	0.339***
	(0.091)	(0.090)	(0.116)	(0.092)	(0.089)	(0.117)	(0.041)	(0.039)	(0.058)	(0.038)	(0.039)	(0.069)
χ^2	17.8	30.7	20.6	14.5	34.4	26.0	30.2	31.6	30.2	30.5	37.1	33.8

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$; one-tailed test for hypothesized variables; two-tailed test for control variables find modest support for differential organizational search (Hypothesis 3) and no support for differential technological search (Hypothesis 4) by centralized research efforts. These two sets of results together imply that, in our sample, the differential impact achieved by centralized R&D may be only partially associated with broader search processes. Rather, following the discussion above, centralized research units' selection of different research problems may drive the differential impact of centralized research to a greater degree than the research units' breadth of search for solutions.

The results for the hybrid forms, when they were measured as categorical variables, are different than anticipated. The coefficients for these measures are generally not significant, indicating that the hybrid organization forms did not consistently generate innovation that is different from that generated by decentralized organizations, at least along the dimensions that we study. More interesting is that the point estimates of the coefficients for hybrid organizations—notably for decentralized hybrids—are often negative. This may indicate that the decentralized hybrid in particular is a challenging organization form for R&D. (Interestingly, this form of organization is the least frequently observed form in our data.) As noted above, most decentralized hybrids in our sample appear to have developed that way through a strategy of acquisition. This focus on acquisition may have led to a de-emphasis on funding and building competence in the extant central R&D labs. Further research could usefully explore whether decentralized hybrids do indeed present particular challenges, and perhaps whether particular paths of corporate growth lead to these organizations. An additional possibility is that the fully decentralized firms in our sample possess divisions that are diverse enough to support fairly non-specific R&D with their divisional labs.[17]

Alternatively, it may be that rather than lying on the continuum between decentralized and centralized R&D, hybrid R&D functions might be designed to solve qualitatively different problems and therefore exhibit qualitatively different performance results. In this sense, hybrid R&D organizations may be 'neither decentralized nor centralized' in the same way that alliances may be 'neither market nor hierarchy' (Powell, 1990). For example, if hybrid R&D firms disproportionately emphasize process R&D, then patent citation measures may be poor indicators of the directions of their R&D efforts. This is because new processes are more difficult to patent, and patents on them are more difficult to enforce, so firms often rely on trade secrecy rather than patents to protect this type of intellectual property. Although beyond the scope of this paper and the currently available data, this is clearly an intriguing area for further study.

Perhaps most intriguing of all regarding hybrids, corporate funding appears to affect the innovative impact of hybrid organizations differently from the way it does either fully centralized or fully decentralized firms. For our models of level of innovative impact, increased centralization of R&D funding leads to increased innovative impact for all three hybrid forms (see Model 5a). In contrast, changes in corporate funding have virtually no impact on fully centralized firms and lead to decreased impact for fully decentralized firms. Perhaps it is the case that in hybrid R&D organizations, where different research personnel report to different centers of authority, ambiguity about R&D objectives is greater than in fully centralized or decentralized organizations. In the presence of such ambiguity, centralization of funding may enable corporate HQ to signal its objectives; in contrast, in the absence of such ambiguity, funding centralization does not offer such a clarifying benefit.

Turning briefly to the control variables, the coefficient for LnSales is significant and negative in all of our models of level of impact. At first glance, this may appear surprising, in that larger firms are presumably more visible and may thus attract attention that translates into patent citations from other organizations (Podolny *et al.*, 1996). However, to the extent that firm size is correlated with firm age, this result is consistent with other evidence that firms tend to look inward more, and have less impact on overall technological evolution, as they age (Sorenson and Stuart 2000). Alternatively, Lerner (1995) finds evidence that small biotechnology firms tend to avoid patenting in the same area as large, well-financed rivals—an effect that he attributes to small firms' desires to avoid the risk of 'sham litigation' in which the well-financed firm launches patent infringement suits of dubious merit to drive the under-capitalized firm

[17] 3M may be one example of such a decentralized R&D firm in our sample. Unfortunately, data on divisional product diversity were not available on the other firms in this category.

out of business through large legal costs. Whether this process operates in the sectors that we study is, of course, an open question. The coefficient for LnR&D is significant and positive in most models of level of impact, indicating that patents generated by firms with larger investments in R&D tend to evidence broader/greater impact. The coefficient for LnPriorPatents is negative and significant in all models of organizational breadth of search, presumably because a firm with more prior patents has a higher 'risk set' of patents to self-cite. The coefficient for Diversification is significant and positive in all models of breadth of impact, and significant and negative in all models of level of impact. This implies that more-diversified firms tend to generate patents that are simultaneously broader in their scope and of less overall importance than those of less diversified firms. The idea that diversified firms generate innovations with broader impacts is consistent with Nelson's (1959) argument that such firms are better able to appropriate returns to broad technological efforts; such an appropriability advantage should give a diversified firm more incentive to develop innovations with broad impact. It is less clear why diversified firms should generate innovations of lower impact. Finally, several sectors evidence systematically different patterns of search and impact, and different technology fields also evidence different patterns of innovative search and impact, as anticipated.

CONCLUSION

The strategy field boasts a long tradition of scholarship on the links between strategy, structure, and performance, and has in the last 20 years increasingly emphasized the importance of technological innovation for firm competitiveness. It is somewhat surprising, therefore, that so little research has addressed the issue of how internal R&D organization affects the directions and impact of technological innovation by multidivisional firms. This is all the more surprising considering the prevalence of scholarship on how organization of *interorganizational* research efforts (i.e., alliances and networks) influence the evolution of technology. Consistent with the implications of established organizational theories, we find that firms in which R&D activities are centralized tend to pursue R&D that has greater impact on future technological development, and spans a broader set of technological domains, than do firms in which R&D activities are decentralized. We also find evidence that firms with centralized R&D draw more on innovations from other organizations than do firms with decentralized R&D. Finally, we find evidence that control over R&D budgets functions as a complementary instrument to support authority relations in affecting innovative impact.

We also find that hybrid R&D organizations do not consistently yield innovation that is 'intermediate' between that of fully decentralized and fully centralized organizations, and that hybrid organizations are particularly responsive to the use of budget authority as a complementary instrument. This last finding underscores a limitation of this study, and an opportunity for future research. Our theoretical discussion of hybrids is not based on a specific theory of hybrid behavior, but rather on the observation that hybrids appear to be intermediate between polar forms of centralization. As such, there are likely nuances in the management of hybrids that we have not captured thus far. Empirically, this study has been limited to analyzing the effects of two rather blunt instruments, to the exclusion of others. Yet the important role accorded budget authority in hybrids raises the possibility that other, more nuanced management instruments—such as rotation of personnel, or cross-divisional teams—may be particularly useful in managing such organizations. Future research may fruitfully explore the influence of other, more targeted instruments, on a firm's innovative outcomes.

Our analysis suggests a number of additional implications and avenues for future research. First and foremost, our empirical results are drawn from a relatively small, if important, sample of firms during a narrow time frame. Future empirical research must examine the key relationships in larger samples and across longer time periods. Of particular interest would be longitudinal studies that examine how a firm's innovative outcomes change with changes in its R&D structure. Fieldwork examining the trade-offs managed by hybrid R&D structures would also be of significant interest.

Relatedly, our analysis suggests implications for the recent stream of research on social networks and innovation. This research has shown how informal communication among scientists and engineers within the firm can stimulate innovation (Reagans and Zuckerman, 2001; Nerkar and Paruchari, 2002). Yet Zenger and colleagues (Nickerson and Zenger, 2002; Zenger, Lazzarini, and Poppo, 2002) have proposed that changes in (discrete) formal organization structures can be judiciously undertaken to spark slower, more continuous changes to informal organization. An intriguing elaboration of this research would be to investigate how changes in formal R&D organization structures interact with informal networks to affect innovative outcomes. For example, does R&D organizational structure affect innovation indirectly, by influencing the development of social networks of scientists and engineers within the firm (or between firms)? If so, how quickly? And how are formal changes moderated by the existence of informal networks?

Further, our analysis points toward potential policy implications for the funding of research. A recent report of the American Association for the Advancement of Science notes a trend in industrial research away from corporate funding and toward business unit funding of R&D: 'it is estimated that 75 percent of all funding for industrial R&D comes from business units [in 1999], up from 50 percent 10 years ago, but still well below the 90 percent level anticipated 10 years from now' (Larson, 1999: 33–34). Given the relationship highlighted in our study between funding source and the nature of innovation, such a shift could potentially have significant repercussions in the trajectory of technological advance. Additional academic research on this relationship may provide additional information to corporate managers regarding the implications of such changes to funding.

Finally, further research on the internal organization of R&D may be fruitfully combined with that on research alliances. Scholars have devoted increasing attention to the existence and source of firm heterogeneity regarding 'alliance capability' (Dyer, Kale, and Singh, 2001). It may be the case that part of a firm's ability to benefit from alliances stems from the way its internal research is organized. Future research identifying both firms' internal organization and pattern of alliances would be challenging in terms of data collection, but could prove to be rewarding.

In sum, questions about the relationship between a firm's internal R&D organization and the outcomes of its research efforts are too important to ignore. We hope that this study will help to reinvigorate their exploration.

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APPENDIX

Coefficients for Firm and Sector Effects for Models of Impact of Search

	Level of impact (1a)	Level of impact (2a)	Level of impact (3a)	Level of impact (4a)	Level of impact (5a)	Level of impact (6a)	Breadth of impact (1b)	Breadth of impact (2b)	Breadth of impact (3b)	Breadth of impact (4b)	Breadth of impact (5b)	Breadth of impact (6b)
Firm controls												
LnSales	−0.341*	−0.432**	−0.419**	−0.298*	−0.439**	−0.414**						
	(0.173)	(0.182)	(0.182)	(0.173)	(0.173)	(0.178)						
LnR&D	0.227	0.295*	0.292*	0.190	0.360**	0.333*						
	(0.147)	(0.153)	(0.153)	(0.146)	(0.148)	(0.153)						
Sector controls												
Resource products							0.028	0.031	0.034	0.038	0.048	0.045
							(0.035)	(0.035)	(0.035)	(0.036)	(0.038)	(0.037)
Industrial products							0.046	0.053	0.059*	0.045	0.056	0.056
							(0.034)	(0.035)	(0.035)	(0.034)	(0.036)	(0.035)
Pharmaceutical/ Chemical products							0.051*	0.051*	0.050*	0.055*	0.060*	0.054*
							(0.029)	(0.028)	(0.029)	(0.029)	(0.032)	(0.029)

	Org. breadth (1c)	Org. breadth (2c)	Org. breadth (3c)	Org. breadth (4c)	Org. breadth (5c)	Org. breadth (6c)	Technol. breadth (1d)	Technol. breadth (2d)	Technol. breadth (3d)	Technol. breadth (4d)	Technol. breadth (5d)	Technol. breadth (6d)
Firm controls												
LnSales	0.019	0.007	0.011	0.023	0.008	0.010						
	(0.014)	(0.014)	(0.015)	(0.015)	(0.014)	(0.014)						
LnR&D	−0.013	−0.007	−0.007	−0.018	−0.008	−0.010						
	(0.013)	(0.012)	(0.013)	(0.013)	(0.012)	(0.013)						
LnPriorp	−0.023***	−0.022***	−0.022***	−0.021**	−0.025***	−0.024***						
	(0.008)	(0.007)	(0.008)	(0.008)	(0.008)	(0.008)						
Sector controls												
Resource							0.156***	0.155***	0.155***	0.149***	0.162***	0.155***
							(0.034)	(0.034)	(0.034)	(0.035)	(0.036)	(0.036)
Indust.							0.111***	0.108***	0.110***	0.112***	0.124***	0.120***
							(0.033)	(0.034)	(0.034)	(0.033)	(0.033)	(0.034)
chemphrm.							0.127***	0.130***	0.127***	0.125***	0.147***	0.133***
							(0.029)	(0.029)	(0.029)	(0.029)	(0.032)	(0.029)

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$; one-tailed test for hypothesized variables; two-tailed test for control variables