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TRANSFORMATIVE CAPACITY: CONTINUAL STRUCTURING BY INTERTEMPORAL TECHNOLOGY TRANSFER

RAGHU GARUD and PRAVEEN R. NAYYAR
Leonard N. Stern School of Business, New York University, New York, U.S.A.

The ability to maintain internally developed technology over time is important for corporate vitality. We label this ability transformative capacity *and suggest that it depends on how well a firm accomplishes three tasks, These tasks are: the choice of technologies, their maintenance over time, and their reactivation and synthesis when required. To establish the need for transformative capacity, we first discuss time lags in the development of technologies and markets to suggest that not all technologies developed by firms can be utilized immediately. We then examine dimensions of technological knowledge that affect knowledge transfer over time. Next, we build on the resource-based view of the firm to discuss how firms can create transformative capacity. The concluding discussion focuses on the implications of transformative capacity for the analysis and management of technological investments as a way to maintain corporate vitality.*

If U.S. giants started making better use of their vast storehouse of technology, 'we would not be able to compete with them.'
Hiroshi Kashiwaga
Director General, Electrotechnical Laboratory
Ministry of International Trade & Industry, Japan
(quoted in O. Port, *Business Week*, 1992)

Periodic scrutiny of previously shelved projects will often reveal ones that are now ripe for 'unshelving' and subsequent commercial success.
(From Wilson and Hlavacek, *Research Management*, 1984)

Corporate restructuring is an attempt to regain lost competitive advantages by making substantial changes in a firm's business portfolio, internal organization, or financial structure. These changes result in a realignment of a firm's key resources. However, the resource-based view of the firm suggests that it might be difficult to regain lost competitive advantages through restructuring (Barney, 1986; Conner, 1991; Dierickx and Cool, 1989; Penrose, 1959; Rumelt, 1984; Wernerfelt, 1984). The resource-based view considers firms as unique bundles of resources yielding sustainable above normal profits. Some of these key resources accumulate in a path-dependent manner. Therefore, they are difficult to replace or acquire quickly when needed. Consequently, substantial changes in resource bundles that corporate restructuring entails destroy key resources and do not allow acquisition of other resources that could provide sustainable competitive advantages.

For instance, corporate restructuring may result in divesting resources that could prove useful later. Similarly, greatly changing internal organizational arrangements could destroy knowledge stocks. Moreover, starting afresh to gather new resources during corporate restructuring implies

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a time lag before a firm accumulates a critical mass to become competitive. In competitive and changing environments, firms may never catch-up with their competitors and their environments. Thus, for firms competing with path-dependent resources, restructuring may be an option of last resort.

An alternative course of action to maintain corporate vitality is to continually create and exploit new business opportunities. *Continual structuring* avoids the detrimental consequences of *restructuring*. This is consistent with Schumpeter's (1975) view on institutionalizing technological innovation to create new business opportunities (see also Quinn, 1969).

New business opportunities can emerge from either internal or external technologies. Although both are important, a firm's ability to exploit external technologies is not sufficient to maintain a sustainable competitive advantage (Barney, 1991; Ghemawat, 1986). This is because external technologies are also accessible to other firms (Mansfield, 1988). In contrast, internal technologies are not widely accessible, thereby forming the basis for sustainable competitive advantage. This is illustrated by 3M's ability to generate a return on assets about 50 percent higher from its 'historic' businesses—adhesives, coating, abrasives, and nonwoven technologies—than from its 'added' businesses—those that were based on acquired technologies beyond its origins such as imaging and instrumentation (Quinn, 1992).

Pavitt (1984) also demonstrated the relative importance of internal technologies compared to external ones. Nearly 59 percent of 3013 significant innovations in the United Kingdom from 1945 to 1979 were based on knowledge from *within* innovating firms. In some industries such as dyestuffs, aluminum, motor vehicles and textiles, internal sources accounted for nearly 70 percent of all innovations.[1] Thus, internal technologies are important for corporate vitality and we focus on them in this paper.

Creating new technological opportunities entails significant risk because only a few efforts succeed (see, for example, Burgelman, 1991 and Van de Ven, 1986); most languish, due to a lack of markets or complementary technologies. Lacking markets or complementary technologies, technological knowledge (hereafter knowledge) created by start-up firms may be irrevocably lost if a venture fails. In contrast, established firms can choose to retain knowledge created, although it is not immediately used, because they may have the necessary organizational resources to do so. For example, Corning spent millions on special glass for lasers and on methods to make high-quality car windshields. However, neither project yielded products right away. Many years later, the laser research led to pure optical fibers, and the windshield technology led to glass for flat-panel displays (Carey, 1992).[2]

Thus, maintaining knowledge for later use can contribute to corporate vitality. This facet of corporate vitality has received surprisingly little attention. A recent article in *Business Week* suggested that U.S. firms have not adequately capitalized on their storehouse of technology (Port, 1992). It is reported that in the U.S. pharmaceutical industry alone 'thousands of drugs have been shelved. . .(although their) death is premature' (Hamilton and Weber, 1988: 90). The value of this storehouse is indicated by the finding that 8 of 10 projects unshelved were successful (Wilson and Hlavacek, 1984), a success rate far greater than for new venture development projects. Hence, a firm can significantly increase returns from technological investments by exploiting its storehouse of technology (Foster, 1982).

Exploiting a storehouse of technology requires firms to transfer technology across time. This ability is termed *transformative capacity*. We offer the concept of transformative capacity as a complement to Cohen and Levinthal's (1990) notion of absorptive capacity. Absorptive capacity

[1] Emphasizing internal technology, Masaru Ibuka, Sony Corporation Founder, stated the 'key to success for Sony. . .is never to follow others. . .We bet the company on that basic technology (the Trinitron TV), and in 23 years nobody has been able to match it' (Schlender, 1992: 77–82). Hitachi can build a nationwide (in Japan) high-speed maglev train system relying only on its own technology (Gross, 1992). Using internal technology only, Hitachi has perfected the world's highest-performance disk drive (Gross, 1992).

[2] Kevlar, a synthetic fiber developed by DuPont, was a failure. Nearly 20 years later it is being used in bulletproof vests and Army helmets (McMurray, 1992). An antinoise technology developed in the 1930s has now become practical with the advent of advanced electronics (Naj, 1991). Sony's successful PalmTop was delayed because it required hardware, software, and manufacturing innovations (Schlender, 1992).

is the ability to recognize and exploit technological opportunities from *outside* a firm. In contrast, transformative capacity is the ability to continually redefine a product portfolio based on technological opportunities created *within* a firm.[3]

Both absorptive capacity and transformative capacity are important. However, absorptive capacity is not sufficient for creating a sustainable competitive advantage when: (1) path-dependent, cumulative knowledge is involved;[4] (2) entry timing is important, or (3) a firm operates in a continually changing environment in which it does not just react to external changes, but instead, creates them by its own actions.[5]

Relying solely on absorptive capacity may result in the loss of competitive advantage as illustrated by the plight of IBM. IBM absorbed external technology for its line of personal computers during the past decade while failing to utilize technologies it created such as its RISC chip. As competitors too absorbed the same technology, IBM lost its competitive advantage (Ferguson and Morris, 1993). Its recent attempts to restructure have so far been unsuccessful because: (1) massive internal change affecting the type of technological resources in question requires considerable time to initiate and implement—time within which the industry has moved far ahead, (2) first mover advantages preclude external technologies as viable means of regaining competitive advantage, and (3) IBM operates in a rapidly changing environment in which a forfeited competitive position cannot be regained.

In contrast, the power of transformative capacity in building and sustaining competitive advantages is illustrated by Honda's approach emphasizing in-house development of all product and process technologies it uses (Shook, 1988). These technologies have helped Honda establish a formidable competitive advantage over its rivals. Recognizing the future importance of internal technologies, 'Hitachi never backs off or lets go of a division (because). . .the company is thinking years down the road' (Gross, 1992: 100). In addition, Hitachi continues to invest in biotechnology, a pursuit unlikely to benefit Hitachi's main businesses for years (Gross, 1992).

In this paper, we suggest that firms can maintain their corporate vitality by developing transformative capacity. First, we show that time lags in the development of knowledge and markets create the need for storehouses of technology. Second, we examine three dimensions of knowledge affecting its maintenance and transfer across time. Third, we discuss the resource-based-view of the firm to understand tasks involved in intertemporal knowledge transfer. Fourth, we use concepts from literature on organizational memory, decision making, and the information processing view of organization design to explore mechanisms affecting transformative capacity. In conclusion, we discuss some implications of transformative capacity for theory and practice. Figure 1 presents a summary of the key elements of our analysis.

Note that there are some bounds to the theory developed in this paper. It applies to firms seeking competitive advantages from certain types of technologies. The theory also assumes that firms are able to create new technologies because, without innovation, there will be nothing to transfer over time. In addition, the theory assumes that firms have the general ability to commercialize innovations.

TIME LAGS IN THE DEVELOPMENT OF KNOWLEDGE AND MARKETS

New technological fields emerge through researchers' problem solving activities. These efforts result in ideas and techniques representing knowledge (Allen, 1966; Laudan, 1984; Layton, 1974; Rosenberg, 1982). Since technology is a form of knowledge, technological change can be

[3] Cohen and Levinthal (1990) used annual spending on research and development as an indicator of a firm's absorptive capacity. Our concept of transformative capacity refers to adoption of organizational mechanisms enabling a firm to transfer technology through time.

[4] Absorptive capacity may be of greater relevance at nascent stages of technological development when ideas still have to be translated into specific technologies and products. This is because once technologies have become firm-specific, it becomes progressively more difficult for others to absorb them even if they have absorptive capacities (Ghemawat, 1991). In contrast, transformative capacity is relevant for technological resources at all stages of their development.

[5] Change creates uncertainty and ambiguity. This creates considerable obstacles for firms using absorptive capacity to identify and evaluate external technologies. In contrast, it is relatively easier to evaluate internal technologies. Thus, when firms face uncertainty and ambiguity, relying on transformative capacity rather than absorptive capacity should result in better informed decisions about which technologies to pursue.

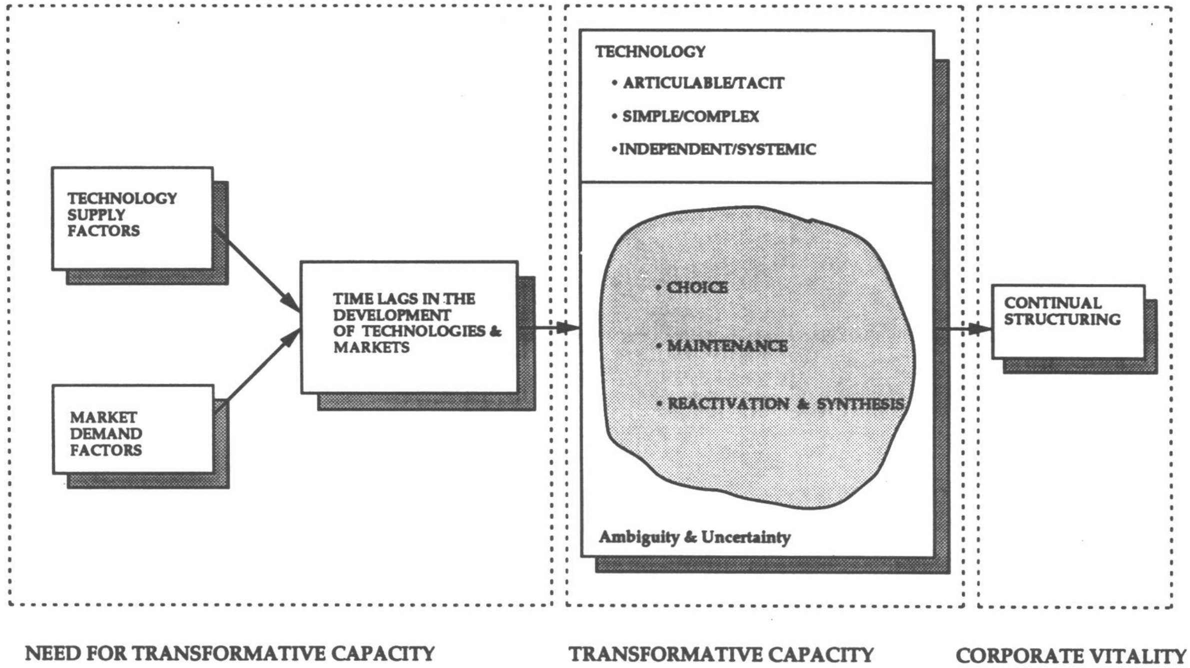

Figure 1. Transformative capacity and continual structuring

understood by examining knowledge development.

Knowledge development proceeds through a cumulative progression of ideas and techniques (Crane, 1972). Antecedent ideas and techniques influence the choice of future problems, thereby making knowledge development path-dependent (David, 1985; Dosi, 1982). The acquisition of relevant experience determines success in solving these problems. This experience translates into 'rules of thumb' (Sahal, 1981) or search 'heuristics' (Nelson and Winter, 1982) that researchers employ. In this way, knowledge development is a cumulative process with only infrequent major disruptions (Rosenberg, 1982).

Levenhagen, Thomas, and Porac (1990) represented the cumulative process of knowledge development with the concept of 'knowledge vectors.' While knowledge within these vectors develops cumulatively, Levenhagen *et al.* suggested that new knowledge is created when vectors intersect. The intersection of vectors represents a moment of cumulative synthesis as once unrelated fields converge (Usher, 1954). Therefore, there is not only knowledge accumulation within vectors, but also occasional knowledge synthesis across different vectors to create new knowledge.

The development of the video tape-recorder vividly illustrates this process. Figure 2, which is taken from Irvine and Martin (1984), highlights the long time of 80 years over which the video tape-recorder slowly evolved. During this time several intermediary products were also developed from the confluence of knowledge vectors from many seemingly unrelated areas such as magnetic and recording materials, electronics, and frequency modulation. Some of these vectors were found useful although a specific purpose had not been envisioned when they were initiated. As the chronology of events suggests, these knowledge vectors developed at different rates at different points in time ultimately culminating in products and technologies by the synthesis of old and new knowledge.

This depiction is consistent with Rosenberg's (1982) observation that knowledge vectors progress at different rates. Some vectors lag others thereby becoming bottlenecks in knowledge development. Researchers then direct their attention to these bottleneck vectors. Advances along these vectors in turn create other bottlenecks. In this way knowledge development is a 'compulsive process' with vectors leading and lagging each other at different points in time. As a result, vectors that are ahead must be maintained and

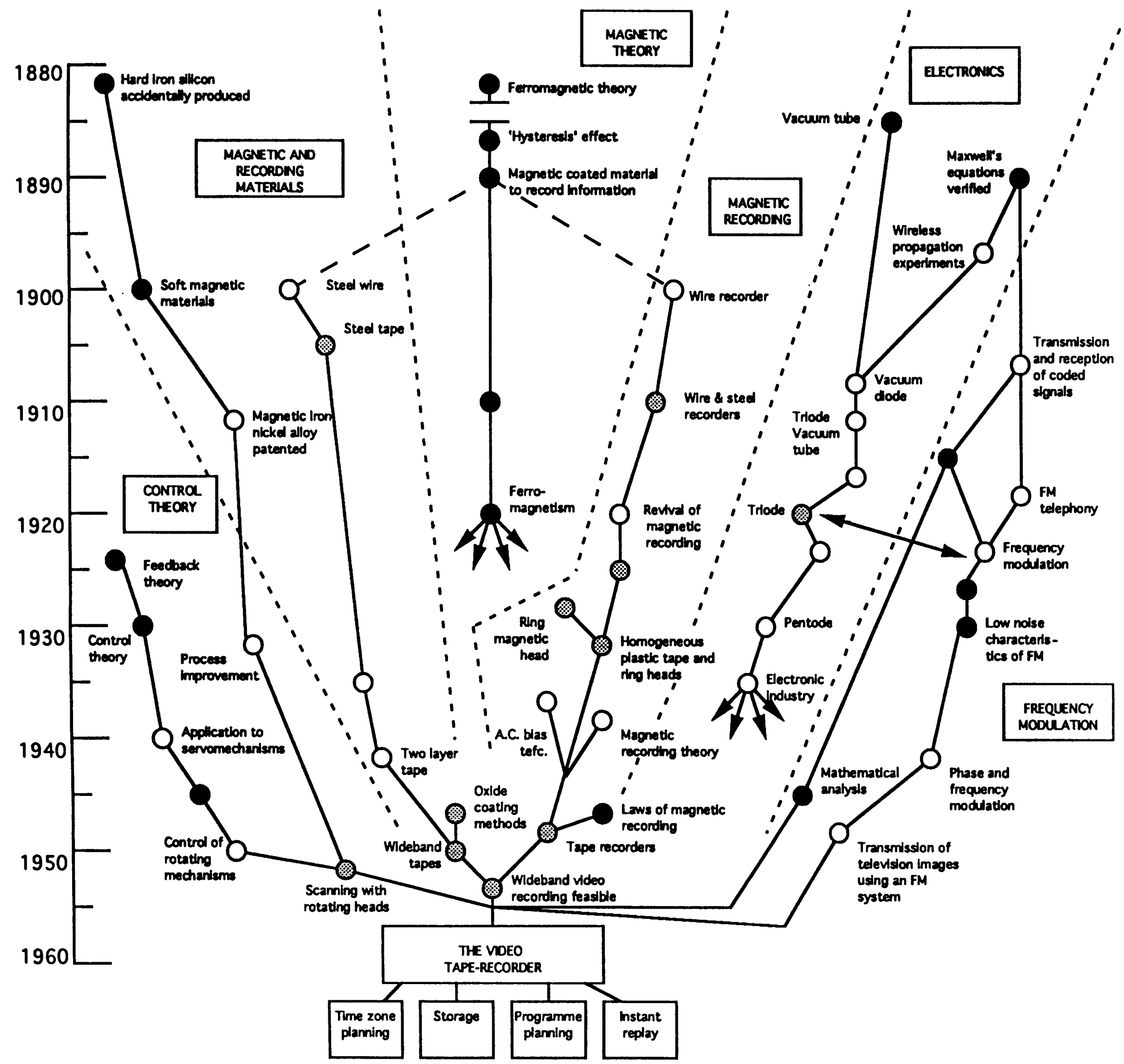

Figure 2. The research origins of the video tape-recorder. Source: Adapted from Irvine, J. and Martin, B. R. *Foresight in Science: Picking the Winners,* Dover, N. H. Frances Pinter, 1984. (●, Nonmission research; ○, mission-oriented research; ○, development and application. Note: BTL = Bell Telephone Laboratories; NRL = Naval Research Laboratory; AEG = Allgemeine Elektrizitats Gesellschaft

later reactivated to be synthesized with other vectors. Thus, knowledge development lags are a supply side reason for maintaining knowledge.

In addition, market lags are a demand side reason for maintaining knowledge. Many innovations flounder because of inadequate product demand (Wilson and Hlavacek, 1984). Demand for a product may emerge at a future date because of institutional changes or because other scientific and technological advances render products more attractive to customers. For example, there is recent renewed interest in video-telephones, the synthetic material Kevlar that DuPont developed, and energy-saving fluorescent lamps. Also, a firm may choose to shelve a product superior to the one it currently markets until a competing firm challenges its market position (Conner, 1988). For example, Intel decided to delay introduction of its new-generation Pentium microprocessor.

Thus, time lags in the development of knowledge and markets create the need for intertemporal knowledge transfer. To understand how this transfer can be affected within firms, it is useful to examine dimensions of knowledge affecting its intertemporal transfer.

Dimensions of knowledge affecting its intertemporal transfer

One dimension of knowledge is whether it is tacit or articulable (Polanyi, 1962; Winter, 1987). Tacit knowledge cannot be described fully. In contrast, articulable knowledge can be codified. A second dimension of knowledge is whether it is simple or complex. It is possible to describe simple knowledge with little information. In contrast, a larger amount of information is required to describe complex knowledge. A third dimension of knowledge is whether it is embedded in a larger system (systemic), or whether it is independent. Systemic knowledge has to be described in relation to other knowledge vectors. In contrast, independent knowledge can be described by itself.[6]

Winter (1987) treated each dimension as a continuum along which any knowledge could be located. As each dimension becomes salient, the ease with which knowledge can be transferred decreases. Winter considered the impact of these dimensions on transferability as being simply additive without any interactive effects. In addition, each dimension evokes different issues in the transfer process. For these reasons, it is useful to separately consider the transfer issues that each dimension raises.

The position of knowledge along each continuous dimension affects the amount and nature of information required to describe it. Therefore, it also affects the relative ease of intertemporal knowledge transfer. Greater knowledge complexity requires greater information for knowledge transfer; and greater knowledge tacitness requires richer media for knowledge transfer (Teece, 1981). Further, systemic knowledge requires the transfer of several interrelated knowlege vectors over time. Knowledge positioned towards the left on each dimension in Figure 3 is relatively easier to transfer across time compared to knowledge positioned towards the right.

It could be argued that ease of knowledge transfer across time also implies ease of its transfer across space to other firms, which reduces its strategic value. This argument alone may suggest that easy-to-transfer knowledge must not be maintained. However, a decision to maintain easy-to-transfer knowledge for a firm's own use also depends on two other factors. First, it depends on a firm's ability to prevent others from accessing this preserved knowledge. Thus, proprietary, yet easy-to-transfer knowledge must be maintained. Second, a decision to maintain easy-to-transfer knowledge also depends on the extent to which knowledge is firm-specific. Firm-specific knowledge is valuable because of a firm's complementary resources (Teece, 1981). Such knowledge may be of little value to other firms who do not possess similar complementary resources. Thus, firm-specific knowledge must also be maintained by a firm possessing it.

In summary, time lags in knowledge and market development create the need for intertemporal knowledge transfer. In addition, three dimensions of knowledge affect its intertemporal transfer. Knowledge transferred across time can form the basis for new businesses. Thus, appropriately managed knowledge is a key resource that can maintain corporate vitality.

INTERTEMPORAL KNOWLEDGE TRANSFER AND THE RESOURCE-BASED VIEW OF THE FIRM

Dierickx and Cool (1989) employed the resource-based view to describe how a firm's assets, or resources, can provide a sustainable competitive advantage. To establish their argument, they drew an analogy between a firm as a bundle of resources and a firm as a bath-tub. In this analogy, inputs are compared with flows of water into a tub, while asset stocks, or resource bundles, are compared with the stock of water in a tub. Dierickx and Cool argued that a sustainable competitive advantage cannot be

[6] As Winter (1987) pointed out, locating knowledge on the simple/complex and independent/systemic dimensions must be based on a consideration of the relevant context. Winter (1987) illustrated this point by the ceramic material used in spark plugs. In the context of spark plugs, the ceramic material is relatively complex. However, in the context of an automobile engine in which such spark plugs are used, the ceramic material is relatively simple. Similarly, the microprocessor used in personal computers is on the one hand a part of a larger system, the computer. On the other hand, it could also be considered as a relatively independent knowledge vector because its development can occur independently of other components of a computer.

ARTICULABLE	————————	TACIT
SIMPLE	————————	COMPLEX
INDEPENDENT	————————	SYSTEMIC

Figure 3. Dimensions affecting intertemporal knowledge transfer. Adapted from Winter (1987)

obtained from resource flows, but instead, it can only be obtained from the resource stock in a tub.

A resource stock provides a sustainable competitive advantage because imitating it is difficult. One reason for this is the existence of time-compression diseconomies (Dierickx and Cool, 1989).[7] Resources characterized by time compression diseconomies are expensive to create under crash conditions. This is illustrated by Mansfield's (1988) data on the mean elasticity of cost with respect to time to develop and commercialize an innovation. He found that the cost increase for a 1 percent reduction in time ranged from 2.5 to 15.7 percent. Further, he found that the cost to accomplish each additional percent time reduction increased at an increasing rate, indicating the presence of time-compression diseconomies. In addition, it may not even be possible to once again create resources abandoned earlier. Firms possessing such *difficult-to-create* anew resources must maintain existing stocks and not rely on creating them again as and when needed.

However, relying only on existing resource stocks can harm corporate vitality. Existing resource stocks can entrap firms into particular modes of operation while the environment changes (Russo, 1992). This creates a need for restructuring. This adverse aspect of resources, which may otherwise be considered as assets, has been called 'competency traps' (Levitt and March, 1988). To avoid competency traps, it is necessary to create new resources from combinations of existing resources.

The bath-tub analogy that Dierickx and Cool proposed does not suggest how new resources can be created. This is because the bath-tub analogy is largely static in nature evoking a vision of stagnant water. One way of making this analogy dynamic is by adding 'leaks' and 'swirls' to the tub.[8] Leaks reduce resources over time. Swirls help mix existing resources to create new ones. Thus, combined with flows of fresh resources, leaks and swirls may evoke insights on how the bath-tub is continually rejuvenated.

We believe, however, that these additions extend the bath-tub analogy beyond its usefulness in understanding knowledge creation. Lacking are fine details of new knowledge creation by combining old knowledge. The bath-tub analogy does not help identify specific tasks affecting intertemporal knowledge transfer and reuse. Hence, it is necessary to replace the bath-tub analogy with another capturing evolutionary facets of resource creation.

Our analogy is the *process of pollination.* Pollination transfers pollen from one flower's stamen to another's stigma. Similar to any evolutionary process, pollination is a probabilistic process. Moreover, it is path-dependent and cumulative, both essential elements of the resource-based perspective. Pollination permits creation of hybrid varieties by crossing one species with another. The success of such cross-pollination depends upon many factors such as wind and rain. Not all hybrids survive. Some are selected out as they cannot survive environmental demands. Other, better adapted ones, propagate their species through self-pollination.

This evolutionary process of survival of the fittest represents 'first-order' learning. In contrast, 'second-order' learning represents artificial interventions in pollination to affect hybrid types

[7] Other reasons for inimitability are asset mass efficiencies, interconnectedness of asset stocks, asset erosion and causal ambiguity. Asset mass efficiencies arise if an existing resource stock facilitates accumulation of additional resource stocks. Interconnectedness implies that additions to existing resource stocks are linked to the level of other resource stocks. Asset erosion occurs when resource stocks decay if not maintained. Causal ambiguity arises when it is impossible to specify how resource stocks are accumulated (Dierickx and Cool, 1989).

[8] We thank an anonymous reviewer for suggesting this way to extend the bath-tub analogy.

created.[9] Artificial-pollination entails the following three tasks: *choice* of pollen, *maintaining it over time and space*, and its *reactivation and synthesis* to produce a hybrid. In this way, artificial-pollination allows pollinators to overcome myopic selection pressures of natural environments by transferring desired pollen across time and space.

Elster (1983) noted that technological change too is a second-order learning process that can overcome myopic selection pressures of natural environments. Elster pointed out that this requires the ability to 'wait.' In particular, a firm's technological knowledge, just like a flower's pollen, must be preserved until conditions favor its use and synthesis. That is, using the pollination analogy, pollen and stigma represent a firm's technological knowledge with the potential (though, as yet unrealized) to create new business opportunities.

TRANSFORMATIVE CAPACITY

Knowledge is like pollen; it creates new knowledge by interacting with other knowledge vectors acting as stamen. As with the creation of hybrid plant varieties, creating new businesses is a probabilistic and path-dependent process. Therefore, consistent with the pollination analogy, time lags in knowledge and market development create the need to: (1) choose technologies, (2) maintain them over time, and (3) reactivate and synthesize them with ongoing technology development efforts. Transformative capacity is the ability to accomplish these three tasks. Table 1 contains illustrations of key elements determining the need for transformative capacity and the mechanisms required to create it. Table 2 presents a summary of information processing demands of the three tasks underlying transformative capacity. These demands vary across the three knowledge dimensions discussed earlier.

Maintaining knowledge for future use is costly because resources must be assigned to keep knowledge 'alive' (Levitt and March, 1988; Wilson and Hlavacek, 1984). Consequently, it is necessary to determine whether to maintain knowledge for future use or to generate it again when needed.[10] As discussed earlier, easy-to-create knowledge need not be maintained for future use. In contrast, difficult-to-create knowledge must be maintained. In addition, consistent with the pollination analogy, firms must choose *which* difficult-to-create knowledge to maintain given limited organizational resources.

One facet of choice is ambiguity due to multiple and conflicting views about the future strategic value of knowledge (Daft and Lengel, 1986), and decision makers' divergent preferences (March, 1978). The extent of ambiguity varies across knowledge vectors. There is a lower potential for ambiguity as the ability to articulate knowledge increases. In contrast, as knowledge tacitness increases, the likelihood of it being misunderstood also increases. Therefore, ambiguity increases with knowledge tacitness.

Firms deal with ambiguity by using rich media to exchange views and opinions among managers about the future of technologies. They might use a combination of formal planning mechanisms, face-to-face meetings and boundary spanning roles to elicit, discuss and exchange interpretations about the future of technologies before choosing to maintain some of them. Under conditions of ambiguity, decision makers employ their judgments and consensus among themselves about a course of action even as they proceed to implement it (Daft and Lengel, 1986).

A second facet of choice is uncertainty due to incomplete information about future demand and supply conditions, competitors' actions, and other externalities (Daft, Sormunen and Parks, 1988; Wernerfelt and Karnani, 1987). Incomplete information arises from a gap between information needed and available. This gap creates difficulties in determining the future strategic value of knowledge. The information gap decreases as knowledge becomes simple. In contrast, as knowledge becomes complex, the information gap increases. Therefore, uncertainty increases with knowledge complexity.

Firms deal with uncertainty by collecting more data. They use organizational practices yielding additional data required to make decisions about

[9] We thank an anonymous reviewer for suggesting we consider this distinction between first-order and second-order learning in this context.

[10] Maintaining knowledge should not be construed to mean innovation is not necessary. Innovation is required to create new knowledge vectors that can be combined with others maintained over time.

Table 1. Illustrative quotations pertaining to transformative capacity

Quotations	Key elements
• A study of how successful unshelvings occur revealed that the incremental returns from unshelved projects were most attractive indeed. Nearly every research person interviewed could cite one successful unshelving, and many identified prospective unshelvings in their organizations. *The unrealized potential from the shelved projects is thus of great importance to any research manager.* (Wilson and Hlavacek, 1984: 27)	• Increasing returns from R&D • Retrieval
• *Seeing an opportunity to make money from compounds collecting dust on their shelves*, drug-makers such as Bristol-Myers, Squibb, Upjohn, American Home Products, and Eli Lilly are aggressively licensing compounds to small players. (Hamilton and Weber, 1988: 90)	• Technology supply factors • Technology maintenance
• *We have thousands of compounds and hundreds of projects that go in and out of favor, often because of perceived marketing issues* says Robert A. Dougan, manager of corporate development for American Cyanamid (Hamilton and Weber, 1988: 90)	• Market demand factors
• Nearly *three decades* after they burst on the scene, why are mass-market video-phones finally at hand? Because of cheap but powerful computer chips, small but reliable cameras and break-throughs in simultaneously sending video and audio signals over phone lines. . . .*Everything is coming together in 1993.* (Bulkeley, 1992)	• Time lags in the development of markets and technologies • Synthesis of knowledge vectors
• *Companies can improve the profit per dollar of R&D investment by 200–300 percent* if they learn how to select the 'best' technology to pursue and the best time to pursue it. (Foster, 1982: 22)	• Technology choice • Maintenance and retrieval and synthesis
• American Cyanamid is *taking an inventory of its drug library for resurrection candidates.* (Hamilton and Weber, 1988: 90)	• Maintenance of technology for retrieval
• Object oriented programming is analogous to ordering entire rooms as units and joining them together with far less effort and expense. *Once written, these self-contained, re-usable chunks of software code*—the objects—*can be mixed and matched by programmers to create new applications without having to start from scratch each time.* (Fisher, 1992: 51)	• Technology maintenance • Retrieval and synthesis

Note: Emphasis added in quotations.

which knowledge vectors to focus on, which to abandon, and which to maintain. They might use one or a combination of rules and procedures, formal information systems, special studies, and formal planning mechanisms to gather and process data about the future strategic value of knowledge vectors before choosing to maintain some of them (Daft and Lengel, 1986; Galbraith, 1973).

Additional data reduce uncertainty. In many instances, this will permit assigning probabilities to outcomes and making choices considering risk. These choices are based on decision makers' risk preferences and expected pay-offs of choices including opportunity costs of not maintaining particular knowledge vectors. Thus, decision makers focus on defining their risk preferences and the pay-off matrix (Hogarth, 1980; March and Shapira, 1987).

However, there remain some knowledge vectors for which probabilities cannot be assigned to alternative outcomes despite collecting additional data. Under these conditions, decision makers

Table 2. Information processing demands placed by transformative capacity

Dimensions of technological knowledge	Tasks underlying transformative capacity: Choice	Maintenance	Reactivation and synthesis
Articulable/tacit	The more tacit the knowledge, the greater the ambiguity and therefore greater the need for richer media to make choices.	The more tacit the knowledge, the greater the need for rich media to preserve knowledge over time.	Both articulable and tacit knowledge have to be internalized when retrieved.
Simple/complex	The greater the complexity of knowledge, the greater the uncertainty and therefore the need to collect more information to make choices.	The greater the complexity of knowledge, the greater the amount of information that must be maintained over time.	The more complex the knowledge, the greater the amount of information that must be retrieved.
Independent/systemic	The more systemic the knowledge, the greater the need for configurational choices.	The more systemic the knowledge, the greater the need for maintaining information about different knowledge vectors.	The more systemic the knowledge, the greater the need to integrate information pertaining to different knowledge vectors.

use their judgment to estimate future strategic values of knowledge vectors. This results in categorizing knowledge vectors into three categories: (1) clearly worth maintaining, (2) clearly not worth maintaining, and (3) requiring more information (Janis and Mann, 1977; Lippman and McCardle, 1991). Decision makers consider the last category more carefully when reviewing knowledge stocks. For example, they may use criteria such as maximization of minimum gain to make a choice (Luce and Raiffa, 1957).

A third facet of choice is the systemic nature of some knowledge vectors. To the extent that knowledge is independent, information about other knowledge vectors is not required to make choice decisions. In contrast, the more systemic the knowledge, the greater the need for information about several interdependent vectors to make choice decisions. Therefore, the need for configurational choices increases as knowledge becomes more systemic.

Under these conditions, decisions are driven by heuristics using information most familiar to decision makers (March, 1991; Nelson and Winter, 1982). That is, a decision about whether to maintain or to terminate projects is based on local knowledge (Baba, 1988). However, as knowledge becomes more systemic, its future strategic value can only be determined in relationship with other knowledge not in the local knowledge set. Therefore, the more systemic the knowledge, the greater the need to consider a diversity of perspectives to make a better informed choice decision (Milliken, 1990), resulting in more desirable outcomes (Gupta and Govindarajan, 1986; Kahneman and Lovallo, 1993).

We illustrate challenges associated with choice within the context of a technology development program we tracked over its 10-year history. Beginning with an idea to develop a biomedical implant, the program quickly proliferated with spin-off projects. Given limited resources, program members decided they would need to focus on certain projects, maintain some for future development, and abandon others.

To prepare for this decision, program members first gathered information about each potential project. Information gathered pertained to issues such as potential markets, developmental time frame, resource deployment, and competition. This information formed the basis for organizing a 2-day retreat to evaluate opportunities.

Recognizing the systemic nature of knowledge required to evaluate each project, managers from several different functional departments attended the retreat. These managers had to first reach a consensus on the criteria against which each project should be evaluated. These included criteria such as technical performance, market penetration, and production cost. The multiplicity of perspectives and associated criteria created ambiguity, especially when knowledge could not be articulated.

To deal with this ambiguity, considerable discussions and negotiations occurred in the group. Recognizing trade-offs, group members allocated weights to criteria. Next, they estimated the extent to which project ratings would drop as performance declined on each criterion. For instance, a project might score 80 points for a 30 percent market penetration and only 40 points for a 10 percent penetration. Since higher performance on any criterion required greater resources, which were limited, this led to a discussion of trade-offs among criteria.

Following this, the group determined a desired level of performance on each criterion. For each project, information collected earlier was shared with the group by respective functional managers. Based on this information, the group estimated the probability of achieving the desired performance level for each project on each criterion.

The group then assessed their risk preferences—whether they were risk seeking, risk averse or neutral. An external consultant encouraged the group to adopt a risk neutral stance. These steps set the stage for a final session to score projects and to prioritize them according to cumulative scores. Based on cumulative scores, the group reached a consensus on which projects they should focus on and which ones they should maintain. A decision to discontinue the development of remaining projects was not taken immediately. Instead, laboratories not associated with the program were informed about projects identified for possible termination to determine whether they would be interested in pursuing them.

Maintenance

Just as it is necessary to maintain pollen for cross-pollination to succeed, it is necessary to maintain knowledge to facilitate its retrieval and use later. If not maintained, knowledge decays as skills, routines and assets fall into disuse, knowledge is lost when personnel leave a firm, or knowledge becomes obsolete (Epple, Argote and Devadas, 1991; Huber, 1991; Kanter, 1988; Levitt and March, 1988).

The notion of 'organizational memory' is relevant to study how firms retain knowledge (Duncan and Weiss, 1979; Levitt and March, 1988; Walsh and Ungson, 1991; Weick, 1979). We suggest that the process of creating memory for technological knowledge varies with the dimensions of knowledge. For instance, as knowledge becomes more articulable, it need only be codified to be available for later use. This can be accomplished by preserving documents and blueprints (Foster, 1971). In contrast, the more tacit the knowledge, the richer the media required to maintain it. As Wilson and Hlavacek (1984) found, firms that benefited from technologies created in the past kept knowledge alive by the active presence of a core group of people. One manager quoted in their study stated: 'In some of our cases, work was never completely terminated, although at times, efforts were minimal' (1984: 28).

Knowledge complexity affects the amount of information needed to maintain it. Two considerations determine how much information about a knowledge vector must be maintained. First, it is important to know how much information will be required to successfully reconstruct an entire knowledge vector. It might be impossible to reactivate a knowledge vector if the information gap (i.e., difference between information needed and available) is greater than a certain threshold level. To safeguard against this contingency, it is necessary to maintain at least the threshold level of information about a knowledge vector so that it can be reactivated later. Greater knowledge complexity requires more information to describe it. Therefore, the more complex the knowledge, the higher this threshold level.

The case of Xerox and personal computers illustrates the existence of a threshold level and it underscores the difficulties associated with attempts to reactivate a technology development effort. Although Xerox developed the first personal computer (Smith and Alexander, 1988), it has been unsuccessful in reentering the computer industry because it discontinued developmental efforts thereby creating gaps in knowledge. Moreover, time compression diseconomies prevent Xerox from catching up.

Thus, a second consideration determining how much information about a knowledge vector must be maintained is the speed at which it must be reactivated. At any level of complexity, time required to generate additional information needed for knowledge reactivation increases with the information gap. This is especially important in fast-moving environments where knowledge must be reactivated quickly. Under these conditions, greater information about a knowledge vector must be maintained than in environments allowing slower reactivation.

The extent of interdependence between knowledge vectors affects the number of vectors that must be maintained simultaneously. As another manager quoted in Wilson and Hlavacek's (1984) study commented: 'Totally shelved projects seem not to occur here. A small core of people, or one person, remained active even if it was part time' (1984: 28). Independent knowledge can be maintained by one or more experts in that knowledge area. For example, venture capitalists retained only Mr. Chen, who had a doctorate in image coding, a critical technology, and a dream of a picture telephone when initial efforts at developing a video-telephone failed (Bulkeley, 1992). Similarly, when Hitachi factories were not interested in hard-to-fabricate semiconductor lasers, a lone researcher, Yasutsugu Takeda, wrote up a catalog of semiconductor lasers he could custom-produce at his workbench and mailed it to customers such as IBM, Bell Telephone, Xerox, and Canon. One he received orders, he gave the list to a Hitachi plant. That was the beginning of Hitachi's flourishing optoelectronics business. Today, Hitachi has a 60 percent market share for devices using this technology (Gross, 1992).

In contrast, as knowledge becomes more systemic, the greater the need to keep entire teams active even if on a part time basis. For example, in the early 1980s, a Hitachi CEO ordered research on hydroelectric power stopped. However, 'the research team went underground, taking advantage of the ample allotment of unmonitored research time to pursue the project. Several years later, they surfaced with a new system that scored big with power companies facing environmental restrictions' (Gross, 1992: 98).

Maintenance is costly. Therefore, firms must continually evaluate maintained knowledge vectors to determine whether any should be discarded, maintained further, or used in some ongoing project. To do this, firms must catalog maintained knowledge vectors and create organizational mechanisms to review the catalog periodically. Otherwise, maintained knowledge vectors may be 'lost' for all practical purposes. The importance of a catalog of shelved, and even ongoing projects, is highlighted by the observation that 'some companies have no idea what projects they have in their inventory' (Gupta, 1989: B2). It should not be assumed, however, that a catalog is enough to ensure the use of shelved technologies. For example, although Sony has many avenues for researchers to share information, the Sony PalmTop 'came out of an engineer's imagination (who). . .discovered by *chance* that Sony's research labs had devised handwriting recognition software' (Schlender, 1992: 79).

Reactivation and synthesis

The promise of the pollination analogy we have proposed lies in a firm's ability to couple knowledge vectors at appropriate points in time. This involves several interrelated tasks: recognizing a business opportunity, reactivating maintained knowledge, and coupling reactivated knowledge with other knowledge vectors to exploit new business opportunities.

Technology supply and market demand triggers lead to recognition of new business opportunities. Supply triggers arise from apparently serendipitous intersections of knowledge vectors such as those that occurred in video tape-recorder development (Graham, 1986; Irvine and Martin, 1984). Demand triggers arise when market conditions become more conducive for using maintained knowledge. For example, this is now occurring for certain contraceptive and abortion methods and pharmaceutical products (Hamilton and Weber, 1988; Newman, 1993).

Firms must recognize technology supply and market demand triggers. As El Sawy and Pauchant (1988) summarized, firms may adopt either reactive or proactive modes to recognize triggers. In a reactive mode, the occurrence of a problem serves as a trigger. In contrast, in a proactive mode, firms engage in exploratory surveillance activities. Suggesting the importance of the proactive approach, Daft *et al.* (1988) found that high performing firms scanned more frequently and more broadly under conditions of strategic uncertainty than low performing firms.

Lenz and Engledow (1986) described several scanning mechanisms to enhance firms' ability to generate and recognize opportunities. These mechanisms include corporate monitors, brainstorming exercises, seminars, reliance on information services, participation in business issues committees, and scanning units. The effectiveness of scanning units in recognizing technological opportunities is illustrated by the experience of a manager we interviewed at a large diversified firm. Recently, this manaager was assigned the responsibility for developing new business opportunities from ideas within the firm. Assisted by two other employees, this New Business Opportunities (NBO) manager systematically scanned the firm to identify currently unused technologies thereby generating over 50 new business ideas. These new ideas were created as the firm's other employees became aware of the NBO team's activities and they offered ideas they were pursuing outside their main activities. Of four ideas ultimately chosen for commercialization, one was created from the synthesis of two different knowledge vectors residing dormant within the firm. The remaining three ideas were based on unused single knowledge vectors resident in the firm and were developed further to exploit emerging market opportunities.

Another way to recognize triggers is illustrated by a practice at Sony Corporation. 'Sony thinks the best technicians are those who are willing to move around among product groups and try their hand at technologies they haven't studied. . . .To encourage employees to move around, Sony has a policy it calls 'self-promotion,' which allows enterprising engineers to seek out projects elsewhere in the company without notifying their supervisors' (Schlender, 1992: 78). The Sony PalmTop is the brainchild of one such 'self-promoted' engineer, Tomoshi Hirayama.

Sony's corporate research group also organizes an annual exposition as a way to recognize triggers for knowledge retrieval. This exposition, open only to employees, provides a forum to display what Sony's engineers and scientists have been tinkering with. According to Schlender, this 3-day event helps to 'cross-pollinate ideas among various business groups' (1992: 84) and it 'keeps the magic going' as Sony introduces a constant stream of innovative products. At NEC Research Institute, Inc. in Princetown, New Jersey, 'curiosity is flourishing at the institute as posters in the corridors highlight topics that NEC investigators are probing' (Weber, 1992: 137). Researchers at Hitachi 'fraternize at technical conferences, swap ideas, and informally advise Hitachi's board on important technology developments' (Gross, 1992: 98).

Once the potential for exploiting a maintained knowledge vector is recognized, the next task is to retrieve the required knowledge. This retrieval is different from the task of picking up a book from a library. This is because firms have difficulty in retrieving old, unused knowledge or skills (Argote, Beckman and Eppel, 1987). As Levitt and March pointed out 'even with a consistent and accepted set of routines, only part of a firm's memory is likely to be evoked at a particular time, or in a particular part of the firm. Some parts of organizational memory are more available for retrieval than others. Availability is associated with the frequency of use of a routine, the recency of its use and its organizational proximity' (1988: 328). Therefore, as discussed earlier, ensuring availability via a catalog of knowledge is important for knowledge retrieval.

Retrieval requires adapting maintained knowledge to changed circumstances. Technology transferred across space and cultures must be modified to complement prevailing social, political and economic conditions (Teece, 1981; Rogers, 1983). Similarly, useful knowledge retrieval requires its modification to suit current needs. This might imply reinvention as new individuals interpret maintained knowledge in different ways (Rogers, 1983). This process of reinvention can reduce the reliability of retrieved knowledge (Levitt and March, 1988). Since reinvention is inevitable, it is necessary to assess reliability of retrieved knowledge before it can be used. In addition, it is necessary to assess the validity of retrieved knowledge in changed circumstances. For example, infrequently used testing equipment is often recalibrated to previous standards to establish its reliability. Moreover, such equipment is also occasionally updated to meet new testing standards to establish its validity.

Retrieval entails several interdependent tasks varying with knowledge characteristics. Maintained knowledge, whether tacit or articulable, must be converted into a usable form (Lindblom and Cohen, 1979). To successfully use maintained knowledge, it must be internalized once again through experience (Nonaka, 1988). For example, knowing physics does not result in expert tool designers. Instead, this knowledge must be internalized by designing tools and by using them in manufacturing settings. In other words, knowledge reactivation requires learning-by-doing (Arrow, 1962) and learning-by-using (Rosenberg, 1982).[11]

As knowledge becomes more complex, the greater the information needed to reactivate a maintained knowledge vector. This task takes time because reactivation entails accessing and bringing into use all of the necessary facets of knowledge, so that information gaps do not remain in a knowledge vector. The more complex the knowledge the greater the information gaps simply because more information is needed to describe more complex knowledge compared to the information needed for relatively simple knowledge. Therefore, the more complex the knowledge, the greater the time needed to reactivate it.

Retrieved systemic knowledge must be integrated with other knowledge vectors. This presents both technological and organizational challenges. From a technological perspective, integration requires establishing common interfaces among knowledge vectors. For example, Honeywell's electronic controls group ensures that future generations of products are backward and forward compatible. It does this by careful attention to interface specifications between the various technologies used in its products.

From an organizational design perspective, knowledge integration requires information processing among diverse groups within a firm. This suggests the need for lateral information processing mechanisms (Galbraith, 1973). For example, at Hitachi's Central Research Laboratory in Tokyo, synergy and integration are explicitly stressed to focus the entire company on electronic systems for the 21st century. Hitachi intends to draw together its far-flung laboratories and factories to 'reinvent the world out of its own toy box of machines and mad science' (Gross, 1992: 94).

[11] If firms reuse employees who maintained a technology, then they need not go through with the internalization process with them but with others whose participation is required. In contrast, firms could reuse persons once associated with the development of a technology but who were not associated with its maintenance. In this case, whether an internalization process is required depends on the time elapsed since a technology was shelved. This is because knowledge decays and the context changes over time.

DISCUSSION AND CONCLUSIONS

A recent issue of *Business Week* noted 'In the global economy, knowledge is king' (Farrell and Mandel, 1992: 70). Later in the same issue the editor noted 'In such an environment, knowledge counts for more than capital or labor. The nations that will prosper will be those that create new knowledge best' (*Business Week*, April 6, 1992: 104). Several suggestions for a 'growth Policy for the 90s' are offered (Farrell and Mandel, 1992: 74) but none focus on how to better utilize the existing vast 'storehouse of technology' that U.S. firms possess.

In this paper, we offer the concept of transformative capacity to help understand not only how firms can utilize their existing storehouse of technological knowledge through reactivation and synthesis of technologies, but also how they can actively create and maintain such a storehouse for future use. To explore the concept of transformative capacity, we built upon the resource-based perspective of the firm to offer the process of pollination as an analogy to gain insights on how firms can create new knowledge from existing knowledge. This analogy led to the identification of three tasks constituting transformative capacity. These tasks are choice, maintenance, and reactivation and synthesis of knowledge vectors. Organizational information processing demands of these three tasks were then explored. In conclusion, we explore some implications of transformative capacity for theory and practice.

Implications for theory

Continuity and change appear to be antithetical to one another. Emphasizing continuity while ignoring the need for change can entrap firms in the past. Therefore, when change becomes imperative, restructuring is required. In contrast, emphasizing change while ignoring continuity denies the past. Therefore, many innovations fail because they are inconsistent with existing resources. The challenge is to promote change while building upon past resources. This paper offers ideas and concepts on how firms can manage this process to continually structure their portfolios by investing in transformative capacity.

IBM's current plight illustrates the importance of maintaining a fine balance between continuity and change. IBM's adherence to the main-frame technology even as it became obsolete exemplifies how a firm can get locked-in to a technology. In IBM's case, lock-in occurred for cognitive, economic and behavioral reasons. Cognitive forces pertain to technological myopia (Dosi, 1982) that crept in as executives at IBM were caught up in a 'main-frame logic' (C. K. Prahalad quoted in Markoff, 1993). Economic forces pertain to reluctance on IBM's part to cannibalize their main-frame business with systems capable of distributed and parallel processing (Ferguson and Morris, 1993). Behavioral forces (David, 1985) pertain to organizational routines that led to persistence with the main-frame business.

These forces have created a situation where it is now difficult for IBM to revitalize itself with its existing resources. IBM has to undertake a significant break from the past to regain its competitive position in the computer industry. Present managers are ill equipped to accomplish this risky restructuring because of their historical association with the corporation. According to Kotter, an outsider is required to carry out this change, underscoring its disruptiveness (Hayes, 1993).

Restructuring, as the IBM example suggests, is disruptive. This disruption can be avoided if a firm is geared to continually innovate. Continual innovation is more likely if a firm institutes an organizational system to better use internal technologies and not be solely dependent on external technologies. As Mr. Welch of GE stated: 'Control your destiny or someone else will' (Tichy and Sherman, 1993). According to industry analysts, 'GE's transformation under Mr. Welch is perhaps the classic contemporary case of successful revolution led from within an aging corporate giant' (Hayes, 1993).

Transformative capacity is an important element of this institutionalized process to develop technologies within firms. The asynchronous nature with which technologies and markets develop requires firms to keep their technologies alive for an appropriate time. Failure to keep technologies alive increases burdens on the chancy and expensive R&D process.

The extent to which a firm may want to undertake such activities is moderated by its size. Size confers on a firm the ability to deploy resources to develop and maintain knowledge vectors in different areas, only some of which may be useful later. The 3M Corporation is one such example. Following a dictum of generating at least 25 percent of its revenues from products introduced in the previous 3 years, this $13 billion company is able to generate above $1 billion in net profits while spending nearly $1 billion in R&D activities annually. Indeed, 3M's early history of the creation of 'Post-it' notes from a failed abrasive technology epitomizes how a firm can create and sustain corporate vitality from intertemporal technology transfer (Nayak and Ketteringham, 1986).

Nelson (1959) pointed out that smaller firms may not have the necessary resources to create diverse knowledge vectors without immediate commercial applications. This may suggest that the usefulness of transformative capacity is moderated by firm size. Specifically, active creation and maintenance of knowledge vectors, without any immediate pay-offs but with the potential for creating future opportunities, may be appropriate only in large firms.

However, a different facet of transformative capacity may be essential for smaller firms. Smaller firms, especially venture start-ups, will have to pursue a technological opportunity on which they were initially based because a decision to discontinue or delay technology development may often imply the demise of a venture. Therefore, smaller firms also have to transfer technologies across time. Consequently, knowledge maintenance, reactivation and synthesis is necessary in small firms as well.

Implications for practice

Cohen and Levinthal (1990) noted that absorptive capacity is an intangible asset. Similarly, transformative capacity is also an intangible asset. Moreover, both these capacities lead to long-term pay-offs that are difficult to measure. Firms may, therefore, be reluctant to invest scarce resources in activities that build these capacities but yield uncertain benefits sometime in the future. Instead, there might be a tendency to focus on other more immediate and tangible actions such as acquisitions, divestitures and other components of corporate restructuring.

However, transformative capacity is a way by which firms may reduce the likelihood that corporate restructuring will be needed. Based on the information processing tasks discussed above and the several examples that illustrated how some firms were dealing with these tasks, Table 3 summarizes some practical implications of the concept of transformative capacity. Additional practical issues are discussed below.

Choice

Transformative capacity creates future options by placing technologies on-the-shelf. From this perspective, the problem of choice is one of valuing the 'option.' This requires determining whether it is worth maintaining a technology for future use considering the maintenance cost given an uncertain and ambiguous future. Managers can exercise the option at any point in time when technological and market conditions are appropriate. Otherwise they can either decide to maintain the technology for future use, or else, to discontinue its maintenance. Thus, managers have the right but not the obligation of exercising such options.

We draw upon the stock options pricing literature (Copeland, Koller, and Mirvin, 1990) to suggest a heuristic managers can employ while making choice decisions about whether to maintain a technology vector for possible future use. A stock option, just like maintained knowledge, provides the owner an opportunity to purchase stock at a specified price (exercise price) at any time prior to an agreed-upon date. Whether or not an option is purchased (cost of keeping the technology alive) depends upon an estimate of future investments needed to capitalize on the R&D program when an investment is made (exercise price) and on an estimate of returns from the investment. This permits an estimation of the value of the stock option. If the estimated value of the stock option is greater than its cost, then it is worthwhile to purchase it. In other words, it is worthwhile to maintain a technology if its value as an option is estimated to be greater than the cost of keeping it alive.

There are several practical benefits of viewing R&D activities from an options perspective. First, by maintaining a technology, major investment decisions can be deferred to a time when uncertainty is lower and the market is ready. This reduces the downside risk of major investments. When subject to traditional capital budgeting analyses, some technological investments may appear very unattractive. Yet, time lags in the development of technological knowledge and markets preclude a short-term perspective. Therefore, transformative capacity suggests that top managers in firms must adopt a long-term perspective as embodied in the options approach.

Second, the options approach also helps understand parameters affecting choice decisions over time. With use, many models and their parameters have been identified to value stock options. Similarly, by adopting an options perspective, managers can develop over time an intuitive understanding of factors determining the value of a technology option and when and whether it should be exercised.

Mitchell and Hamilton (1988) illustrated the usefulness of this approach with technology development in the telecommunications industry. They pointed out that relentless progress in microelectronics has had and will continue to have a powerful influence on design, performance, reliability, and cost. Thus, research programs directed towards understanding and developing microelectronics will be critical, not simply for the immediate next generation of products, but for many others not yet identified. Given the considerable uncertainty and ambiguity associated with future developments in this industry, firms would be well advised to consider their investment as options.

Viewing R&D programs as options has implications for the common debate on whether or not firms should invest in basic research with little immediate commercial application. This debate extends to investments in developing technologies with few links to current technologies in use. If made public, such investments might even appear misguided. Our concept of transformative capacity suggests that investing in basic research and technology may be justifiable if it helps to keep knowledge alive for later use. Moreover, firms with greater transformative capacity are more likely to invest in basic research and technology development because they can utilize knowledge developed in-house later.

Table 3. Some practical implications of transformative capacity

Choice

Gather information.

Choose difficult-to-create knowledge to maintain.

Adopt rich media when making choice decisions concerning tacit knowledge.

Coordinate efforts across businesses and research laboratories to identify technologies for shelving.

Develop criteria for evaluating technological options.

Brainstorm on which technological paths to follow and which ones to abandon.

Consider the impact on other businesses and technologies when making technology maintenance decisions.

Maintenance

Catalog shelved technologies.

Periodically review the catalog of shelved technologies.

Develop avenues for researchers to share information.

Permit 'underground' research and development activity.

Conduct internal scanning for shelved technologies.

Provide incentives for maintaining currently unwanted technologies.

Retain key personnel who possess tacit knowledge.

Maintain a minimum threshold of knowledge.

In fast-moving environments, retain more knowledge.

Retain entire teams when knowledge is systemic.

Reactivation and synthesis

Encourage scientists, technologists, and engineers to move around among product groups and research laboratories.

Coordinate the work of businesses and research laboratories through sharing information.

Organize symposia and expositions to share information.

Install lateral information processing mechanisms to encourage cooperation among researchers and businesses.

Internally publicize topics being researched.

Periodically review the catalog of shelved technologies.

Formalize the task of recognizing demand and supply triggers.

Minimize any negatives associated with the not-invented-here-and-now syndromes.

Reward reactivation.

Assess reliability and validity of retrieved knowledge.

Allow enough time for successful reactivation and synthesis.

Encourage the development of interface standards to allow synthesis later.

Maintenance

Perhaps the most important practical maintenance issue is the status of maintenance as a legitimate activity for researchers. Difficulties associated with legitimizing maintenance activity are illustrated by the case of AT&T in videophone technology. No one at AT&T wanted to be associated with a technology regarded as a failure (Bulkeley, 1992).

Viewing technological 'setbacks' as mistakes will discourage researchers from maintaining technologies. In contrast, viewing technological setbacks as latent opportunities might encourage researchers to maintain a technology. Therefore, fostering a culture that views technological development as a means to create and use knowledge over time is essential to build transformative capacity.

Incentive systems are a powerful determinant of organizational culture. Providing incentives only for entirely new knowledge as measured by patents and publications will discourage researchers from being associated with maintenance activities. Therefore, appropriate incentive systems must be designed to encourage researchers to undertake tasks that build transformative capacity.

Another essential maintenance activity is to catalog shelved technologies. An example of the importance and use of cataloging is provided by the increasing reuse of computer software in the software programing industry (Fisher, 1992). Software is often idiosyncratic because it is written to accomplish a particular task. Often, only the programer who wrote the software fully understands it. Further, different programers, and even the original writer, will often accomplish the same task later by using different lines of code. When similar tasks have to be accomplished in another software application, considerable resources can be saved if existing software codes can be used. Such software reuse was relatively uncommon until the recent advent of object-oriented-programing. This system of programing permits software to be written in modules (or objects) with standardized interfaces between modules. Proper cataloging of these modules facilitates easy access when required to build other software applications.

It is also necessary to periodically review the catalog of maintained knowledge. Reviewing maintained knowledge may be considered as an internal scanning process similar to the often discussed external environmental scanning undertaken by most firms (Daft *et al.*, 1988). Arguing that all firms can obtain the same information about competitive opportunities from external scanning and then act on it similarly, Barney suggested that firms may obtain significant competitive advantages by 'turning inwardly and analyzing information about the assets a firm already controls' (1986: 1239). Such internal information is more likely to be firm-specific, proprietary and rare. Therefore, it offers opportunities that other firms may not have. For example, a few years ago, several pharmaceutical firms were reportedly scanning their shelves looking for unique drugs and compounds that could be introduced (Hamilton and Weber, 1988).

Reactivation and synthesis

Many firms may have inadvertently encouraged the maintenance of technologies that were not immediately used. These technologies may be put to good use now, or in the future. Thus, even in firms that may not have proactively thought about maintaining technologies in the past, searching for shelved technologies may increase returns from technological investments (Hamilton and Weber, 1988; Wilson and Hlavacek, 1984).

A case in point is the apparently 'surreptitious' development and introduction of RISC based chips at Intel Corporation (Burgelman, 1991). Another case is the firm discussed earlier that found four new business opportunities by assigning a team of managers to search among technologies lying 'dormant' within the firm. The concept of transformative capacity suggests that firms can increase the likelihood of such events. One way to do this is to catalog shelved technologies as discussed above and to circulate the catalog widely within a firm, although with appropriate safeguards to prevent the dissemination of proprietary technological knowledge outside a firm.

Our discussion of the tasks underlying transformative capacity suggests that the reactivation and synthesis of maintained technologies is neither easy nor automatic. This is because the retrieval process is potentially fraught with the possibility of failure arising from a 'not-invented-here-*and-now*' syndrome. The difficulties associated with a not-invented-here syndrome are well known. The not-invented-now syndrome may introduce other difficulties. Not only do new technologies evoke greater excitement, but also old and unused technologies may have the stigma of failure attached to them (Wilson and Hlavacek, 1984).

Therefore, firms must guard against biases toward new technologies in comparison to old ones. In the current 'throw-away' society it is easy to overlook significant opportunities firms can seize if only they would explore their storehouses of technology. It is here that we can see the full benefits of developing transformative capacity. Creation, choice, and maintenance activities would be useful only if reactivation and synthesis occur when needed. Firms that recognize the worth of past efforts will be best able to maintain their corporate vitality.

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