Absorptive Capacity: A New Perspective on Learning and Innovation

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In this paper, we argue that the ability of a firm to recognize the value of new, external information, assimilate it, and apply it to commercial ends is critical to its innovative capabilities. We label this capability a firm's absorptive capacity and suggest that it is largely a function of the firm's level of prior related knowledge. The discussion focuses first on the cognitive basis for an individual's absorptive capacity including, in particular, prior related knowledge and diversity of background. We then characterize the factors that influence absorptive capacity at the organizational level, how an organization's absorptive capacity differs from that of its individual members, and the role of diversity of expertise within an organization. We argue that the development of absorptive capacity, and, in turn, innovative performance are history- or path-dependent and argue how lack of investment in an area of expertise early on may foreclose the future development of a technical capability in that area. We formulate a model of firm investment in research and development (R&D), in which R&D contributes to a firm's absorptive capacity, and test predictions relating a firm's investment in R&D to the knowledge underlying technical change within an industry. Discussion focuses on the implications of absorptive capacity for the analysis of other related innovative activities, including basic research, the adoption and diffusion of innovations, and decisions to participate in cooperative R&D ventures.•

INTRODUCTION

Outside sources of knowledge are often critical to the innovation process, whatever the organizational level at which the innovating unit is defined. While the example of Japan illustrates the point saliently at the national level (e.g., Westney and Sakakibara, 1986; Mansfield, 1988; Rosenberg and Steinmueller, 1988), it is also true of entire industries, as pointed out by Brock (1975) in the case of computers and by Peck (1962) in the case of aluminum. At the organizational level, March and Simon (1958: 188) suggested most innovations result from borrowing rather than invention. This observation is supported by extensive research on the sources of innovation (e.g., Mueller, 1962; Hamberg, 1963; Myers and Marquis, 1969; Johnston and Gibbons, 1975; von Hippel, 1988). Finally, the importance to innovative performance of information originating from other internal units in the firm, outside the formal innovating unit (i.e., the R&D lab), such as marketing and manufacturing, is well understood (e.g., Mansfield, 1968).

The ability to exploit external knowledge is thus a critical component of innovative capabilities. We argue that the ability to evaluate and utilize outside knowledge is largely a function of the level of prior related knowledge. At the most elemental level, this prior knowledge includes basic skills or even a shared language but may also include knowledge of the most recent scientific or technological developments in a given field. Thus, prior related knowledge confers an ability to recognize the value of new information, assimilate it, and apply it to commercial ends. These abilities collectively constitute what we call a firm's "absorptive capacity."

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At the level of the firm—the innovating unit that is the focus here—absorptive capacity is generated in a variety of ways. Research shows that firms that conduct their own R&D are *better able to use externally available information* (e.g., Tilton, 1971; Allen, 1977; Mowery, 1983). This implies that absorptive capacity may be created as a byproduct of a firm's R&D investment. Other work suggests that absorptive capacity may also be developed as a byproduct of a firm's manufacturing operations. Abernathy (1978) and Rosenberg (1982) have noted that through direct involvement in manufacturing, *a firm is better able to recognize and exploit new information* relevant to a particular product market. Production experience provides the firm with the background necessary both to recognize the value of and implement methods to reorganize or automate particular manufacturing processes. Firms also invest in absorptive capacity directly, as when they send personnel for advanced technical training. The concept of *absorptive capacity can best be developed through an examination* of the cognitive structures that underlie learning.

Cognitive Structures

The premise of the notion of absorptive capacity is that the organization needs prior related knowledge to assimilate and use new knowledge. Studies in the area of cognitive and behavioral sciences at the individual level both justify and enrich this observation. Research on memory development suggests that accumulated prior knowledge increases both the ability to put new knowledge into memory, what we would refer to as the acquisition of knowledge, and the ability to recall and use it. With respect to the acquisition of knowledge, Bower and Hilgard (1981: 424) suggested that memory development is self-reinforcing in that the more objects, patterns and concepts that are stored in memory, the more readily is new information about these constructs acquired and the more facile is the individual in using them in new settings.

Some psychologists suggest that prior knowledge enhances learning because memory—or the storage of knowledge—is developed by associative learning in which events are recorded into memory by establishing linkages with pre-existing concepts. Thus, Bower and Hilgard (1981) suggested that the breadth of categories into which prior knowledge is organized, the differentiation of those categories, and the linkages across them permit individuals to make sense of and, in turn, acquire new knowledge. In the context of learning a language, Lindsay and Norman (1977: 517) suggested the problem in learning words is not a result of lack of exposure to them but that "to understand complex phrases, much more is needed than exposure to the words: a large body of knowledge must first be accumulated. After all, a word is simply a label for a set of structures within the memory system, so the structures must exist before the word can be considered learned." Lindsay and Norman further suggested that knowledge may be nominally acquired but not well utilized subsequently because the individual did not already possess the appropriate contextual knowledge necessary to make the new knowledge fully intelligible.

The notion that prior knowledge facilitates the learning of new related knowledge can be extended to include the case in

which the knowledge in question may itself be a set of learning skills. There may be a transfer of learning skills across bodies of knowledge that are organized and expressed in similar ways. As a consequence, experience or performance on one learning task may influence and improve performance on some subsequent learning task (Ellis, 1965). This progressive improvement in the performance of learning tasks is a form of knowledge transfer that has been referred to as "learning to learn" (Ellis, 1965; Estes, 1970). Estes (1970: 16), however, suggested that the term "learning to learn" is a misnomer in that prior experience with a learning task does not necessarily improve performance because an individual knows how to learn (i.e., form new associations) better, but that an individual may simply have accumulated more prior knowledge so that he or she needs to learn less to attain a given level of performance. Notwithstanding what it is about prior learning experience that may affect subsequent performance, both explanations of the relationship between early learning and subsequent performance emphasize the importance of prior knowledge for learning.

The effect of prior learning experience on subsequent learning tasks can be observed in a variety of tasks. For instance, Ellis (1965: 4) suggested that "students who have thoroughly mastered the principles of algebra find it easier to grasp advanced work in mathematics such as calculus." Further illustration is provided by Anderson, Farrell, and Sauers (1984), who compared students learning LISP as a first programming language with students learning LISP after having learned Pascal. The Pascal students learned LISP much more effectively, in part because they better appreciated the semantics of various programming concepts.

The literature also suggests that problem-solving skills develop similarly. In this case, problem-solving methods and heuristics typically constitute the prior knowledge that permits individuals to acquire related problem-solving capabilities. In their work on the development of computer programming skills, Pirolli and Anderson (1985) found that almost all students developed new programs by analogy-to-example programs and that their success was determined by how well they understood why these examples worked.

We argue that problem solving and learning capabilities are so similar that there is little reason to differentiate their modes of development, although exactly what is learned may differ: learning capabilities involve the development of the capacity to assimilate existing knowledge, while problem-solving skills represent a capacity to create new knowledge. Supporting the point that there is little difference between the two, Bradshaw, Langley, and Simon (1983) and Simon (1985) suggested that the sort of necessary preconditions for successful learning that we have identified do not differ from the preconditions required for problem solving and, in turn, for the creative process. Moreover, they argued that the processes themselves do not differ much. The prior possession of relevant knowledge and skill is what gives rise to creativity, permitting the sorts of associations and linkages that may have never been considered before. Likewise, Ellis (1965: 35) suggested that Harlow's (1959) findings on the development of learning sets provide a possible explanation for the behavioral

phenomenon of "insight" that typically refers to the rapid solution of a problem. Thus, the psychology literature suggests that creative capacity and what we call absorptive capacity are quite similar.

To develop an effective absorptive capacity, whether it be for general knowledge or problem-solving or learning skills, it is insufficient merely to expose an individual briefly to the relevant prior knowledge. Intensity of effort is critical. With regard to storing knowledge in memory, Lindsay and Norman (1977: 355) noted that the more deeply the material is processed—the more effort used, the more processing makes use of associations between the items to be learned and knowledge already in the memory—the better will be the later retrieval of the item. Similarly, learning-set theory (Harlow, 1949, 1959) implies that important aspects of learning how to solve problems are built up over many practice trials on related problems. Indeed, Harlow (1959) suggested that if practice with a particular type of problem is discontinued before it is reliably learned, then little transfer will occur to the next series of problems. Therefore, he concluded that considerable time and effort should be spent on early problems before moving on to more complex problems.

Two related ideas are implicit in the notion that the ability to assimilate information is a function of the richness of the preexisting knowledge structure: learning is cumulative, and learning performance is greatest when the object of learning is related to what is already known. As a result, learning is more difficult in novel domains, and, more generally, an individual's expertise—what he or she knows well—will change only incrementally. The above discussion also suggests that diversity of knowledge plays an important role. In a setting in which there is uncertainty about the knowledge domains from which potentially useful information may emerge, a diverse background provides a more robust basis for learning because it increases the prospect that incoming information will relate to what is already known. In addition to strengthening assimilative powers, knowledge diversity also facilitates the innovative process by enabling the individual to make novel associations and linkages.

From Individual to Organizational Absorptive Capacity

An organization's absorptive capacity will depend on the absorptive capacities of its individual members. To this extent, the development of an organization's absorptive capacity will build on prior investment in the development of its constituent, individual absorptive capacities, and, like individuals' absorptive capacities, organizational absorptive capacity will tend to develop cumulatively. A firm's absorptive capacity is not, however, simply the sum of the absorptive capacities of its employees, and it is therefore useful to consider what aspects of absorptive capacity are distinctly organizational. Absorptive capacity refers not only to the acquisition or assimilation of information by an organization but also to the organization's ability to exploit it. Therefore, an organization's absorptive capacity does not simply depend on the organization's direct interface with the external environment. It also depends on transfers of knowledge across and within subunits that may be quite removed from the original point of

entry. Thus, to understand the sources of a firm's absorptive capacity, we focus on the structure of communication between the external environment and the organization, as well as among the subunits of the organization, and also on the character and distribution of expertise within the organization.

Communication systems may rely on specialized actors to transfer information from the environment or may involve less structured patterns. The problem of designing communication structures cannot be disentangled from the distribution of expertise in the organization. The firm's absorptive capacity depends on the individuals who stand at the interface of either the firm and the external environment or at the interface between subunits within the firm. That interface function may be diffused across individuals or be quite centralized. When the expertise of most individuals within the organization differs considerably from that of external actors who can provide useful information, some members of the group are likely to assume relatively centralized "gatekeeping" or "boundary-spanning" roles (Allen, 1977; Tushman, 1977). For technical information that is difficult for internal staff to assimilate, a gatekeeper both monitors the environment and translates the technical information into a form understandable to the research group. In contrast, if external information is closely related to ongoing activity, then external information is readily assimilated and gatekeepers or boundary-spanners are not so necessary for translating information. Even in this setting, however, gatekeepers may emerge to the extent that such role specialization relieves others from having to monitor the environment.

A difficulty may emerge under conditions of rapid and uncertain technical change, however, when this interface function is centralized. When information flows are somewhat random and it is not clear where in the firm or subunit a piece of outside knowledge is best applied, a centralized gatekeeper may not provide an effective link to the environment. Under such circumstances, it is best for the organization to expose a fairly broad range of prospective "receptors" to the environment. Such an organization would exhibit the organic structure of Burns and Stalker (1961: 6), which is more adaptable "when problems and requirements for action arise which cannot be broken down and distributed among specialist roles within a clearly defined hierarchy."

Even when a gatekeeper is important, his or her individual absorptive capacity does not constitute the absorptive capacity of his or her unit within the firm. The ease or difficulty of the internal communication process and, in turn, the level of organizational absorptive capacity are not only a function of the gatekeeper's capabilities but also of the expertise of those individuals to whom the gatekeeper is transmitting the information. Therefore, relying on a small set of technological gatekeepers may not be sufficient; the group as a whole must have some level of relevant background knowledge, and when knowledge structures are highly differentiated, the requisite level of background may be rather high.

The background knowledge required by the group as a whole for effective communication with the gatekeeper highlights the more general point that shared knowledge and expertise

is essential for communication. At the most basic level, the relevant knowledge that permits effective communication both within and across subunits consists of shared language and symbols (Dearborn and Simon, 1958; Katz and Kahn, 1966; Allen and Cohen, 1969; Tushman, 1978; Zenger and Lawrence, 1989). With regard to the absorptive capacity of the firm as a whole, there may, however, be a trade-off in the efficiency of internal communication against the ability of the subunit to assimilate and exploit information originating from other subunits or the environment. This can be seen as a trade-off between inward-looking versus outward-looking absorptive capacities. While both of these components are necessary for effective organizational learning, excessive dominance by one or the other will be dysfunctional. If all actors in the organization share the same specialized language, they will be effective in communicating with one another, but they may not be able to tap into diverse external knowledge sources. In the limit, an internal language, coding scheme, or, more generally, any particular body of expertise could become sufficiently overlapping and specialized that it impedes the incorporation of outside knowledge and results in the pathology of the not-invented-here (NIH) syndrome. This may explain Katz and Allen's (1982) findings that the level of external communication and communication with other project groups declines with project-group tenure.

This trade-off between outward- and inward-looking components of absorptive capacity focuses our attention on how the relationship between knowledge sharing and knowledge diversity across individuals affects the development of organizational absorptive capacity. While some overlap of knowledge across individuals is necessary for internal communication, there are benefits to diversity of knowledge structures across individuals that parallel the benefits to diversity of knowledge within individuals. As Simon (1985) pointed out, diverse knowledge structures coexisting in the same mind elicit the sort of learning and problem solving that yields innovation. Assuming a sufficient level of knowledge overlap to ensure effective communication, interactions across individuals who each possess diverse and different knowledge structures will augment the organization's capacity for making novel linkages and associations—innovating—beyond what any one individual can achieve. Utterback (1971), summarizing research on task performance and innovation, noted that diversity in the work setting "stimulates the generation of new ideas." Thus, as with Nelson and Winter's (1982) view of organizational capabilities, an organization's absorptive capacity is not resident in any single individual but depends on the links across a mosaic of individual capabilities.

Beyond diverse knowledge structures, the sort of knowledge that individuals should possess to enhance organizational absorptive capacity is also important. Critical knowledge does not simply include substantive, technical knowledge; it also includes awareness of where useful complementary expertise resides within and outside the organization. This sort of knowledge can be knowledge of who knows what, who can help with what problem, or who can exploit new information. With regard to external relationships, von Hippel (1988) has

shown the importance for innovation of close relationships with both buyers and suppliers. To the extent that an organization develops a broad and active network of internal and external relationships, individuals' awareness of others' capabilities and knowledge will be strengthened. As a result, individual absorptive capacities are leveraged all the more, and the organization's absorptive capacity is strengthened.

The observation that the ideal knowledge structure for an organizational subunit should reflect only partially overlapping knowledge complemented by nonoverlapping diverse knowledge suggests an organizational trade-off between diversity and commonality of knowledge across individuals. While common knowledge improves communication, commonality should not be carried so far that diversity across individuals is substantially diminished. Likewise, division of labor promoting gains from specialization should not be pushed so far that communication is undermined. The difficulties posed by excessive specialization suggest some liabilities of pursuing production efficiencies via learning by doing under conditions of rapid technical change in which absorptive capacity is important. In learning by doing, the firm becomes more practiced and hence more capable at activities in which it is already engaged. Learning by doing does not contribute to the diversity that is critical to learning about or creating something that is relatively new. Moreover, the notion of "remembering by doing" (Nelson and Winter, 1982) suggests that the focus on one class of activity entailed by learning by doing may effectively diminish the diversity of background that an individual or organization may have at one time possessed and, consequently, undercut organizational absorptive capacity and innovative performance.

It has become generally accepted that complementary functions within the organization ought to be tightly intermeshed, recognizing that some amount of redundancy in expertise may be desirable to create what can be called cross-function absorptive capacities. Cross-function interfaces that affect organizational absorptive capacity and innovative performance include, for example, the relationships between corporate and divisional R&D labs or, more generally, the relationships among the R&D, design, manufacturing, and marketing functions (e.g., Mansfield, 1968: 86–88). Close linkages between design and manufacturing are often credited for the relative success of Japanese firms in moving products rapidly from the design stage through development and manufacturing (Westney and Sakakibara, 1986). Clark and Fujimoto (1987) argued that overlapping product development cycles facilitate communication and coordination across organizational subunits. They found that the speed of product development is strongly influenced by the links between problem-solving cycles and that successful linking requires "direct personal contacts across functions, liaison roles at each unit, cross-functional task forces, cross-functional project teams, and a system of 'product manager as integrator' " (Clark and Fujimoto, 1987: 24). In contrast, a process in which one unit simply hands off the design to another unit is likely to suffer greater difficulties.

Some management practices also appear to reflect the belief that an excessive degree of overlap in functions may reduce

the firm's absorptive capacity and that diversity of backgrounds is useful. The Japanese practice of rotating their R&D personnel through marketing and manufacturing operations, for example, while creating knowledge overlap, also enhances the diversity of background of their personnel. Often involving the assignment of technical personnel to other functions for several years, this practice also suggests that some intensity of experience in each of the complementary knowledge domains is necessary to put an effective absorptive capacity in place; breadth of knowledge cannot be superficial to be effective.

The discussion thus far has focused on internal mechanisms that influence the organization's absorptive capacity. A question remains as to whether absorptive capacity needs to be internally developed or to what extent a firm may simply buy it via, for example, hiring new personnel, contracting for consulting services, or even through corporate acquisitions. We suggest that the effectiveness of such options is somewhat limited when the absorptive capacity in question is to be integrated with the firm's other activities. A critical component of the requisite absorptive capacity for certain types of information, such as those associated with product and process innovation, is often firm-specific and therefore cannot be bought and quickly integrated into the firm. This is reflected in Lee and Allen's (1982) findings that considerable time lags are associated with the integration of new technical staff, particularly those concerned with process and product development. To integrate certain classes of complex and sophisticated technological knowledge successfully into the firm's activities, the firm requires an existing internal staff of technologists and scientists who are both competent in their fields and are familiar with the firm's idiosyncratic needs, organizational procedures, routines, complementary capabilities, and extramural relationships. As implied by the discussion above, such diversity of knowledge structures must coexist to some degree in the same minds. Moreover, as Nelson and Winter's (1982) analysis suggests, much of the detailed knowledge of organizational routines and objectives that permit a firm and its R&D labs to function is tacit. As a consequence, such critical complementary knowledge is acquired only through experience within the firm. Illustrating our general argument, Vyssotsky (1977), justifying the placement of Bell Labs within AT&T, argued: "For research and development to yield effective results for Bell System, it has to be done by . . . creative people who understand as much as they possibly can about the technical state of the art, and about Bell System and what System's problems are. The R&D people must be free to think up new approaches, and they must also be closely coupled to the problems and challenges where innovation is needed. This combination, if one is lucky, will result in insights which help the Bell System. That's why we have Bell Labs in Bell System, instead of having all our R&D done by outside organizations."

Path Dependence and Absorptive Capacity

Our discussion of the character of absorptive capacity and its role in assimilating and exploiting knowledge suggests a simple generalization that applies at both the individual and organizational levels: prior knowledge permits the assimilation

and exploitation of new knowledge. Some portion of that prior knowledge should be very closely related to the new knowledge to facilitate assimilation, and some fraction of that knowledge must be fairly diverse, although still related, to permit effective, creative utilization of the new knowledge. This simple notion that prior knowledge underlies absorptive capacity has important implications for the development of absorptive capacity over time and, in turn, the innovative performance of organizations. The basic role of prior knowledge suggests two features of absorptive capacity that will affect innovative performance in an evolving, uncertain environment (Cohen and Levinthal, 1989b). Accumulating absorptive capacity in one period will permit its more efficient accumulation in the next. By having already developed some absorptive capacity in a particular area, a firm may more readily accumulate what additional knowledge it needs in the subsequent periods in order to exploit any critical external knowledge that may become available. Second, the possession of related expertise will permit the firm to better understand and therefore evaluate the import of intermediate technological advances that provide signals as to the eventual merit of a new technological development. Thus, in an uncertain environment, absorptive capacity affects expectation formation, permitting the firm to predict more accurately the nature and commercial potential of technological advances. These revised expectations, in turn, condition the incentive to invest in absorptive capacity subsequently. These two features of absorptive capacity—cumulativeness and its effect on expectation formation—imply that its development is domain-specific and is path- or history-dependent.

The cumulativeness of absorptive capacity and its effect on expectation formation suggest an extreme case of path dependence in which once a firm ceases investing in its absorptive capacity in a quickly moving field, it may never assimilate and exploit new information in that field, regardless of the value of that information. There are two reasons for the emergence of this condition, which we term "lockout" (Cohen and Levinthal, 1989b). First, if the firm does not develop its absorptive capacity in some initial period, then its beliefs about the technological opportunities present in a given field will tend not to change over time because the firm may not be aware of the significance of signals that would otherwise revise its expectations. As a result, the firm does not invest in absorptive capacity and, when new opportunities subsequently emerge, the firm may not appreciate them. Compounding this effect, to the extent that prior knowledge facilitates the subsequent development of absorptive capacity, the lack of early investment in absorptive capacity makes it more costly to develop a given level of it in a subsequent period. Consequently, a low initial investment in absorptive capacity diminishes the attractiveness of investing in subsequent periods even if the firm becomes aware of technological opportunities.[1] This possibility of firms being "locked-out" of subsequent technological developments has recently become a matter of concern with respect to industrial policy. For instance, Reich (1987: 64) declaims Monsanto's exit from "float-zone" silicon manufacturing because he believes that the decision may be an irreversible exit from a technology, in that ". . . each new generation of technology

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A similar result emerges from models of adaptive learning. Levitt and March (1988: 322) noted that "a competency trap can occur when favorable performance with an inferior procedure leads an organization to accumulate more experience with it, thus keeping experience with a superior procedure inadequate to make it rewarding to use."

builds on that which came before, once off the technological escalator it's difficult to get back on."

Thus, the cumulative quality of absorptive capacity and its role in conditioning the updating of expectations are forces that tend to confine firms to operating in a particular technological domain. If firms do not invest in developing absorptive capacity in a particular area of expertise early on, it may not be in their interest to develop that capacity subsequently, even after major advances in the field. Thus, the pattern of inertia that Nelson and Winter (1982) highlighted as a central feature of firm behavior may emerge as an implication of rational behavior in a model in which absorptive capacity is cumulative and contributes to expectation formation. The not-invented-here syndrome, in which firms resist accepting innovative ideas from the environment, may also at times reflect what we call lockout. Such ideas may be too distant from the firm's existing knowledge base—its absorptive capacity—to be either appreciated or accessed. In this particular setting, NIH may be pathological behavior only in retrospect. The firm need not have acted irrationally in the development of the capabilities that yields the NIH syndrome as its apparent outcome.

A form of self-reinforcing behavior similar to lockout may also result from the influence of absorptive capacity on organizations' goals or aspiration levels. This argument builds on the behavioral view of organizational innovation that has been molded in large part by the work of March and Simon (1958). In March and Simon's framework, innovative activity is instigated due to a failure to reach some aspiration level. Departing from their model, we suggest that a firm's aspiration level in a technologically progressive environment is not simply determined by past performance or the performance of reference organizations. It also depends on the firm's absorptive capacity. The greater the organization's expertise and associated absorptive capacity, the more sensitive it is likely to be to emerging technological opportunities and the more likely its aspiration level will be defined in terms of the opportunities present in the technical environment rather than strictly in terms of performance measures. Thus, organizations with higher levels of absorptive capacity will tend to be more proactive, exploiting opportunities present in the environment, independent of current performance. Alternatively, organizations that have a modest absorptive capacity will tend to be reactive, searching for new alternatives in response to failure on some performance criterion that is not defined in terms of technical change per se (e.g., profitability, market share, etc.).

A systematic and enduring neglect of technical opportunities may result from the effect of absorptive capacity on the organization's aspiration level when innovative activity (e.g., R&D) contributes to absorptive capacity, which is often the case in technologically progressive environments. The reason is that the firm's aspiration level then depends on the very innovative activity that is triggered by a failure to meet the aspiration level itself. If the firm engages in little innovative activity, and is therefore relatively insensitive to the opportunities in the external environment, it will have a low aspiration level with regard to the exploitation of new technology, which in turn

implies that it will continue to devote little effort to innovation. This creates a self-reinforcing cycle. Likewise, if an organization has a high aspiration level, influenced by externally generated technical opportunities, it will conduct more innovative activity and thereby increase its awareness of outside opportunities. Consequently, its aspiration level will remain high. This argument implies that reactive and proactive modes of firm behavior should remain rather stable over time. Thus, some organizations (like Hewlett-Packard and Sony) have the requisite technical knowledge to respond proactively to the opportunities present in the environment. These firms do not wait for failure on some performance dimension but aggressively seek out new opportunities to exploit and develop their technological capabilities.[2]

The concept of dynamically self-reinforcing behavior that may lead to the neglect of new technological developments provides some insight into the difficulties firms face when the technological basis of an industry changes—what Schumpeter (1942) called "the process of creative destruction." For instance, the change from electromechanical devices to electronic ones in the calculator industry resulted in the exit of a number of firms and a radical change in the market structure (Majumdar, 1982). This is an example of what Tushman and Anderson (1986) termed competence-destroying technical change. A firm without a prior technological base in a particular field may not be able to acquire one readily if absorptive capacity is cumulative. In addition, a firm may be blind to new developments in fields in which it is not investing if its updating capability is low. Accordingly, our argument implies that firms may not realize that they should be developing their absorptive capacity due to an irony associated with its valuation: the firm needs to have some absorptive capacity already to value it appropriately.

Absorptive Capacity and R&D Investment

The prior discussion does not address the question of whether we can empirically evaluate the importance of absorptive capacity for innovation. There is a key insight that permits empirical tests of the implications of absorptive capacity for innovative activity. Since technical change within an industry—typically incremental in character (Rosenberg and Steinmueller, 1988)—is often closely related to a firm's ongoing R&D activity, a firm's ability to exploit external knowledge is often generated as a byproduct of its R&D. We may therefore consider a firm's R&D as satisfying two functions: we assume that R&D not only generates new knowledge but also contributes to the firm's absorptive capacity.[3] If absorptive capacity is important, and R&D contributes to it, then whatever conditions the firm's incentives to learn (i.e., to build absorptive capacity) should also influence R&D spending. We may therefore consider the responsiveness of R&D activity to learning incentives as an indication of the empirical importance of absorptive capacity. The empirical challenge then is to understand the impact of the characteristics of the learning environment on R&D spending.

We construct a simple static model of firm R&D intensity, which is defined as R&D divided by sales. Normalization of R&D by firm sales controls for the effect of firm size, which

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This argument that such reactive and proactive behavior may coexist in an industry over the long run assumes that there is slack in the selection environment and that technologically progressive behavior is not essential to survival. One can, alternatively, identify a number of industries, such as semiconductors, in which it appears that only firms that aggressively exploit technical opportunities survive.

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We refer readers interested in the details of the theoretical and subsequent empirical analysis and results to Cohen and Levinthal (1989a), from which the following discussion is drawn.

affects the return per unit of R&D effort. This model is developed in the broader context of what applied economists have come to believe to be the three classes of industry-level determinants of R&D intensity: demand, appropriability, and technological opportunity conditions (Cohen and Levin, 1989). Demand is often characterized by the level of sales and the price elasticity of demand. The latter indicates the degree to which a firm's revenue will increase due to a reduction in price. For example, in the case of a process innovation that reduces the cost of production and, in turn, the product price, the price elasticity of demand reflects the associated change in total revenue that influences the economic return to innovative effort. Appropriability conditions refer to the degree to which firms capture the profits associated with their innovative activity and are often considered to reflect the degree to which valuable knowledge spills out into the public domain. The emphasis here is on valuable knowledge, because if a competitor's knowledge spills out but the competitor has already exploited a first-mover advantage in the marketplace, this knowledge is no longer valuable to the firm and does not constitute a spillover by our definition. The level of spillovers, in turn, depends on the strength of patents within an industry, the efficacy of secrecy, and/or first-mover advantages. Technological opportunity represents how costly it is for the firm to achieve some normalized unit of technical advance in a given industry. As typically conceived, there are two dimensions of technological opportunity (Cohen and Levin, 1989). The first, incorporated in our model, refers simply to the quantity of extraindustry technological knowledge, such as that originating from government or university labs, that effectively complements and therefore leverages the firm's own knowledge output. The second dimension of technological opportunity is the degree to which a unit of new knowledge improves the technological performance of the firm's manufacturing processes or products and, in turn, the firm's profits. For example, given the vitality of the underlying science and technology, an advance in knowledge promises to yield much larger product-performance payoffs in the semiconductor industry than in steel.[4]

The basic model of how absorptive capacity affects the determination of R&D expenditures is represented diagramatically in Figure 1. We postulate that learning incentives will have a direct effect on R&D spending. We also suggest that where the effect of other determinants, such as technological opportunity and appropriability, depend on the firm's or rivals' assimilation of knowledge, absorptive capacity—and therefore learning incentives—will mediate those effects. Finally, we suggest that the effect of appropriability conditions (i.e., spillovers) will be conditioned by competitor interdependence. In this context, we define interdependence as the extent to which a rival's technical advances diminish the firm's profits.

There are two factors that will affect a firm's incentives to learn, and, therefore, its incentives to invest in absorptive capacity via its R&D expenditures. First, there is the quantity of knowledge to be assimilated and exploited: the more there is, the greater the incentive. Second, there is the difficulty (or, conversely, the ease) of learning. Some types of information are more difficult to assimilate and use than others. We inter-

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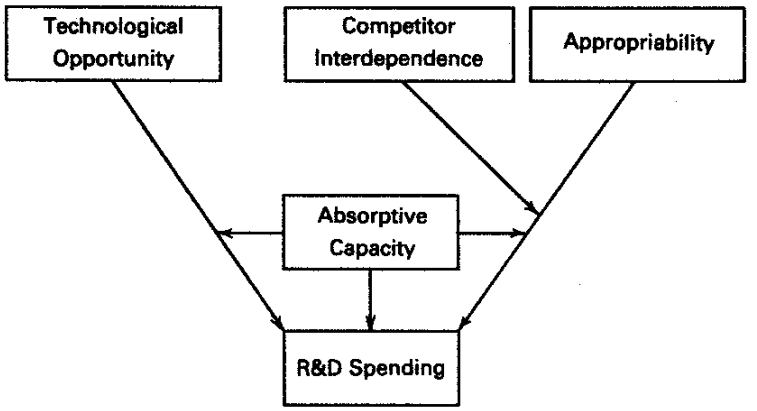
This second dimension is incorporated in the model developed in Cohen and Levinthal (1989a). We do not incorporate this second dimension in the present model because all the qualitative theoretical and empirical results associated with this second dimension of technological opportunity are the same as those associated with the first considered here.

Figure 1. Model of absorptive capacity and R&D incentives.



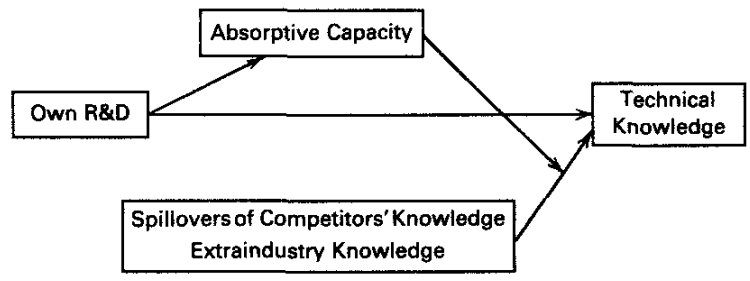
pret this to mean that per unit of knowledge, the cost of its absorption may vary depending on the characteristics of that knowledge. As learning is more difficult, more prior knowledge has to have been accumulated via R&D for effective learning to occur. As a result, this is a more costly learning environment. In such a setting, R&D is more important to building absorptive capacity and the more R&D effort the firm will need to have expended to achieve some level of absorptive capacity. Thus, for a given level of a firm's own R&D, the level of absorptive capacity is diminished in environments in which it is more difficult to learn. In addition, we are suggesting that a more difficult learning environment increases the marginal effect of R&D on absorptive capacity. In contrast, in environments in which learning is less demanding, a firm's own R&D has little impact on its absorptive capacity. In the extreme case in which external knowledge can be assimilated without any specialized expertise, a firm's own R&D would have no effect on its absorptive capacity.

We have argued that the ease of learning is in turn determined by the characteristics of the underlying scientific and technological knowledge. Although it is difficult to specify a priori all the relevant characteristics of knowledge affecting the ease of learning, they would include the complexity of the knowledge to be assimilated and the degree to which the outside knowledge is targeted to the needs and concerns of the firm. When outside knowledge is less targeted to the firm's particular needs and concerns, a firm's own R&D becomes more important in permitting it to recognize the value of the knowledge, assimilate, and exploit it. Sources that produce less targeted knowledge would include university labs involved in basic research, while more targeted knowledge may be generated by contract research labs, or input suppliers. In addition, the degree to which a field is cumulative, or the field's pace of advance, should also affect how critical R&D is to the development of absorptive capacity. The more that findings in a field build on prior findings, the more necessary is an understanding of prior research to the assimilation of subsequent findings. The pace of advance of a field affects the importance of R&D to developing absorptive capacity because the faster the pace of knowledge generation, the larger

the staff required to keep abreast of new developments. Finally, following Nelson and Winter (1982), the less explicit and codified the relevant knowledge, the more difficult it is to assimilate.

To structure the analysis, we assumed that firms purposefully invest in R&D to generate profit and take into account R&D's dual role in both directly generating new knowledge and contributing to absorptive capacity. Knowledge is assumed to be useful to the firm in that increments to a firm's own knowledge increase the firm's profits while increments to rivals' knowledge diminish them. We posit a simple model of the generation of a firm's technological knowledge that takes into account the major sources of technological knowledge utilized by a firm: the firm's own R&D knowledge that originates with its competitors' R&D, spillovers, and that which originates outside the industry. Figure 2 provides a stylized representation of this model in which, first, the firm generates new knowledge directly through its own R&D, and second, extramural knowledge, drawn from competitors as well as extraindustry sources such as government and university labs, also contribute to the firm's knowledge. A central feature of the model is that the firm's absorptive capacity determines the extent to which this extramural knowledge is utilized, and this absorptive capacity itself depends on the firm's own R&D. Because of this mediating function, absorptive capacity influences the effects of appropriability and technological opportunity conditions on R&D spending. Thus, the effects of appropriability and technological opportunity are not independent of R&D itself.

Figure 2. Model of sources of a firm's technical knowledge.



A key assumption in the model is that exploitation of competitors' research findings is realized through the interaction of the firm's absorptive capacity with competitors' spillovers. This interaction signifies that a firm is unable to assimilate externally available knowledge passively. Rather, to utilize the accessible R&D output of its competitors, the firm invests in its absorptive capacity by conducting R&D. Figure 2 also illustrates that, like its assimilation of competitors' R&D output, a firm's assimilation of extraindustry knowledge—the dimension of technological opportunity considered here—is constrained by its absorptive capacity. According to our model, therefore, the factors that affect learning incentives (i.e., the ease of learning and the quantity of available knowledge) influence the effects of appropriability and technological opportunity conditions on R&D.

Direct effect of ease of learning. As shown formally in Cohen and Levinthal (1989a), this model implies that as the ease of learning diminishes, learning becomes more dependent on a firm's own R&D, and R&D spending increases because of two effects. First, the marginal impact of R&D on absorptive capacity is greater in more difficult learning environments. As the learning environment becomes more difficult, however, there is a second, more subtle effect. Since, ceteris paribus, a more difficult learning environment lowers firms' absorptive capacities, R&D activity becomes more of a private good in the sense that competitors are now less able to tap into the firm's R&D findings that spill out.

Technological opportunity. We predict that an increase in technological opportunity—the amount of available relevant external technical knowledge—will elicit more R&D in more difficult learning environments. Greater technological opportunity signifies greater amounts of external information, which increase the firm's incentive to build absorptive capacity, and a more challenging learning environment increases the level of R&D necessary to build absorptive capacity.

Appropriability. We predict that spillovers will provide, in part, a positive incentive to conduct R&D due to the interaction of spillovers with an endogenous absorptive capacity. Traditionally, spillovers have been considered only a deterrent to R&D activity (e.g., Nelson, 1959; Arrow, 1962; Spence, 1984). In the standard view, a firm's incentive to invest in R&D is diminished to the extent that any findings from such activities are exploited by competitors and thereby diminish the innovator's own profits. In our framework, however, this negative appropriability incentive associated with spillovers is counterbalanced by a positive absorptive-capacity-building incentive. The more of its competitors' spillovers there are out there, the more incentive the firm has to invest in its own R&D, which permits it to exploit those spillovers.

We have shown elsewhere (Cohen and Levinthal, 1989a) that when this absorption incentive is large, as when learning is difficult, spillovers may actually encourage R&D. The relative magnitude of the absorption incentive is greater when firms within an industry are less interdependent in the sense that rivals' technical advances have less of an effect on the firm's own profits. With less interdependence, the degree to which rivals gain from the firm's R&D spillovers at the firm's expense diminishes relative to the benefit of being able to exploit the rivals' spillovers. Either a more competitive market structure or a higher price elasticity of demand for the firm's product can diminish interdependence in an industry.

METHODS

Data and Measures

To test the predictions of our framework for R&D activity, we used cross-sectional survey data on technological opportunity and appropriability conditions in the American manufacturing sector collected from R&D lab managers by Levin et al. (1983, 1987), and the Federal Trade Commission's Line of Business Program data on business unit sales, transfers, and R&D expenditures. The dependent variable, R&D intensity, was de-

fined as company-financed business-unit research and development expenditures, expressed as a percentage of business unit sales and transfers over the period 1975 through 1977. The data on interindustry differences in technological opportunity and appropriability are industry (line of business) mean scores computed as an average over all respondents within a given industry. The sample consists of 1,719 business units representing 318 firms in 151 lines of business.

The data pose two estimation issues. First, some 24 percent of the firms performed no R&D in at least one year. If the independent variables reflect both the probability of conducting R&D, as well as the amount of R&D spending, then a Tobit analysis would be appropriate. Alternatively, a firm may require some initial level of absorptive capacity before it is influenced by the characteristics of the learning environment. In this case, the variables reflecting the ease of learning only affect the amount of R&D conducted by firms engaging in R&D activity and not the probability of engaging in R&D activity. In light of the uncertainty over the appropriate estimation technique, we explored the robustness of the results by analyzing a Tobit and an OLS (or GLS) specification. The second estimation issue is the presence of heteroscedasticity. We found the assumption of homoscedasticity to be violated, with the logarithm of the error variance being a linear function of the exogenous variables and the number of respondents to Levin et al.'s (1983, 1987) survey. Unless otherwise noted, the results we report in this section reflect robust effects that hold across three different estimation methods, including ordinary least squares (OLS), generalized least squares (GLS) in which we adjust for heteroscedasticity, and Tobit, which was used when we included the observations for which R&D expenditures were zero.

We tested our predictions in the context of an empirical model of business unit R&D intensity in which technological opportunity, appropriability, and demand conditions are considered as the principal industry-level determinants of firms' R&D spending. While data constraints do not permit observation of the direct effect of the ease of learning or its determinants on firms' R&D spending, we were able to examine how these variables condition the influence on R&D of technological opportunity and appropriability conditions.

Technological opportunity was assessed with variables measuring the "relevance" or "importance" for technological progress in each line of business of what are considered to be two critical sources of technological opportunity—the science base of the industry and extraindustry sources of knowledge (Cohen and Levin, 1989). These measures are drawn from Levin et al.'s survey, in which R&D managers indicated on a 7-point Likert scale the relevance of eleven basic and applied fields of science and the importance of external sources of knowledge to technological progress in a line of business. The basic fields of science include biology, chemistry, mathematics, and physics, and the applied fields of science include agricultural science, applied math/operations research, computer science, geology, materials science, medical science, and metallurgy.[5] The five extraindustry

5

Although geology was classed as a basic science by Levin et al., we classed it as an applied science because of its inductive methodology and intensive use by firms in the extractive sector.

sources of knowledge considered here included equipment suppliers (EQUIPTECH), materials suppliers (MATERIALTECH), downstream users of the industry's products (USERTECH), government laboratories and agencies (GOVTECH), and universities (UNIVTECH). We interpreted the measures of the relevance or importance of each field or knowledge source to index the relative quantity of knowledge generated by that field or source that is potentially useful. We then distinguished across the eleven scientific fields and the five extraindustry knowledge source variables on the basis of the ease of learning associated with each. We suggested above that one important determinant of the ease of learning is the degree to which outside knowledge is targeted to a firm's needs and concerns. One can readily distinguish among both the eleven fields and the five extraindustry knowledge sources on that basis. The knowledge associated with the basic sciences is typically less targeted than that associated with the applied sciences. We also distinguished among the extraindustry knowledge sources on the same basis. A priori, we ranked university labs, government labs, materials suppliers, and equipment suppliers as providing increasingly more targeted knowledge to firms. We did not rank the relative effect of knowledge originating from users because, as suggested by von Hippel (1978), users will often provide a product idea to potential suppliers, but the informativeness of the "solution concept" is quite variable. Therefore, the targeted quality of the information is variable as well.

To represent intraindustry spillovers of R&D, we employed measures from Levin et al.'s survey of the effectiveness of six mechanisms used by firms to capture and protect the competitive advantages of new processes and new products: patents to prevent duplication, patents to secure royalty income, secrecy, lead time, moving quickly down the learning curve, and complementary sales and service efforts. We employed the maximum value of the effectiveness scores attained by these mechanisms as our measure of appropriability or spillovers, and label this variable APPROPRIABILITY; a high level of APPROPRIABILITY reflects a low level of spillovers.

In our theory, we predicted an interaction effect by which, as the ease of learning diminishes, or firms become less interdependent, the effect of spillovers on R&D spending should become more positive (or less negative). In the absence of any direct measure of the ease of learning, we distinguished categorically between those industries in which basic science was more relevant to technical progress than the relatively more targeted applied sciences and assumed that learning was generally less difficult in industries that fell into the latter category. Thus, we created a dummy variable, DUMBAS, that equals one when the average value of the relevance scores associated with the basic fields exceeds that associated with the applied fields and that equals zero otherwise. We specified the dummy variable, DUMAPP, analogously. To capture the interdependence of firms, we employed measures of industries' competitiveness as represented by each industry's four-firm concentration ratio (C4) and industry-level estimates of the price elasticity of demand (PELAS).

To further control for industry demand conditions, we used industry estimates developed by Levin (1981) of price elas-

ticity (PELAS) and income elasticity (INCELAS) and a demand time-shift parameter (DGROWTH). Finally, we included another control variable that may also reflect technological opportunity, industry maturity. We used a somewhat crude measure of industry maturity, NEWPLANT, that measures the percentage of an industry's property, plant, and equipment installed within the preceding five years.

RESULTS

Technological opportunity. Our theory suggests that when the targeted quality of knowledge is less (i.e., learning is more difficult), an increase in the relevance (i.e., quantity) of knowledge should have a more positive effect on R&D intensity. Therefore, the coefficient estimates of the variables measuring the relevance of the four basic scientific fields should exceed those of the variables measuring the relevance of the seven applied scientific fields. Confirming the prediction, Table 1 indicates that the estimated coefficients for the applied sciences are, with the exception of computer science, lower than that for the basic sciences. The similarity of the estimate of the effect of the relevance of computer science, an applied science, to those of some of the basic sciences suggests that the assumption may not be correct that only one determinant of the ease of learning, the targeted quality of the field, varies systematically across the fields of applied and basic science. Another determinant of the ease of learning postulated above is a field's pace of advance, where faster pace should require more R&D to permit assimilation, and the pace of advance in computer science has been relatively rapid over the past two decades.

To further test the prediction that the coefficient values of the less targeted, basic science field variables would exceed those of the applied fields, we estimated a specification, otherwise identical to the first, in which we constrained the coefficients of the basic sciences to be the same and the coefficients of the applied sciences to be the same. This shows the effect on R&D spending as the overall technological opportunity associated with basic science and applied science, respectively, change. The constrained coefficient estimates of the effect of the technological opportunity associated with the basic and applied sciences are significantly different (at the $p < .01$ level) across all estimation methods, with the former equal to .189 and the latter equal to $-.080$ in the GLS estimation. Therefore, relative to the effect of an increase in the technological opportunity associated with applied science, an increase in that associated with basic science elicits more R&D.

Our predicted ranking of the coefficient magnitudes associated with the extraindustry sources of knowledge, reflecting increasingly targeted knowledge from these sources, is largely confirmed. The coefficient estimate for the importance of knowledge originating from universities exceeds that for government labs, which, in turn, is greater than that for materials suppliers, which exceeds that for equipment suppliers. The difference between coefficient values is statistically significant in the case of government sources versus materials suppliers for both the OLS and Tobit results ($p < .01$) and in the case of materials suppliers versus equipment suppliers in

Table 1

Analysis of R&D Intensity*

Variable	OLS (N = 1302)	Regression Coefficient GLS (N = 1302)	Tobit (N = 1719)
Intercept	−5.184**	−2.355*	−4.086**
	(1.522)	(1.037)	(1.461)
APPROPRIABILITY × C4	.213	.342**	.368**
	(.128)	(.103)	(.130)
APPROPRIABILITY × PELAS	−.192	−.200*	−.176
	(.106)	(.091)	(.103)
APPROPRIABILITY × DUMAPP	.448*	.248	.211
	(.202)	(.143)	(.194)
APPROPRIABILITY × DUMBAS	.302	.174	.094
	(.208)	(.144)	(.206)
USERTECH	.470**	.397**	.612**
	(.104)	(.069)	(.107)
UNIVTECH	.374**	.318**	.395**
	(.131)	(.091)	(.147)
GOVTECH	.221*	.069	.137
	(.106)	(.079)	(.107)
MATERIALTECH	−.258**	−.074	−.303**
	(.098)	(.070)	(.100)
EQUIPTECH	−.401**	−.484**	−.574**
	(.111)	(.077)	(.117)
Biology	.314**	.185**	.276*
	(.102)	(.071)	(.114)
Chemistry	.289**	.081	.191*
	(.084)	(.062)	(.088)
Math	.184	.151	.123
	(.131)	(.097)	(.143)
Physics	.373**	.323**	.310*
	(.117)	(.091)	(.128)
Agricultural Science	−.441**	−.273**	−.308**
	(.088)	(.064)	(.099)
Applied Math/Operations Research	−.237	−.117	−.366*
	(.148)	(.102)	(.152)
Computer Science	.294*	.116	.433**
	(.124)	(.090)	(.122)
Geology	−.363**	−.240**	−.365**
	(.084)	(.061)	(.097)
Materials Science	−.110	−.150	.116
	(.125)	(.095)	(.118)
Medical Science	−.179	−.133	−.133
	(.093)	(.070)	(.103)
Metallurgy	−.315**	−.195**	−.393**
	(.077)	(.053)	(.089)
NEWPLANT	.057**	.049**	.045**
	(.008)	(.006)	(.007)
PELAS	.936	1.082*	.892
	(.611)	(.527)	(.573)
INCELAS	1.077**	.587**	1.112**
	(.170)	(.131)	(.188)
DGROWTH	.068	−.074	.004
	(.090)	(.053)	(.105)
R^2	.287		

* $p < .05$; ** $p < .01$.
* Reproduced from Cohen and Levinthal (1989a: 590–591, 569–596). Standard errors are in parentheses.

the GLS results ($p < .01$). While we had no prediction regarding the coefficient value for USERTECH, the consistently high value of the coefficient estimate may reflect some element of demand conditions. Consistent with this, we have observed the variable USERTECH to be significantly correlated with measures of the importance of product differentiation (cf. Cohen and Levinthal, 1989a).

Appropriability. The results largely support the prediction that the ease of learning conditions the effect of knowledge spillovers. The effect on R&D intensity of increasing appropriability (i.e., diminishing spillovers) was significantly greater ($p < .05$) in those industries in which the applied sciences are more relevant to innovation than the basic sciences. This result suggests that the positive absorption incentive associated with spillovers is greater in industries in which the difficulty of learning is greater. Second, there is a significant positive effect ($p < .01$) of the interaction between market concentration and the appropriability level. As market concentration increases (indexing a diminution in competitiveness), the positive effect of a given appropriability level on R&D intensity increases, as predicted. Likewise, the effect of the interaction of the price elasticity of demand and the level of appropriability is negative (but only significant at $p < .05$ in the GLS estimate), providing additional support for the proposition that the positive effect of spillovers will increase in industries in which firms are less interdependent. The results suggest that the learning environment affects the impact of spillovers on R&D spending and that the importance of the positive absorptive-capacity-building incentive relative to that of the negative appropriability incentive is conditioned by the degree of competitor interdependence.

While we have shown that the learning environment modifies the effect of appropriability conditions, the question remains whether spillovers may, on balance, actually encourage R&D in some industries. To explore this possibility, we examined the effect of spillovers in the four two-digit SIC code level industries for which our sample contains enough lines of business to permit separate industry regressions. These include SICs 20 (food processing), 28 (chemicals), 35 (machinery), and 36 (electrical equipment). Due to the reduction in the degrees of freedom for industry-level variables, we simplified the estimating equation to consider only the direct effect of APPROPRIABILITY, and the science field variables were summarized as the maximum relevance scores attained by the basic and applied fields, respectively. In SICs 28 and 36, the effect of the APPROPRIABILITY variable was negative and significant at conventional levels, implying that R&D intensity rises with spillovers. In the Tobit results, the sign was also positive for SICs 28 and 36, but the coefficient estimates were not quite significant at the .05 confidence level. Thus, in SICs 28 (chemicals) and 36 (electrical equipment), R&D intensity rose with spillovers when we controlled for other industry-level variables conventionally thought to drive R&D spending, including technological opportunity and demand conditions. Although the analyses showing a positive effect of spillovers in these two industry groups do not represent a direct test of our model, the results suggest, particularly when considered with the interaction results, that the positive absorption incentive associated with spillovers may be sufficiently strong in some cases to more than offset the negative appropriability incentive.

IMPLICATIONS FOR INNOVATIVE ACTIVITY

Drawing on our prior work (Cohen and Levinthal, 1987, 1989a), we offer some implications of absorptive capacity for

the analysis of other innovative activities, including basic research, the adoption and diffusion of innovations, and decisions to participate in cooperative R&D ventures, that follow from the preceding analyses.

The observation that R&D creates a capacity to assimilate and exploit new knowledge provides a ready explanation of why some firms may invest in basic research even when the preponderance of findings spill out into the public domain. Specifically, firms may conduct basic research less for particular results than to be able to provide themselves with the general background knowledge that would permit them to exploit rapidly useful scientific and technological knowledge through their own innovations or to be able to respond quickly—become a fast second—when competitors come up with a major advance (see also Rosenberg, 1990). In terms of our discussion of the cognitive and organizational aspects of absorptive capacity, we may think of basic research as broadening the firm's knowledge base to create critical overlap with new knowledge and providing it with the deeper understanding that is useful for exploiting new technical developments that build on rapidly advancing science and technology.

This perspective on the role of basic research offers a rather different view of the determinants of basic research than that which has dominated thinking in this area for the thirty years since Nelson's (1959) seminal article. Nelson hypothesized that more diversified firms will invest more heavily in basic research because, assuming imperfect markets for information, they will be better able to exploit its wide-ranging and unpredictable results. Nelson thus saw product-market diversification as one of the key determinants of basic research.[6] Emphasizing the role of basic research in firm learning, our perspective redirects attention from what happens to the knowledge outputs from the innovation process to the nature of the knowledge inputs themselves. Considering that absorptive capacity tends to be specific to a field or knowledge domain means that the type of knowledge that the firm believes it may have to exploit will affect the sort of research the firm conducts. From this vantage point, we would conjecture that as a firm's technological progress becomes more closely tied to advances in basic science (as has been the case in pharmaceuticals), a firm will increase its basic research, whatever its degree of product-market diversification. We also suggest, with reference to all firm research, not just basic research, that as the fields underlying technical advance within an industry become more diverse, we may expect firms to increase their R&D as they develop absorptive capacities in each of the relevant fields. For example, as automobile manufacturing comes to draw more heavily on newer fields such as microelectronics and ceramics, we expect that manufacturers will expand their basic and applied research efforts to better evaluate and exploit new findings in these areas.

The findings on the role of absorptive capacity and the ways in which it may be developed also have implications for the analysis of the adoption and diffusion of innovations. Our perspective implies that the ease of learning, and thus technology adoption, is affected by the degree to which an innovation is related to the pre-existing knowledge base of

6

Markets for information often fail because they inherently represent a situation of information asymmetry in which the less informed party cannot properly value the information he or she wishes to purchase, and the more informed party, acting self-interestedly, attempts to exploit that inability (Williamson, 1975).

prospective users. For example, personal computers diffused more rapidly at the outset among consumers and firms who had prior experience on mainframes or minicomputers. Likewise, software engineering practices seem to be adopted more readily by programmers with previous Pascal rather than Fortran experience because the structure of Pascal more closely reflects some of the underlying principles of software engineering (Smith et al., 1989). Our argument also suggests that an innovation that is fully incorporated in capital equipment will diffuse more rapidly than more disembodied innovations that require some complementary expertise on the part of potential users. This is one of the anticipated benefits of making computers more "user friendly."

The importance of absorptive capacity also helps explain some recent findings regarding firms' cooperative research ventures. First, Link (1987) has observed that cooperative research ventures are actually found more typically in industries that employ more mature technologies rather than in industries in which technology is moving ahead quickly—as seems to be suggested by the popular press. Second, it has been observed that cooperative ventures that have been initiated to pursue basic research, as well as more applied research objectives, have been subject over the years to increasing pressure to focus on more short-term research objectives (Mowery and Rosenberg, 1989). The simple notion that it is important to consider the costs of assimilating and exploiting knowledge from such ventures provides at least a partial explanation for these phenomena. Many cooperative ventures are initiated in areas in which the cost to access the output of the venture is low, or they often gravitate toward such areas over time. Conversely, those who are attempting to encourage cooperative research ventures in quickly advancing fields should recognize that the direct participation in the venture should represent only a portion of the resources that it will take to benefit from the venture. Participating firms also must be prepared to invest internally in the absorptive capacity that will permit effective exploitation of the venture's knowledge output.

CONCLUSION

Our empirical analysis of R&D investment suggested that firms are in fact sensitive to the characteristics of the learning environment in which they operate. Thus, absorptive capacity appears to be part of a firm's decision calculus in allocating resources for innovative activity. Despite these findings, because absorptive capacity is intangible and its benefits are indirect, one can have little confidence that the appropriate level, to say nothing of the optimal level, of investment in absorptive capacity is reached. Thus, while we have proposed a model to explain R&D investment, in which R&D both generates innovation and facilitates learning, the development of this model may ultimately be as valuable for the prescriptive analysis of organizational policies as its application may be as a positive model of firm behavior.

An important question from a prescriptive perspective is When is a firm most likely to underinvest in absorptive capacity to its own long-run detriment? Absorptive capacity is more likely to be developed and maintained as a byproduct of

routine activity when the knowledge domain that the firm wishes to exploit is closely related to its current knowledge base. When, however, a firm wishes to acquire and use knowledge that is unrelated to its ongoing activity, then the firm must dedicate effort exclusively to creating absorptive capacity (i.e., absorptive capacity is not a byproduct). In this case, absorptive capacity may not even occur to the firm as an investment alternative. Even if it does, due to the intangible nature of absorptive capacity, a firm may be reluctant to sacrifice current output as well as gains from specialization to permit its technical personnel to acquire the requisite breadth of knowledge that would permit absorption of knowledge from new domains. Thus, while the current discussion addresses key features of organizational structure that determine a firm's absorptive capacity and provides evidence that investment is responsive to the need to develop this capability, more research is necessary to understand the decision processes that determine organizations' investments in absorptive capacity.

REFERENCES

Abernathy, William J.
1978 The Productivity Dilemma. Baltimore: Johns Hopkins University Press.

Allen, Thomas J.
1977 Managing the Flow of Technology. Cambridge, MA: MIT Press.

Allen, Thomas J., and Stephen D. Cohen
1969 "Information flows in R&D labs." Administrative Science Quarterly, 20: 12–19.

Anderson, John R., Robert Farrell, and Ron Sauers
1984 "Learning to program in LISP." Cognitive Science, 8: 87–129.

Arrow, Kenneth J.
1962 "Economic welfare and the allocation of resources for invention." In R. R. Nelson (ed.), The Rate and Direction of Inventive Activity: 609–625. Princeton, NJ: Princeton University Press.

Bower, Gordon H., and Ernest R. Hilgard
1981 Theories of Learning. Englewood Cliffs, NJ: Prentice-Hall.

Bradshaw, Gary F., Patrick W. Langley, and Herbert A. Simon
1983 "Studying scientific discovery by computer simulation." Science, 222: 971–975.

Brock, Gerald W.
1975 The U.S. Computer Industry. Cambridge, MA: Ballinger.

Burns, Tom, and George M. Stalker
1961 The Management of Innovation. London: Tavistock.

Clark, Kim B., and Takahiro Fujimoto
1987 "Overlapping problem solving in product development." Technical Report, Harvard Business School.

Cohen, Wesley M., and Richard C. Levin
1989 "Empirical studies of innovation and market structure." In R. C. Schmalensee and R. Willig (eds.), Handbook of Industrial Organization: 1059–1107. Amsterdam: Elsevier.

Cohen, Wesley M., and Daniel A. Levinthal
1987 "Participation in cooperative research ventures and the cost of learning." Technical Report, Dept. of Social and Decision Sciences, Carnegie Mellon University.
1989a "Innovation and learning: The two faces of R&D." Economic Journal, 99: 569–596.
1989b "Fortune favors the prepared firm." Technical Report, Dept. of Social and Decision Sciences, Carnegie Mellon University

Dearborn, R., and Herbert A. Simon
1958 "Selective perception in executives." Sociometry, 21: 140–144.

Ellis, Henry Carlton
1965 The Transfer of Learning. New York: MacMillan.

Estes, William Kaye
1970 Learning Theory and Mental Development. New York: Academic Press.

Hamberg, Daniel
1963 "Invention in the industrial research laboratory." Journal of Political Economy, 71: 95–115.

Harlow, H. F.
1949 "The formation of learning sets." Psychological Review, 56: 51–65.
1959 "Learning set and error factor theory." In S. Koch (ed.), Psychology: A Study of Science, 2: 492–537. New York: McGraw-Hill.

Johnston, R., and M. Gibbons
1975 "Characteristics of information usage in technological innovation." IEEE Transactions on Engineering Management, 27–34, EM-22.

Katz, Daniel, and Robert L. Kahn
1966 The Social Psychology of Organizations. New York: Wiley.

Katz, Ralph
1982 "The effects of group longevity on project communication and performance." Administrative Science Quarterly, 27: 81–104.

Katz, Ralph, and Thomas J. Allen
1982 "Investigating the not invented here (NIH) syndrome: A look at the performance, tenure, and communication patterns of 50 R&D project groups." R&D Management, 12: 7–12.

Lee, Denis M. S., and Thomas J. Allen
1982 "Integrating new technical staff: Implications for acquiring new technology." Management Science, 28: 1405–1420.

Levin, Richard C.
1981 "Toward an empirical model of *Schumpeterian competition.*" Technical Report, Dept. of Economics, Yale University.

Levin, Richard C., Alvin K. Klevorick, Richard R. Nelson, and Sidney G. Winter
1983 "Questionnaire on industrial research and development." Dept. of Economics, Yale University.
1987 "Appropriating the returns from industrial R&D." Brookings Papers on Economic Activity, 783–820.

Levitt, Barbara, and James G. March
1988 "Organizational learning." Annual Review of Sociology, 14: 319–340.

Lindsay, Peter H., and Donald A. Norman
1977 Human Information Processing. Orlando, FL: Academic Press.

Link, Albert N.
1987 "Cooperative research activity in U.S. Manufacturing." Technical Report, University of North Carolina, Greensboro, Final report submitted to the National Science Foundation under grant PRA 85-212664.

Majumdar, Bodiul Alam
1982 Innovations, Product Developments and Technology Transfers: An Empirical Study of Dynamic Competitive Advantage, The Case of Electronic Calculators. Lanham, MD: University Press of America.

Mansfield, Edwin
1968 Economics of Technological Change. New York: Norton.
1988 "The speed and cost of industrial innovation in Japan and the United States: External vs. internal technology." Management Science, 34(10): 1157–1168.

March, James G., and Herbert A. Simon
1958 Organizations. New York: Wiley.

Mowery, David C.
1983 "The relationship between intrafirm and contractual forms of industrial research in American manufacturing, 1900–1940." Explorations in Economic History, 20: 351–374.

Mowery, David C., and Nathan Rosenberg
1989 *Technology and the Pursuit of* Economic Growth. New York: Cambridge University Press.

Mueller, Willard F.
1962 "The origins of the basic inventions underlying DuPont's major product and process innovations, 1920 to 1950." In R. R. Nelson (ed.), The Rate and Direction of Inventive Activity: 323–358. Princeton: Princeton University Press.

Myers, Sumner, and Donald C. Marquis
1969 "Successful industrial innovations." Washington, DC: National Science Foundation, NSF 69-17.

Nelson, Richard R.
1959 "The simple economics of basic research." Journal of Political Economy, 67: 297–306.

Nelson, Richard R., and Sidney Winter
1982 An Evolutionary Theory of Economic Change. Cambridge, MA: Harvard University Press.

Peck, Merton J.
1962 "Inventions in the postwar American aluminum industry." In R. R. Nelson (ed.), The Rate and Direction of Inventive Activity: 279–298. Princeton: Princeton University Press.

Pirolli, Peter L., and John R. Anderson
1985 "The role of learning from example in the acquisition of recursive programming skill." Canadian Journal of Psychology, 39: 240–272.

Reich, Robert B.
1987 "The rise of techno-nationalism." Atlantic, May: 63–69.

Rosenberg, Nathan
1982 Inside the Black Box: Technology and Economics. New York: Cambridge University Press.
1990 "Why do firms do basic research (with their own money)?" Research Policy (in press).

Rosenberg, Nathan, and W. Edward Steinmueller
1988 "Why are Americans such poor imitators?" American Economic Review, 78(2): 229–234.

Schumpeter, Joseph A.
1942 Capitalism, Socialism and Democracy. New York: Harper and Row.

Simon, Herbert A.
1985 "What we know about the creative process." In R. L. Kuhn (ed.), Frontiers in Creative and Innovative Management: 3–20. Cambridge, MA: Ballinger.

Smith, Gordon, Wesley M. Cohen, William Hefley, and Daniel A. Levinthal
1989 "Understanding the adoption of Ada: A field study report." Technical Report, Software Engineering Institute, Carnegie Mellon University.

Spence, A. Michael
1984 "Cost reduction, competition, and industry performance." Econometrica, 52: 101–122.

Tilton, John E.
1971 International Diffusion of Technology: The Case of Semiconductors. Washington, DC: Brookings Institution.

Tushman, Michael L.
1977 "Special boundary roles in the innovation process." Administrative Science Quarterly, 22: 587–605.
1978 "Technical communication in R&D laboratories: The impact of project work characteristics." Administrative Science Quarterly, 21: 624–644.

Tushman, Michael L., and Philip Anderson
1986 "Technological discontinuities and organizational environments." Administrative Science Quarterly, 31: 439–465.

Utterback, James M.
1971 "The process of technological innovation within the firm." Academy of Management Journal, 12: 75–88.

von Hippel, Eric
1978 "Successful industrial products from customer ideas." Journal of Marketing, 42: 39–49.
1988 The Sources of Innovation. New York: Oxford University Press.

Vyssotsky, V. A.
1977 "The innovation process at Bell Labs." Technical Report, Bell Laboratories.

Westney, D. Eleanor, and Kiyonori Sakakibara
1986 "The role of Japan-based R&D in global technology strategy." In M. Hurowitch (ed.), Technology in the Modern Corporation: 217–232, London: Pergamon.

Williamson, Oliver E.
1975 Markets and Hierarchies: Analysis and Antitrust Implications. New York: Free Press.

Zenger, Todd R., and Barbara S. Lawrence
1989 "Organizational demography: The differential effects of age and tenure distributions on technical communication." Academy of Management Journal, 32: 353–376.

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