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EVOLUTIONARY PERSPECTIVES ON STRATEGY

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We advocate studying strategic management from an evolutionary perspective: using dynamic, path-dependent models that allow for possibly random variation and selection within and among organizations. We argue that this perspective directs our attention to some of the most interesting problems in strategic management. The papers in this special issue are summarized, along with some of their implications for the advancement of an evolutionary perspective on strategy. Collectively, the papers draw on various theoretical rationales, illustrating how an evolutionary perspective can help to integrate the diverse and otherwise separate theoretical traditions that meet within the field of strategic management.

Most strategy research offers some rationale to account for performance differences among organizations or to account for strategic differences that presumably have performance consequences. For instance, a better-performing organization may be in a market position that is protected from competition (Porter, 1980), may have unique capabilities that enable it to innovate or differentiate (Wernerfelt, 1984; Barney, 1991), may occupy a powerful position in a network of organizations (Pfeffer and Salancik, 1978; Burt, 1992), may have a structure or strategy that fits well with the challenges offered by the market (Scott, 1975; Venkatraman and Prescott, 1990), may be efficiently designed so as to minimize transaction costs (Williamson, 1991), or may have outwitted its rivals in strategic interaction (Dixit and Nalebuff, 1991; Saloner, 1991)—to mention just some of the more popular rationales. A common belief among these various schools of thought is that a theoretical rationale can be expected to correspond to empirical patterns observable at any given time. In this belief, strategy researchers typically look for cross-sectional correlations in data at a single point in time, or sometimes even in a single case at a single time. Such evidence generally is accepted as a test, or at least an illustration, of a theoretical rationale.

But through what mechanisms do these predicted results come about? We beg this question when we focus our rationale and research on what exists at a point in time, without specifying the dynamics through which these outcomes develop. As Carroll and Harrison (1994) observe, such thinking is based implicitly on what March and Olsen (1989) call the assumption of 'historical efficiency'. By making this assumption, we expect that the cause–effect relations in our rationale will play themselves out to steady-state equilibrium quickly, uniquely, and independently of the particulars of the development process. Under this assumption, 'evolution' is a rapidly optimizing force—one that brings about empirical regularities as if by a design consistent with our theoretical rationale (Nelson, 1994).[1]

Those who take an evolutionary perspective

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[1] This 'as if' line of reasoning is rarely used explicitly (cf. Friedman, 1953), but rather is left implicit in theories that do not consider the development process.

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on strategy, by contrast, explicitly question how strategic outcomes develop, and in so doing treat the assumption of historical efficiency as part of the research agenda. This approach has several important consequences for our research. First, it requires that we specify a *dynamic* model. This means constructing theory that can predict patterns of change, including rates of change (the speed at which change occurs) and alternative paths of change (particular sequences of events). Dynamic models may predict convergence toward a steady state, several possible steady states, or possible ranges rather than states (Tuma and Hannan, 1984; Anderson, Arrow, and Pines, 1988). But regardless of their treatment of equilibrium conditions, evolutionary models attend to the *pace and path of strategic change*. For instance, we might model how quickly—and along which paths—organizations will grow, change their performance, or experience strategic events such as birth, restructuring, product innovation, merger, technological change, or failure. Of course, such changes are what pique the interest of strategy researchers. Thus taking an evolutionary perspective directs our attention to those occurrences that are most interesting to the field of strategic management—and yet are the least understandable through static theories and cross-sectional research designs.

Second, an evolutionary perspective allows for *variation* in the possible strategies that organizations pursue. Most theories in strategic management take the 'strategy space' of possible variants as a given and then predict which would prevail if organizations pursuing the different possible strategies were to enter into competition. But how do new strategic variants develop? How do organizations search for and learn about strategic options, especially given well-known constraints on organizational rationality (Cyert and March, 1963; March, 1981)? How adaptive is this process of search (Levinthal and March, 1981; Mezias and Lant, 1994)? These questions invite us to study the rate and path of innovation among and within existing organizations, when organizations grow (Ijiri and Simon, 1977; Penrose, 1968), when strategic initiatives are launched within firms (Burgelman, 1983a; Garud and Van de Ven, 1992), or when new jobs are created (Miner, 1990). These questions also suggest that we study the degree to which innovations are brought by existing organizations vs. through the founding of new organizations (Freeman, 1995).

In either case, an evolutionary perspective allows that many variations arise essentially at random—a possibility sometimes built into evolutionary models (Cohen, March, and Olsen, 1972; Padgett, 1982; Levinthal, 1991; Nelson, 1994). More commonly, random development represents a baseline model, serving as the null hypothesis. Theory is then challenged to explain variation or selection beyond that which arises stochastically.

Third, evolutionary inquiry asks how *selection* processes affect, and are affected by the pace and path of strategic change. Research on selection among organizations has proliferated within the research project of organizational ecology (Hannan and Freeman, 1989), with a strong emphasis on processes of organizational founding and failure. In this volume several of the studies model organizational failure rates. These studies report several findings that appear inconsistent with the assumption of historical efficiency. Selection in the auto industry favored different strategies at different points in the organizations' development (Carroll *et al.*); selection among hotel chains worked against those that were the most locally adaptive (Ingram); selection worked against software firms that relied on once-beneficial alliances (Singh and Mitchell); selection eliminated money market fund organizations that appeared to engage in the greatest amount of strategic search (Makadok and Walker); and selection among retail banks depended on the historical path of competition (Barnett and Hansen). Overall, these results add to mounting evidence that selection processes often do not function as a smoothly and rapidly optimizing force (Barron, West and Hannan, 1994; Carroll and Harrison, 1994; Barnett, 1996)—contrary to the assumption of historical efficiency.[2]

Oddly, some recoil at an emphasis on organizational failure, preferring to focus instead on instances of well-planned, sustained, excellent performance. This preference is seriously flawed on scientific grounds. One cannot adjudicate cause and effect when analyzing only today's survivors—a problem of sample-selection bias made all the worse if we focus on only the best of those survivors. Furthermore, this problem is

[2] In general evolutionary theory, little support remains for the idea that selection can be relied upon as an optimizing force (Gould and Lewontin, 1979; Sober, 1984; Casti and Karlqvist, 1995).

compounded when we retrace the histories of successful organizations with our theories in mind. Such research invites retrospective rationality, as illustrated by notorious cases where strategic analysis consisted of post hoc rationalizing of events that, in fact, developed over time in unexpected and unplanned ways (Weick, 1995). Rather, in order to understand strategic success, we must study both the winners and losers—as we do in the systematic analysis of organizational failure.

Selection processes take place within organizations, as well as among them, as illustrated here by Noda and Bower, Doz, and Burgelman. A central idea of this work is 'strategic context:' the process through which new (existing) strategic variations are internally selected (deselected) and retained (abandoned) through an amendment of the firm's concept of strategy (Burgelman, 1983a, 1986). This work builds on the variation–selection–retention paradigm of cultural evolutionary theory (Campbell, 1969; Aldrich, 1979; Weick, 1979), which keeps it general enough to be applicable in various cultural contexts (Burgelman, 1988a). Other work in this vein integrates ideas from organizational ecology and strategic management (Burgelman and Singh, 1987; Burgelman, 1990). For instance, this research analyzes strategy making within firms as an intraorganizational ecological process (Burgelman, 1991, 1994; Burgelman and Mittman, 1994), where internal selection can substitute, to some extent, for external selection. A central proposition of this line of work is that external and internal selection, together, determine the fates of organizations. Those that continue to survive have an internal selection environment that reflects the relevant selection pressures in the external environment and produces externally viable new strategic variations that are internally selected and retained (Burgelman, 1988b; see also Hrebiniak and Joyce, 1985). Similarly, work on punctuated-equilibrium organizational change notes that whether organizations survive depends on how they manage through sequential cycles of reorientation and convergence (Tushman and Romanelli, 1985; Gersick, 1991; Romanelli and Tushman, 1994).

In summary, taking an evolutionary perspective on strategy means developing dynamic, path-dependent models that allow for possibly random variation and selection within and among organizations.[3] To contribute to the evolutionary perspective, it is not necessary for a study to satisfy all the components of this definition. Most careful research looks at only one or another aspect of strategic evolution, as when a study looks only at failure rates or only at variations due to innovation, but all work in this vein studies strategic dynamics. Each of the papers within this volume deals with variation and strategic search or with selection, and most have to do with both.

We organize our review beginning with the papers by Stuart and Podolny, Makadok and Walker, and Doz, which deal primarily with strategic search and organizational learning. Then we review the several papers that deal primarily with selection processes, including those by Ingram, Singh and Mitchell, Carroll *et al.*, Barnett and Hansen, Noda and Bower, and Burgelman. These papers represent a wide variety of approaches. Methodologically, they include intensive case studies, continuing a stream of process research well established in the strategy literature (e.g., Bower and Doz, 1979; Burgelman, 1983b). They also include analyses of large data sets used to obtain estimates of dynamic statistical models. Regardless of methodology, however, the papers in this issue each report an empirical analysis. This choice reflects the belief, on our part, that the greatest value of an evolutionary perspective comes in its use as a lens that can identify interesting regularities in empirical settings.

STRATEGIC SEARCH

How do organizations search for new strategies? This clearly is an important question, but research on strategic search is hampered by the fact that it is very difficult to measure. Stuart and Podolny make considerable progress on this problem in their study of local search in technology strategy.

Local search

Stuart and Podolny study the development of technological variation among Japanese semicon-

[3] The problem of defining what constitutes evolutionary theory in general is not resolved (Sober, 1984). In the social sciences, most working definitions include the use of explicitly dynamic models and an allowance for randomness, variation, selection, and sometimes retention (Nelson, 1994; Aldrich, 1979).

ductor companies. They propose to measure a firm's 'technological niche' according to the inventions on which an organization builds its own inventions. This method then allows firms to be described as either close or distant to one another in technology space, depending on whether they build on similar or different inventions. By aggregating these differences, one can characterize firms at a given time according to their relative distance from other firms in technology space. This technique permits the identification of clusters of technologically similar organizations, of organizations that are unique technologically, or of organizations that stand somewhere between different technological groupings. For instance, among the largest 10 Japanese semiconductor companies, the authors discover a cluster of technological leaders and a cluster of firms with a technological base geared toward consumer electronics. This analysis then is repeated using 'egocentric' data—a subset of the data including only firms that have at least some technological overlap with a given organization. Using this approach, the authors conduct a competitor analysis in technology space—in this case identifying the technological competitors of Mitsubishi.

Stuart and Podolny generalize this distance measure to include differences over time, both among firms and within a single firm's history. It makes a powerful tool for the evolutionary analysis of technological change, allowing one to measure the 'localness' of search by the relative distance that a firm travels in technology space over time. Using these generalized distance measures, the authors discover suprisingly stable *relative* technological positions among these companies over the period 1982–92—even though the Japanese semiconductor industry experienced extreme *absolute* change both quantitatively and qualitatively over that period. Furthermore, their analysis draws our attention to the companies that have experienced more extreme relative changes in their technological base or that have followed unique technological trajectories. Mitsubishi, for instance, shifted from the consumer electronics cluster to the technology leader cluster—a result, the authors report, of a strategic change by Mitsubishi during the study period.

One of the most attractive characteristics of Stuart and Podolny's method is that it allows one to depict technological distances both numerically and graphically. The numerical result is the familiar Euclidean distance score, measured over technology space both at a point in time and over time. Of course, the advantage of such a numerical measure is that it can be used as an independent variable in a predictive model. The distance scores can also be arrayed in two (or three) dimensions with standard techniques of multidimensional scaling, making it possible then to describe the relative technological positions of firms graphically. The plots generated by Stuart and Podolny offer compelling evidence of technological clustering, which they then corroborate by regressing the multidimensional scaling coordinates on several variables representing aspects of technology strategy. Lines bisecting these regressions clearly separate the group of technology leaders from the group based on consumer electronics technology.

Stuart and Podolny use their results to investigate whether the technological positions of these firms affect their involvement in strategic alliances. They find, interestingly, that most alliances involved firms within the group of technology leaders—developing either among leaders or between leaders and the more technologically peripheral firms based in consumer electronics. They also find that alliances especially involve firms that have changed their relative position over time.

The Stuart and Podolny study represents a considerable advance in the evolutionary study of technology strategy in particular and of strategic search generally. As the authors observe, evolutionary theories frequently emphasize—but almost never measure—relative, local change among organizations. This omission has impeded the advancement of our knowledge in this area. Using the ideas and method of Stuart and Podolny, one can now empirically model firms' time paths of search and explicitly study the relative development of technological trajectories. What's more, this approach may be able to bring empirical definition to the often-elusive 'resource base' of organizations. The authors note that, to the extent that an organization's technological position reflects its strategic capabilities, this analytical approach allows us to measure an organization's position in resource space distinct from its behavior in the market. Consequently, the authors' approach to evolutionary analysis may represent a way to study the link between strategic resources and market competitiveness without falling prey to tautological or *ex post* definitions of competence. As Stuart and Podolny suggest, future work on strategic evolution would do well to employ the ideas and methods developed in this paper.

Search and selection

Makadok and Walker investigate the selection consequences of strategic search by the 233 money-market fund organizations that existed from the inception of the industry in the U.S.A. in 1975 through 1991. Strategic search is not directly observed in this study. Rather, search is inferred from an analysis of each organization's 'growth system', comprising its size, scope, performance, and cross-product subsidies—modeled so that each of these variables is allowed to affect the development of the others. Organizations with strong estimated effects among these variables have especially responsive growth systems, evidence of effective strategic policies. For instance, some organizations are more effective than others at parlaying good performance in one period into increased demand and growth in the next period. By estimating each organization's growth system for each of several time periods, Makadok and Walker are able to trace the path followed by each firm as its growth system becomes more or less responsive—presumably reflecting its search for an effective growth strategy.

The authors then speculate about the selection consequences of search and use their estimates of each firm's growth system to test two main hypotheses. First, they note that search may be adaptive, as argued in some theories of organizational learning and evolutionary economics. If search is adaptive, then the authors expect to see organizational failure rates decline as firms discover more effective growth strategies. Operationally, this would mean that firms with more responsive growth systems--those with higher estimated coefficients in their growth system—will have lower failure rates. This result should hold, moreover, after one controls separately for the *level* of each variable in the growth system. That is, it is not simply that large, broad, good-performing, well-subsidized firms are expected to survive. Rather, it is that after controlling for size, scope, performance, and subsidy, failure rates should be lower for firms with stronger estimated effects among these variables—since these are presumably the firms that have discovered more effective growth strategies. Thus Hypothesis 1 is tested by including the time-varying estimated coefficients of each organization's growth system as independent variables in a model predicting organizational failure.

Makadok and Walker are skeptical of Hypothesis 1, however, noting the plausible counter-argument that search is not adaptive. They draw on Bowman's (1963) idea that managers typically oversearch for better practices, as optimum practices are unlikely to be much better than practices near the optimum—yet attempts to reach the optimum are extremely costly and are plagued by random disturbances that prevent convergence on the optimum. Firms with the very best growth strategies are unlikely to be more viable than those with less effective growth strategies—contrary to the logic of fully adaptive search in Hypothesis 1. In fact, Makadok and Walker do not find support for Hypothesis 1—failing to reject the null hypothesis that an organization's growth system coefficients do not improve (collectively) on a failure model without these effects.

The authors also investigate a second main hypothesis, that strategic search is maladaptive, as suggested by Hannan and Freeman's (1984) structural inertia theory. This argument is based on the premise that organizations are expected to be reliable and accountable. Frequent and rapid changes in strategic policies imply reduced reliability and accountability, leading to social sanctions and ultimately to an increased likelihood of organizational failure. Makadok and Walker operationalize this idea as the cumulative change in each organization's growth system coefficients over time. Organizations with greatly changing growth policies are expected to show a great deal of cumulative change in the coefficients of their growth systems. Measures of the cumulative change in each organization's growth system, therefore, are expected to be associated with higher rates of organizational failure.

Correctly testing Hypothesis 2 requires the authors to isolate the survival implications of change *per se*—of the change process—apart from the implications of the content of organizational strategy. It is conceivable, perhaps likely, that organizations experiencing a great deal of cumulative change in their growth policies end up with extremely responsive growth systems. Nonetheless, the hazards of structural inertia come from the process of strategic change, and they threaten organizational viability apart from whatever improvements in strategic content they may have yielded. Consequently, in order to empirically model the maladaptive consequences of the change process, one must separately control for the consequences of strategy content (see Barnett and Carroll, 1995). Makadok and Walker do this in their failure models by controlling for the time-varying coefficients of each organization's growth system and then estimating the distinct effect of the cumulative amount of change in those coefficients. This procedure gives an estimate of the survival implications of change *per se*, holding constant the responsiveness of the growth policies that resulted from this change. With this model, the authors find strong support for Hypothesis 2.

Learning and initial conditions

How corrigible are organizations? On the one hand, we know that initial conditions continue to have enduring consequences, and yet we also see organizations learn. Doz's study looks at this tension in the context of strategic alliances. He investigates the extent to which firms alter their collaboration in an alliance in response to feedback, and how this process is constrained by the initial design and objectives of the alliance. Doz asks under what circumstances initial conditions foster or block interpartner learning in collaborative projects.

Doz documents change at the project level among six strategic alliances involving six companies. The emerging picture is complex. Partners start the collaboration process with a given set of initial conditions. They improve their knowledge in areas that have bearing on each of the initial conditions and re-evaluate whether the alliance should continue. The re-evaluation is based on whether the alliance appears to be efficient, adaptive, and equitable. This learning has cognitive and behavioral aspects that may or may not support one another. In some cases, cognitive learning is accompanied by behavioral learning that leads to mutual adjustment, making the initial conditions less salient. But in other cases, it is not. If cognitive and behavioral learning support each other, the alliance is likely to become stronger. Such learning seems to be facilitated when the task definition and the interface design remain somewhat open-ended at the outset so that they can change. If cognitive and behavioral learning are not mutually supportive, the alliance is likely to wind down and disband.

One especially interesting finding in Doz's study concerns the use of organizational routines. It is well known that organizations typically respond to new problems by using existing routines (March, 1981; Nelson and Winter, 1982). Doz finds a similar response in these strategic alliances: organizations tended to activate their own routines when dealing with one another, exacerbating the potential for misunderstanding, conflict, and distrust. In a related finding, Doz observed that the strategic context established by top management caused alliances to suffer if it was either extremely deterministic or extremely permissive: the former does not allow taking advantage of unanticipated strategic opportunities; the latter may lead partners to doubt their mutual commitment to the success of the alliance.

Doz's longitudinal-processual field research is a good example of how an evolutionary lens helps us to see the constraints faced by managers and to see that these constraints are often the result of previous adaptive efforts. His study identifies interesting phenomena such as the exaggerated use of organizational routines in the interface between organizational partners and the tension between determinism and permissiveness in setting the strategic context. The title of Doz's paper asks 'Initial conditions or learning processes?' But the paper's answer is initial conditions *and* learning processes. Its findings underscore the role of managers in recognizing inertial forces and, rather than denying them or simply wishing them away, taking action that alleviates or redirects them.

STRATEGY AND SELECTION

Many thousands of organizations fail each year, often in the heat of competitive 'shake outs.' Despite its ubiquity, natural selection among organizations still is only rarely studied by strategy researchers. Yet scholars of many perspectives rely implicitly on selection processes to bring about their predicted outcomes. On closer examination, selection processes often generate unexpected and sometimes counterintuitive consequences. The environment often confronts organizations with conflicting selection pressures, making it uncertain which strategies will succeed. Several of the studies in this issue illuminate this more complex view of strategy and selection.

Adaptation by parts vs. wholes

A classic example of conflicting selection pressures occurs when an organization operates in more than one market. In this case, the organization faces a trade-off between highly localized adaptation and system-wide coordination. If it takes the localized-adaptation strategy, then the organization will be structured into independent units—each conforming to the demands of its own market. By contrast, if the organization takes a coordination strategy, then reliability and uniformity are preferred across an entire system.

An instance of this trade-off appears in Ingram's study of alternative naming strategies in the U.S. hotel industry. Ingram documents naming differences among all U.S. hotel chains that ever existed from 1896 to 1980, predicting and finding that this difference helped to determine which ones survived or failed. Throughout this period, U.S. hotel chains faced a choice, either to allow each of their establishments to identify with its particular locale or to adopt the name and image of the chain. Hotels pursuing the local-naming strategy were free to adapt their identities to whatever was most appropriate in their own locale—an advantage denied to hotels that adopted the name and image of a chain. By contrast, chain-named establishments had advantages due to their identification with a larger system of hotels. By adopting the common-naming strategy, a hotel changed its transactions with customers from one-time, spot market exchanges to repeated transactions. Ingram argues that this shift to repeated transactions made credible the hotel's commitment to providing valuable service, as it allowed customers to punish the hotel chain in future transactions for failing to do so. Locally named hotels, by contrast, suffered from a lack of credibility because their transactions with buyers typically were one time only, and so did not permit buyers to discipline the hotel for reneging on the contract for quality service.

Ingram predicts that this credibility gave the common-naming strategy a selection advantage over the local-naming strategy, and so he predicts lower failure rates for hotel chains adopting the common-naming strategy. Supporting this prediction, he finds those chains experienced failure rates 36 percent lower than did chains employing the local-naming strategy. This effect held despite his controls for various other independent variables, and it strengthened when aspects of organizational size were controlled in estimates from a subsample of the data.

More generally, Ingram's study nicely illustrates how one can turn the unit of selection 'problem' into an interesting research topic. An important question in theories of evolution concerns the unit that is selected or deselected. This issue is especially difficult when we study the evolution of complex organizations, as their nested, hierarchical structure makes it possible to study selection of products, divisions, establishments, or departments, as well as of entire corporations (or even networks of organizations). Ingram's approach is to allow the whole organization—the hotel chain—to be characterized by the strategies taken by its constituent establishments. In this way, he finds a compelling operationalization of the trade-off between establishment-level advantages of local adaptation and system-wide advantages of reliability.

Ingram's study compares the selection consequences of two different strategies used by a particular organizational form—in this case the multiunit organization. An interesting, alternative comparison is to see how different organizational forms fared when using the local-naming strategy. Did locally named establishments within hotel chains have a selection advantage over single-unit hotels? Both forms of organization pursued the local-naming strategy, but the members of hotel chains conceivably benefited from their affiliation with the larger chain. Alternatively, single-unit hotels may have been individually vulnerable, but as a *population* these hotels may have been strong competitors because selection processes would be especially effective in weeding out weak variants (Barnett, 1996). Furthermore, a population of stand-alone, single-unit organizations might arguably produce greater variation to begin with than would the many members of relatively few chain organizations. Ingram's novel comparison of strategies could be extended to other comparisons where strategy and organization together affect selection processes as industries evolve.

The liability of collective action

Strategic moves taken at one point in time have ongoing implications for an organization's fate. This process is illustrated by Singh and Mitchell's study of collaborative commercialization relationships in the U.S. hospital software systems industry from 1961 to 1991. In particular, they note that, once formed, alliances imply increased dependence between firms, as they come to rely on one another's capabilities. This dependence, in turn, might become hazardous if the future brings unexpected changes—the 'two-edged sword' of increased access to, and loss of control to, another organization (Selznick, 1949). Singh and Mitchell study two ways that this loss of control can make organizations more likely to fail: when a firm loses a partner because the partner fails, and when a firm's partner forms a relationship with another firm.

In the first case, losing an alliance partner to failure means losing access to the capabilities of the partner. Singh and Mitchell predict that this loss will increase a firm's failure rate—unless it can replace the failed partner with another. Here the loss of a partner is arguably an unexpected shock to the organization. At the time of their formation, no doubt such alliances are seen by all parties as beneficial. Yet by depending on these benefits, the organization makes itself vulnerable in the event that its partner fails. The empirical results support this prediction.

In the second case, where a firm's partner finds a new partner, a hazard is predicted because of a consequent change in the relationship. The firm's partner improves its negotiating position by forming a new alliance—changing the terms of trade to its benefit by reducing its dependence on any one relationship. Furthermore, Singh and Mitchell argue that if resources are constrained, then the formation of a new alliance may cause the partner to underinvest in the first alliance—harming the firm that became dependent on that alliance. In these ways, the authors expect that when a firm's partner forms new alliances, the firm's failure rate will increase. The results support this prediction, at least in specifications that allow for a time lag in the effect.

More generally, the Singh and Mitchell study suggests the usefulness of analyzing strategies with an eye for possibly adverse evolutionary consequences of policies that appear to be adaptive at the time they are implemented. By and large, our understanding of strategic alliances has remained strongly functionalist, with theorists proposing various advantages that are presumably explanations of the existence of alliances. No doubt these advantages are noted at the time of alliance formation, but it is important for us also to understand the liabilities that may result from collective action among organizations (Barnett, 1994). Singh and Mitchell offer evidence of two ways that a firm's hazard of failure might increase as a result of its past decisions to enter into alliances. Future work should continue to look into additional ways that alliance formation generates a liability of collective action.

Selection and initial conditions

The strongest form of evolutionary argument holds that current organizational fates can be traced to causes at the time of founding. In their paper, Carroll, Bigelow, Seidel, and Tsai note that two popular ideas in the strategy field can be usefully thought of as this sort of 'founding conditions' argument, with contradictory implications. On the one hand, resource-based theory states that laterally diversifying firms can leverage capabilities in order to perform well in new markets (Hamel and Prahalad, 1994). This argument implies that new entrants that come from some other industry ('De Alio' entrants) will perform especially well. By contrast, theories of entrepreneurship argue that brand new 'De Novo' firms are especially adaptive to new conditions, because they are free from established routines developed for different times and places. Carroll *et al.* set out to study both of these ideas together by modeling organizational failure among all 2197 firms ever to have produced automobiles in the U.S.A. from 1885 to 1981.

To reconcile these competing stories, Carroll *et al.* go far beyond the claim that founding conditions matter, specifying detailed patterns of dynamic effects implied by both ideas. First, they expect that the resource advantages of De Alio firms will give them an initially lower failure rate, and they predict a similar advantage for De Novo firms that experience a 'preproduction' period in which the organization prepares to do business. Both of these predictions are supported by their empirical analysis.

Second, Carroll *et al.* then model the advantage of De Novo firms by specifying separate patterns of change in the failure rate for De Novo firms as compared to De Alio firms and to preproduction firms. They predict that as time passes, the advantage of existing routines and resources for De Alio and preproduction firms will become disadvantages due to inertia. De Novo firms with no preproduction experience are free from this liability, by contrast. Consequently, the initial disadvantage of the De Novo entrant is expected to reverse, so that it becomes less likely to fail. They then find evidence of this pattern—although the reversal is significant only compared to preproduction firms.

In addition, Carroll *et al.* investigate the survival implications of a De Alio entrant's industry of origin. Although the resource-based theory is not yet developed enough to make general predictions in this vein, the authors note some particular, potentially important differences among three common industries of origin: engine manufacturers, bicycle manufacturers, and carriage manufacturers. They suggest that the received wisdom among industry experts is that engine manufacturers would have an advantage as De Alio entrants into automobile production, but in fact they find the opposite—that carriage and bicycle manufacturers are the most viable De Alio entrants. The authors then explore several possible reasons for this finding.

The hypothesis tests of Carroll *et al.* are conducted with the well-developed 'density-dependent' model of organizational ecology (Hannan and Freeman, 1989; Hannan and Carroll, 1992). Carroll *et al.* use that model as a baseline, so that the basic evolutionary processes of legitimation, competition, and founding conditions are controlled. In particular, they find that failure rates of each kind of entrant fall with initial increases in the numbers of that kind of entrant—evidence of increasing legitimacy of that strategy. At high numbers, however, the effect turns competitive, so that additional increases in a given strategy predict an increase in the failure rate. Also, in addition, the number of competitors in an organization's year of founding is included as a covariate, and it predicts a higher lifetime failure rate for organizations born in a year with more competitors. This effect, known as 'density delay,' is evidence that organizations set up during scarce times suffer ongoing hazards as a result.

Carroll *et al.*'s use of a well-established model to test a strategic hypothesis is exemplary for several reasons. First, it shows that their hypothesis tests hold even after they control for processes that are known to affect organizational evolution. Second, this approach yields results that are comparable to those in other studies. Third, they study a new set of ideas within a generalizable modeling framework. This approach makes their findings more compelling than if they were to use ad hoc specifications, and it makes their novel ideas testable on other data sets. Researchers can attempt to replicate and advance their findings simply by estimating or extending their model in other organizational settings. Empirical modeling of this sort can go a long way to increase the accretion of knowledge in the strategy field.

The Red Queen

Barnett and Hansen study how exposure to competition affects organizational survival, using a synthesis of organizational learning theory (March, 1988) and organizational ecology (Hannan and Freeman, 1989). They propose that an organization exposed to competition is likely to learn as a consequence (Barnett, Greve and Park, 1994). Assuming that learning is adaptive, the organization becomes a stronger competitor, triggering search and learning in its rivals. This response, in turn, strengthens competition from rivals felt by the first organization, starting the whole process over again. This reciprocal system of causality has been dubbed 'Red Queen' evolution by the biologist Van Valen (1973)—a reference to Lewis Carroll's *Through the Looking Glass*, in which Alice observes that she appears to be standing still even as she is running a race, and the Red Queen replies that in a fast world one must run just to stay still.

Barnett and Hansen argue that the Red Queen probably is very important in strategic evolution because, like an 'arms race' model, it is self-reinforcing. Even if each incremental adjustment is minor, over time this mutual incrementalism could conceivably add up to a very large difference. The authors also note, however, that it is potentially difficult to detect the consequences of this process, as each organization becomes more viable but its competitors become stronger too. As a result, net measures of performance or survival may lead us to believe wrongly that nothing has changed even when a Red Queen exists.

To overcome this problem, Barnett and Hansen model organizational failure rates as a function of two distinct, simultaneous effects. Each organization's *own* competitive experience is included in the model, because organizations with more competitive experience will be more likely to survive. At the same time, each organization's survival is allowed to depend on its *rivals'* competitive experience. Organizations with more experienced rivals are expected to be less likely to survive. Although descriptive statistics would confound these two opposing effects, Barnett and Hansen's multivariate model of organizational survival separates them into distinct terms. The key to separating these effects is in operationalizing 'competitiveness' as a property of organizations, rather than markets, allowing organizations to be stronger or weaker competitors as revealed by their effects on other organizations' viability (Barnett, 1993, 1996).

Going beyond these baseline effects, Barnett and Hansen also consider the condition under which learning may be maladaptive. Two historical constraints are considered. First, drawing on Levitt and March's (1988) idea of a 'competency trap,' Barnett and Hansen propose that competition-driven learning in the distant past is likely to have taught organizations outdated lessons. Consequently, they predict that exposure to competition in the distant past is maladaptive, making organizations both more likely to fail and weaker competitors. Whether Red Queen evolution is adaptive or maladaptive should depend on historical timing: recent experience is predicted to increase survival and competitiveness, whereas distant-past experience is predicted to have the opposite effects.

A second constraint arises when organizations compete against many different cohorts of rivals. An organization facing a single cohort of rivals shares with them a single sequence and timing of incremental adaptations. When a new cohort enters, the organization may also adapt to the challenges of this new competition, but it is constrained by adaptations made in the past to established rivals. In the same way, adaptations made in response to the new cohort of rivals constrain what can be done in response to established rivals. This pattern suggests that we should attend to the *variance* as well as the amount of competitive experience had by an organization. Organizations with their experience spread across many different cohorts of rivals—those with high variance among their competitive relationships—are more constrained in their ability to adapt to any one cohort. As these constraints increase, adaptations are less likely to exceed the costs of search and learning. Consequently, the authors predict that organizations with high variance among their competitive relationships are more likely to fail.

Barnett and Hansen empirically model these arguments together by specifying each organization's *experience distribution* in models of organizational survival. Number of competitors represents just one aspect of an organization's experience distribution: its *number of competitive relationships*. Beyond this, their arguments suggest that they also model (1) the amount of competitive experience (the *mean duration* of relationships), (2) the *historical timing* of these relationships, and (3) the *variance* in durations of these relationships. They also control for the effects of selection that might otherwise lead to spurious evidence of organizational learning. Only by modeling all of these effects together, they argue, can one detect both the adaptive and maladaptive consequences of Red Queen evolution.

The authors estimate their model using data on all 2970 retail banks ever to operate in this century in the state of Illiniois (excluding Chicago). Until recently, bank branches and holding companies were prohibited in Illinois. With only unit banks operating, each of the 650 communities within Illinois was a distinct and independent local market. These data provided ample differences in the competitive histories of organizations and their rivals—a requirement for identifying the Red Queen model. They found support for their predictions in estimates of the organizational failure rate among these banks.

Several conclusions come from the Barnett and Hansen study. First, the Red Queen model finds strong support, suggesting that a dynamic model of competitive strength may be a much better predictor of organizational success and failure than are models of static competition, which typically look at only the numbers and size distribution of competitors at a single point in time. Second, their approach is based on the idea that 'competitiveness' is a property of individual organizations, not of markets, as is usually thought to be the case. This innovation should be extremely useful for the field of strategic management, where much of our theory is based on the idea that some organizations are more competitive than others. Third, their study demonstrates that evolutionary processes have both maladaptive and adaptive consequences. Finally, Barnett and Hansen's model allows for strategic interaction among competitors, and at the same time it acknowledges that organizations are limited in their ability to strategize. The explanatory power of their model demonstrates the usefulness of basing our models on realistic assumptions when we describe the evolutionary consequences of strategic interaction.

Selection, initial conditions, and managerial discretion

One of the ways in which an evolutionary perspective on strategy can be helpful is by identifying constraints on managerial action. Some of these constraints come from outside any particular organization, such as industry structures, laws, or consumer preferences. But other constraints come from within a firm, arising over its history—such as the initial conditions and organizational routines highlighted by Doz's paper. These internal constraints may limit managerial discretion in important ways.

Such internal constraints are revealed in the study by Noda and Bower. They begin their study of BellSouth and U S WEST with an interesting question: why would two organizations having similar initial market positions, similar competencies, similar structures and routines, and similar management talent embark on different courses of action when a new business opportunity arises for both? The authors then describe the different internal constraints that shaped these firms' very different strategies in cellular telephony during the period 1984 (after the breakup of AT&T) through the early 1990s.

Noda and Bower's paper shows ways in which corporate context affects the pattern of new business development with these firms. The authors use the Bower–Burgelman (B-B) process model (Bower, 1970; Burgelman, 1983c) to conceptualize the strategic decision-making processes concerning cellular telephony in BellSouth and U S WEST, and to highlight the differences between these processes in both firms. Their paper is the first to examine the usefulness of the B-B process model in a comparative study at the firm level.

Like Doz, Noda and Bower show that initial conditions associated with the corporate context are important in the strategy-making process. Top management sets the structural context, in particular the resource allocation rules. Top management also sets the initial strategic context, which reflects their 'crude strategic intent' regarding particular areas of business. Structural and strategic contexts, together, define the playing field for middle-level and operational-level managers. Managers below top management pursue business activities that give substance to the strategic context.

Although Noda and Bower confirm that top management sets the corporate context within which new business development takes shape, their findings also show that top management finds it very hard to change the pattern of resource allocation once it has been set in motion. U S WEST's CEO intended to move away from regulated businesses and focus on businesses that would allow the company to generate net income as soon as possible. He did not anticipate (as many others did not anticipate) the potential of cellular. Even though the CEO and other top managers became aware that resource allocation and key premises in the strategic context were leading U S WEST to miss out on opportunities in cellular telephony within the U.S.A., they did not change the rules and premises to avoid this unanticipated outcome. At BellSouth, in contrast, where there was initially great skepticism about the business prospects of cellular telephony at the top management level, financial rules governing resource allocation were less short-term oriented than at U S WEST, and cellular was viewed as complementary to wireline telephony rather than just as one of many potential new business opportunities. The design of corporate context thus determined patterns of escalation (BellSouth) or de-escalaton (U S WEST) of commitment on the part of top management as a result of the iterations of resource allocation. The finding that structural context—in particular the resource allocation rules—was very stable highlights an important constraint on managerial discretion.

Noda and Bower also find evidence of an intraorganizational ecology in which business activities compete for resources. Initial success measured in terms of the resource allocation rules provides momentum. At U S WEST, the strategic context for new business development was less tied to telecommunications businesses than at BellSouth. Top corporate executives found that real estate and financial businesses were initially very successful and generated net income quickly. Incremental learning drove to expand nonwireless businesses (under the impulse of the managers associated with those businesses).

Finally, Noda and Bower's case data confirm that individual managers—'champions'—are important in getting a business initiative going and providing it with momentum. Their data also suggest, however, that once the business is taking shape, it becomes somewhat independent of particular individuals, as new managers replace the original champions. This result demonstrates that the unit of analysis for the B-B process model is the pattern of interlocking managerial activities, rather than the individual managers themselves.

Internal selection and managerial activities

How do selection processes operate within organizations? And what patterns of managerial activities are involved in internal selection? These questions are posed in Burgelman's paper on strategic business exit (SBE). The paper studies the pattern of managerial activities involved in Intel Corporation's strategic business exit from its core business in 1984–85, dynamic random access memory (DRAM), and the redeployment of some associated distinctive competencies in the more profitable erasable programmable read-only memory (EPROM) business and, especially, the microprocessor business. The pattern of managerial activities involved in SBE was identified by using the process model of internal corporate venturing (Burgelman, 1983b) to analyze the behavioral data generated by the SBE study.

At the business level, the combined activities of operational and middle-level managers caused Intel to decline from initial dominance in DRAMs to a losing position. Some middle-level managers who embodied some of the firm's most important distinctive technical competencies deployed these competencies inflexibly, despite the fact that the industry was changing. Other middle-level managers, responding to Intel's resource allocation rules, shifted scarce manufacturing resources away from DRAMs. Operational-level managers tried to reposition Intel as a niche player in DRAMs, in an attempt to respond to internal and external conditions while taking advantage of Intel's distinctive competencies. This unsuccessful effort exacerbated Intel's loss of strategic position and reinforced the internal resource shifting and the concomitant de-escalation of commitment to DRAMs. These activities were intendedly rational, but they responded to incompatible internal and external pressures and so had the unanticipated consequence of setting Intel onto a course to exit from DRAMs.

Burgelman, like Noda and Bower, finds that at the corporate level the context set by top management had strong selective effects on the strategic actions of middle and operational managers at the business level. The resource allocation rules were a strong determinant of what the firm did, regardless of the rhetoric associated with official (or stated) corporate strategy. Like Noda and Bower in the case of U S WEST, Burgelman finds that Intel's top management did not change the resource allocation rules, even though the outcomes regarding DRAMs were not what top managers had in mind when they put the rules in place. The paper also finds that strategic business exit requires the *dissolution* of the strategic context of that business. Strategic context dissolution was found to be a complex process involving the combined but not always deliberately aligned activities of middle and top managers. By documenting the managerial activities involved in strategic context dissolution, the paper provides additional insight into the process of deinstitutionalization and a link between evolutionary and institutional perspectives.

Burgelman's paper shows some of the ways that internal selection may serve as a coordination mechanism. The paper also illustrates the intraorganizational ecology of strategy making, reporting the managerial activities that gradually decreased commitment to DRAMs and increased commitment to microprocessors. It also provides some evidence that strategic change that looks 'punctuated' at the corporate level of analysis may sometimes be the result of more gradual change taking place at lower levels in the organization.

CONCLUSION

Each of the papers in this volume takes an evolutionary perspective, looking at dynamic, path-dependent processes and allowing for variation and selection within or among organizations. Each offers new insights and reveals important empirical findings. Taken collectively, they demonstrate that an evolutionary perspective may allow us to synthesize the many disparate theories now circulating in the field. The key here is that the evolutionary perspective is not inherently in contradiction with most theories of strategic management. Most rationales favored by a particular theory—efficiency, power, market position, distinctive capabilities, or whatever—usually can be understood in evolutionary perspective. In this volume, for instance, Ingram draws on economic rationale; Doz combines ideas from organizational learning theory and structural inertia theory; Singh and Mitchell analyze an asset specificity problem more often thought of as an issue for transaction cost economics; Noda and Bower as well as Burgelman combine ideas about economic incentives with an understanding of structural constraints; Stuart and Podolny use techniques and ideas from role theory in sociology; Carroll *et al.* synthesize ideas about strategic capability with structural inertia theory; Barnett and Hansen combine ideas from organizational learning theory and organizational ecology. What we advocate here is not a singular theory, but an *evolutionary perspective* that potentially can synthesize the many theoretical approaches now proliferating in the strategy field.

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LOCAL SEARCH AND THE EVOLUTION OF TECHNOLOGICAL CAPABILITIES

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The assumption that 'local search' constrains the direction of corporate R&D is central in evolutionary perspectives on technological change and competition. In this paper, we propose a network-analytic approach for identifying the evolution of firms' technological positions. The approach (1) permits graphical and quantitative assessments of the extent to which firms' search behavior is locally bounded, and (2) enables firms to be positioned and grouped according to the similarities in their innovative capabilities. The utility of the proposed framework is demonstrated by an analysis of strategic partnering and the evolution of the technological positions of the 10 largest Japanese semiconductor producers from 1982 to 1992.

INTRODUCTION

A common assumption of evolutionary perspectives on industrial innovation is that 'local search' significantly constrains the direction of corporate R&D (Nelson and Winter, 1973; Dosi, 1988; Teece, 1988; Cohen and Levinthal, 1989). The characterization of search as 'local' or 'problemistic' (Cyert and March, 1963) implies that organizations initiate new R&D projects that share technological content with the outcomes of their prior searches. It seems uncontroversial to assert that the notion of 'local search' is relative: the term *local* presumes a broader context of inventive activity forming the backdrop against which the search behavior of a focal firm can be referenced. However, while the qualifier *local* has meaning only when it is paired with the specification of a broader search context, the literature has yet to provide a generalizable approach for characterizing this technological landscape and the positions of firms within it.

In this paper, we propose a network-analytic methodology to measure the technological landscape that is produced by the simultaneous search activities of a group of high-technology firms. A firm's position or niche in this landscape derives from the overlap of its inventive activities with those of its competitors. In our approach, a firm engages in search when its niche shifts across time periods, and the manifestation of 'localness' is equivalent to the amount of its niche shift. We propose this approach because it enables a systematic assessment of the extent of interfirm, intertemporal, or interindustry differences in the 'localness' of search.

Our primary objective is to illustrate the methodology's capacity to describe changes in firms' technological positions. However, the approach we present is relevant to other areas of research, particularly theories of the resource-based view of the firm and of strategic groups. In our analysis, firms' technological positions derive from one competence that partly shapes their competitive success: the ability to innovate in particular technological subfields. Specifically, we propose a relational construction of technological positions such that firms that have developed portfolios consisting of similar technologies are located near to one another. Assuming that firms' abilities to

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develop technologically similar inventions reveal proximities in their underlying 'innovative capabilities,' then firms' technological positions in this paper reflect their innovative capabilities. Moreover, clusters of firms with adjacent technological positions cohere because their members have similar innovative capabilities, and so they can be seen as strategic groups. In the discussion, we suggest that sociologists' notion of a role lends to our construction of technological positions a theoretical basis and represents a compelling approach to measuring clusters of firms. The benefit of this approach is that sociologists have developed well-established techniques for measuring role equivalencies in a network.

The paper is organized according to the following plan. The first section discusses the literature that elaborates diverse organizational causes of local search. The next section develops the methodology for representing local search within a broader context. The third section discusses a data source, patent citations, which is used to measure firms' technological niches and niche shifts. The fourth section introduces the empirical setting and the sample—the Japanese semiconductor industry during a 15-year period. The fifth section contains the maps of technological positions of the sample members, and it relates position in these maps to the market shares, number of patents, and a measure of the innovativeness of the sampled firms. The sixth section is a discussion that draws parallels between the approach developed in this paper and the resource-based view of the firm. The final section elaborates implications of and extensions to this research.

LOCAL SEARCH IN R&D

The literatures on evolutionary economics, the management of technology and organizational theory, all posit that R&D is history dependent. In other words, organizations search for novel technologies in areas that enable them to build upon their established technological base. This local search results from individual and organizational level processes, as well as from the nature of the firm's innovative capabilities.

At the level of the individual decision maker, bounded rationality engenders local search when organizational members fail to consider the universe of possible applications of R&D funds and, instead, look to the firm's previous development decisions for guidance. The management of R&D involves investment decisions that must be made in the context of uncertain technical, economic, and social environments in which the actions of competitors are particularly difficult to anticipate (MacKenzie, 1992; Tushman and Rosenkopf, 1992). In such ambiguous and uncertain settings, a heavy reliance on historical experience is the norm (March, 1988). In other words, the results of past searches become natural starting points for initiating new searches (Nelson and Winter, 1982).

At the organizational level, local search is produced by the smooth functioning of organizational routines (Cyert and March, 1963; Nelson and Winter, 1982). A routine is defined by Nelson and Winter (1982: 96) to be a pattern of activity that is repeatedly invoked. In Nelson and Winter's schema, routines generate similar organizational responses to frequently encountered stimuli, and are therefore the source of continuity in organizational behaviors. The upshot of this conception of the firm is that organizational behaviors like R&D are delimited by the routines that evolve in a firm. Even when environmental conditions have decreased the attractiveness of a particular activity to a firm in possession of a given skill set, intraorganizational politics and historical precedent can prevent or slow managers from abandoning a particular technical undertaking (Burgelman, 1994).

Another reason that search is likely to be local is that organizations have a higher likelihood of successful technology development in areas in which they have prior experience. Organizational learning is a cumulative activity that is facilitated by concentrating it in areas of prior knowledge accumulation. The competence to innovate in a particular domain follows consistent investments to develop the facilities, personnel, intellectual property, interorganizational relations, and tacit organizational knowledge to successfully innovate in that technological area (Teece, 1988). This means that the knowledge stock a firm has accumulated in a technological subfield conditions its returns to R&D investments in that subfield (Cohen and Levinthal, 1989). Therefore, it is natural to expect that R&D will produce superior results when it is concentrated in the areas of a firm's established competencies.

Historical, case study, and other empirical research provide scattered evidence to support the hypothesis of local search in many technological areas. Even when a major shift in technology strategy is desired, the literature proposes a number of reasons why firms may have a limited ability to make rapid adjustments. Lee and Allen (1982) showed that one firm required a number of years to integrate new technical staff, suggesting that it may take a considerable amount of time for organizations to acquire and assimilate new technological knowledge by augmenting or making substitutions in their staff of technologists. There is also evidence to show that high-tech firms do not capriciously shift the market niches in which they participate. In a study of the semiconductor industry, Boeker (1989) found that entrepreneurial firms typically maintained the strategies that they had at the time of founding. Podolny and Stuart (1995) found that semiconductor technologies in crowded technological areas were the ones most likely to be elaborated in later periods because they were within reach of the search areas of many firms.

The constraint of local search is also implied by conceptual frameworks that have highlighted the difficulties experienced by incumbent firms in adjusting their technology strategies to major environmental changes (Abernathy and Clark, 1985; Tushman and Anderson, 1986; Henderson and Clark, 1990). These studies have discussed and documented the effects of 'competence destroying' technical changes, which are defined as major technological changes that obviate the technical competencies of established firms. A finding of these studies is that when radical technological developments shift the basis of competition, the path-dependent nature of firms' capabilities prevents them from responding quickly. Importantly, such observations do not suggest that there is no variation in a firm's technological developments, but they strongly imply that a firm's technical developments do not follow sudden and unanticipated changes.

This review of the literature has been devoted to establishing the widespread prevalence of the assumption of local search. Nevertheless, it remains the case that the primary empirical evidence to support this assumption comes from in-depth case studies of individual organizations or industries (Abernathy and Clark, 1985; Burgelman, 1994; Helfat, 1994; Rosenberg, 1969; Sahal, 1985). Qualitative studies with the firm as the unit of analysis (e.g., Burgelman, 1994) have documented the history-dependent quality of corporate R&D, while those concentrating on the industry or technical field (e.g., Sahal, 1985) have traced the path-dependent nature of industry- or field-level technical change. Although these studies richly describe organizational learning and technological evolution in specific historical periods, the methodologies that they employ do not lend themselves to a systematic assessment of interfirm, intertemporal, or interindustry variance in the scope of search.[1] Without a generalizable method allowing for such a systematic assessment, it is difficult to (1) identify which members of a group of competitors have been the most locally bounded in the outcomes of their R&D, (2) measure the extent to which the search trajectories of the members of a group of firms converge or diverge over time, or (3) test basic hypotheses of how a firm's technological position at one point in time is contingent on its prior position and search trajectory.

NICHE OVERLAP AND EVOLVING TECHNOLOGICAL POSITIONS

Clearly, the appropriate place to look to assess the degree of path dependence in corporate innovation is the actual technological knowledge created by a firm. In this section, we develop a methodology in which all of the recent inventions of a group of firms serve as a reference point for identifying relative technological shifts of individual members. We propose that companies which shift technological positions relative to their competitors are the ones that have moved the greatest technological distance from the po-

[1] An alternative approach has been to explore the implications of local search in simulation studies (Nelson and Winter, 1982; Winter, 1984). Simulations have typically situated corporate search in the context of an abstract space identified by standard economic variables. such as input coefficient magnitudes (Winter, 1984). This approach entails defining the context of search as a probability distribution that represents a set of input coefficients *in the neighborhood of a firm's current production techniques*. In other words, the terrain over which search takes place is an 'economic space' of input coefficients, and the degree to which localness is built into the model is reflected in the parameters of the search distribution. Given the assumptions of this approach, it is simple to assess interfirm distances and the rate and direction of a firm's movement in 'economic space'.

sitions that they had previously occupied. These are the companies that have deviated from locally circumscribed research.

Our methodology allows each firm to occupy a 'technological niche' that emerges from the distribution of technological antecedents of the firm's current technology developments (Stuart, 1995; Podolny, Stuart and Hannan, 1996). We define the technological overlap between the members of a pair of firms in terms of the extent to which they build on the same foundations for their current inventions. We will use the notation α_{ij} to denote the proportion of firm i's niche that is occupied by another firm j: α_{ij} represents the proportion of inventions built upon by firm i that are also foundations for the inventions of j. Therefore, α_{ij} is bounded by zero and one: at zero, two firms are completely differentiated; at one, j fully occupies i's niche.

For a system of N innovators, complete information about interfirm technological overlaps can be expressed in an asymmetric matrix of order $N \times N$ (McPherson, 1983; Hannan and Freeman, 1989). The elements of this matrix are called 'competition coefficients,' and the matrix itself is known in the literature as a 'community matrix.' The competition coefficients are simply the α_{ij}, α_{ji} for ($j = 1, 2, \ldots, N$; $i = 1, 2, \ldots, N$; $i \neq j$).

Figure 1 depicts a hypothetical technological network including three firms, denoted A, B, and C. The figure includes arrows, which represent technological building relations at the level of the discrete invention. The arrows are directed from the firms to a number of inventions that belong to unidentified actors; each arrow represents the act of building on a discrete invention. For example, four inventions were foundations for A's technologies. In the hypothetical network, α_{AB} is 0.5 because B builds on two of the four inventions that are foundations for the technologies of A.

Figure 1 also illustrates the corresponding community matrix for the three networked firms. The first row of this matrix registers the degree to which each of the companies in the sample occupies the niche of firm A. Thus, B occupies 50 percent and C occupies 75 percent of A's niche. The first column indicates the extent to which firm A occupies the niches of the other members of its network. Thus, A overlaps with 100 percent of B's and 37.5 percent of C's niche. The main diagonal has no significance and so it is set to missing.

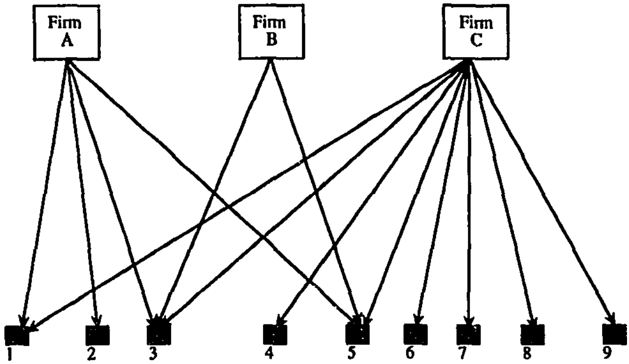
The community matrix will be denoted $\mathbf{A}_{t_m}$. The measure of overlap that we use produces asymmetric competition coefficients in each pair of firms. The elements of the $\mathbf{A}_{t_m}$ matrix for the ijth dyad at time t_m are defined to be:

$$\alpha_{ijt_m} = \frac{\sum_{v=1}^{p} a_{ivt_m} a_{jvt_m}}{\sum_{v=1}^{p} a_{ivt_m}} \quad (1)$$

$$\alpha_{jit_m} = \frac{\sum_{v=1}^{p} a_{ivt_m} a_{jvt_m}}{\sum_{v=1}^{p} a_{jvt_m}} \quad (2)$$

where v denotes a technological antecedent, and p indexes the total number of distinct antecedents that were foundations for the sampled firms at time t_m. The value a_{ivt_m} is coded 1 if antecedent v served as a foundation for the inventions of firm i at time t_m, and 0 otherwise; similarly, a_{jvt_m} is coded 1 if antecedent v is a foundation for the inventive activity of firm i at time and 0 otherwise. Two firms, i and j, produce both an ij and a ji cell in the $\mathbf{A}_{t_m}$ matrix. The ijth cell results from counting the number of common antecedents of i and j's inventions at time t_m and then dividing this sum by the total number of distinct technological precursors of firm i's activity. Similarly, the jith element results from taking the same numerator, but in this case dividing by the total number of antecedents of j's activity. Clearly, the ijth and jith cells in the $\mathbf{A}_{t_m}$ matrix generally will not be equal to one another; although the numerator is common to both cells, the denominator in almost all cases will differ (one exception is if there is no overlap in the antecedents of i and j, in which case both cells equal zero).

Given that the ijth cell represents the degree to which firm j is in firm i's niche, it should be clear that row i specifies the extent to which all other firms are in i's niche, and column i specifies the degree to which firm i is present in the niches of all other firms. (Returning to the hypothetical community matrix of Figure 1, row 1 specifies the occupants of firm A's niche and column 1 registers A's presence in the niches of its alters). Taken together, row i and column i define the



Corresponding Community Matrix:

Firm	A	B	C
A	0	.50	.75
B	1	0	1
C	.375	.25	0

Figure 1. Hypothetical technological network for three firms. The figure illustrates the level of competitive crowding among three hypothetical firms, A, B, and C. In the figure, the objects of the arrows emanating from the firms, the numbered boxes, represent existing inventions. The lines with arrows represent technological building relations. For example, firm B has developed inventions that built on inventions 3 and 5. Firm A's row in the community matrix registers the percentage of its niche filled by B and C. Firm A's column in the matrix is the percentage of the niches of B and C that it occupies

technological position of a focal firm with respect to all other firms at a particular time t_m. In effect, the entries in row and column i define a *global position* for firm i in a $2N - 2$ dimensional space, where N is the number of firms in the community matrix.

This conception of a firm's global position as a function of the proximities of its technological developments to those of the members of a group of competing firms serves as our point of departure for measuring the technological distance between firms in each period of time. In addition, we will use this measure of position to define the extent of a firm's technological movement across time periods. Specifically, we define the distance between i and j at time t_m in terms of the degree to which i and j have a similar pattern of niche overlap with all other firms k. Formally, the (Euclidean) distance between firm i and j for a given time t_m is defined to be:

$$d_{jit_m} \equiv d_{ijt_m} = \left\{ \sum_{k=1}^{n} [(\alpha_{ikt_m} - \alpha_{jkt_m})^2 + (\alpha_{kit_m} - \alpha_{kjt_m})^2] \right\}^{1/2}, k \neq i, j \qquad (3)$$

where the alphas are the (asymmetric) competition coefficients for the ikth and jkth dyads at time t_m. Notice that the distance between firms i and j in Equation 3 is a function of the level of the dissimilarity of their patterns of niche overlap with each of the other $(N - 2)$ firms in the sample. Thus, $(\alpha_{kit_m} - \alpha_{kjt_m})$ is the difference in the extent to which firms i and j occupy the niche of a third firm k, and $(\alpha_{ikt_m} - \alpha_{jkt_m})$ is the difference in the extent to which the niche of k overlaps the niches of i and j.

Similarly, it is possible to quantify the intertemporal shift of firm i's technological niche in terms of the degree to which its pattern of niche overlap changes over time. Formally, we define the shift in firm i's technological niche from time t_l to t_m as:

$$d_{it_l it_m} \equiv d_{it_m it_l} = \left(\frac{n-2}{n-1}\right) \left\{ \sum_{k=1}^{n} [(\alpha_{ikt_l} - \alpha_{ikt_m})^2 + (\alpha_{kit_l} - \alpha_{kit_m})^2] \right\}^{1/2}, k \neq i \quad (4)$$

The expression inside of the sum operator registers the extent to which firm i's niche overlap with the other $(n - 1)$ firms changes between time periods t_l and t_m. The more that the pattern of i's overlap changes between t_l and t_m, the larger will be the summed expression of Equation 4.[2]

Equation 3 represents the distance between different firms within a single time period. Equation 4 yields the amount of a single firm's niche shift across time periods (i.e., the distance between the positions occupied by firm i in period t_l and the same firm in period t_m). Finally, to represent the distance between different firms in different time periods, we construct a symmetric matrix, **D**, where cell it_ljt_m registers the difference in the pattern of overlap between firm i at time t_l and firm j at time t_m. Formally, we define the elements of the matrix **D**:

$$d_{it_l jt_m} \equiv d_{jt_m it_l} = \left(\frac{n-2}{n-1}\right)^{\delta} \left\{ \sum_{k=1}^{n} [(\alpha_{ikt_l} - \alpha_{jkt_m})^2 + (\alpha_{kit_l} - \alpha_{kjt_m})^2] \right\}^{1/2}, k \neq i, j \quad (5)$$

where δ equals 1 if $i = j$ and $l \neq m$, and 0 otherwise. According to Equation 5, the more that firm i's pattern of niche overlap with its competitors in period t_m is similar to firm j's pattern of overlap with its competitors in period t_l, the lower will be the value of cells $d_{it_ljt_m}$, $d_{jt_mit_l}$.

Equation 5 incorporates the specifications of Equations 3 and 4. Specifically, when $\delta = 1$, $t_l \neq t_m$ and $i = j$, Equation 5 reduces to Equation 4, and when $\delta = 0$ and $t_l = t_m$, Equation 5 reduces to Equation 3. Assuming that all firms are present for all time periods, the dimensions of the symmetric **D** matrix are $N * T$ rows by $N * T$ columns, where N is the number of firms and T is the number of time periods. Given the nested equations, Equation 5 identifies a matrix that includes three types of information: (i) the distance between all firms within time periods, (ii) the distance between each firm and *itself* across time periods, and (iii) the distance between different firms across different time periods.

Readers familiar with the social network literature will recognize the Euclidean distances of Equations 3, 4 and 5 as continuous measures of structural equivalence. Structural equivalence is a measure of the extent to which two actors are closely situated in their network because they have similar ties to the other network members. As Burt (1987) observed, the more similar are the relational patterns of two network members, the greater is their structural equivalence and therefore the more that one member could substitute for the other member in its role relations. In effect, our approach defines the context of a focal firm's search by the technological undertakings of competing firms. Search can be considered to be a structural property in that a focal firm's change in position across periods of time can be defined by its niche shift between times t_l and t_m.

Using conventional multidimensional scaling (MDS) routines, it is possible to convert the information in the **D** matrix to a graphical representation of interfirm distances. However, it is first necessary to construct the competition coefficients (the $\mathbf{A}_{t_m}$ matrices) from which technological distances can be derived. To do this, we use the patent citations made by a sample of semiconductor firms.

PATENTS AND TECHNOLOGICAL LINEAGE

Patents identify inventions because they are only granted to products, processes, or designs that are industrially useful and nonobvious to an individual who is knowledgeable in the relevant technical field. An important component of the patent

[2] The sum in Equation 4 is multiplied by $((n - 2)/(n - 1))$ so that the metric is comparable to that in Equation 3. When the Euclidean distance between i and j is measured, the comparison is across $n - 2$ other actors. However, when the Euclidean distance between i at time period t_l and i at t_m is assessed, there are $n - 1$ comparisons. Since there are more comparisons when i is compared to itself across time period, we deflate the distance by $(n - 2)/(n - 1)$ so that the distance that a firm shifts over time is comparable to the distances between firms within a particular time.

application procedure is the 'prior art' provision. In the United States, previous U.S. patents that are identified as technological precursors to the current invention are referred to as 'prior art.' The citation process is legally important because it limits the claims of a pending patent: legal protection is awarded only to the technological claims that are not anticipated by the prior art. A number of scholars have noted that patent citations trace out technological building relationships among inventions (e.g., Jaffe, Trajtenberg and Henderson, 1993).

Given that patent citations identify the technological antecedents of a firm's current inventions, we use patent citations to quantify technological niche overlaps among a community of innovating firms. Recall that α_{ij} was used to represent the extent to which the inventions of firm j shared antecedents with firm i. Because patent citations identify technological building relations, we measure the α_{ij} as the proportion of patents cited by i that are also cited by j. For example, if i cites 100 patents and j cites 50 of those patents, α_{ij} equals 0.5.

SETTING: THE JAPANESE SEMICONDUCTOR INDUSTRY

To illustrate the utility of this methodology for identifying search trajectories, we map the technological positions of the largest firms in the Japanese semiconductor industry. A number of considerations motivated the choice of this setting. First, the semiconductor industry is one that is still very much technology-driven. Semiconductor production involves tremendously complex processes (Langlois *et al.*, 1988), and technical advances have incessantly driven down the price and increased the performance of semiconductor devices throughout the history of the industry. For this reason, R&D expenditures are quite high (routinely exceeding 10% of revenues for many incumbents), and firms' decisions about which technological area(s) to target are critical factors in determining organizational performance. Second, the Japanese industry underwent radical change during the period of the analysis. Our data span the period from 1978 to 1992. Although a few Japanese firms began semiconductor production in the 1950s, they were comparatively minor players in the global marketplace until the late 1970s and early 1980s. Therefore, we observe the evolution of the industry during the interval in which it achieved global prominence. Finally, a number of detailed books on the Japanese industry offer a yardstick against which to compare the results of this analysis.

The sample includes the 10 largest Japanese semiconductor manufacturers: Fujitsu, Hitachi, Matsushita, Mitsubishi, NEC, Oki Electric, Sanyo, Sharp, Sony, and Toshiba. These firms were vertically integrated, and there was substantial overlap among them in their participation in end-use markets. For example, all of these companies produced computers and consumer electronics products, and most had telecommunications operations.

The data for the analysis are the U.S. semiconductor patents held by each of the 10 sampled Japanese producers. The United States is the world's largest technology marketplace, and for this reason non-U.S.-based firms routinely submit patent applications in the United States. Each of the 10 sampled firms are among the largest U.S. patent holders for semiconductor device, design, and process innovations. The semiconductor patents held by these 10 firms were collected for the period from 1978 to 1992, inclusive.[3]

Following the preceding discussion, at a time t_m the matrix of competition coefficients for the network formed by the 10 sampled firms is a 10×10 in which each element registers the extent to which the row firm overlaps with the column firm in its patent citations. One measurement issue encountered in computing the $\mathbf{A}_{t_m}$ matrices is the length of time during which the competition coefficients specified by Equations 1 and 2 are calculated. It is unreasonable to define an organization's technological focus at time t_m only by the inventions that it had patented during the previous year. We therefore chose to create the $\mathbf{A}_{t_m}$ matrices from the patent cocitations made by

[3] Semiconductor patents were retrieved from the Micropatent CD series. This series contains all patents granted in the United States since 1976. When a patent is granted, the patent examiner assigns it to a primary class and subclass. The patent is also typically cross-referenced in a number of other classes. We identified approximately 2400 patent class/subclass combinations that included semiconductor device, design, or process inventions, and we included in the dataset all semiconductor patents held by the sampled firms that were either primary-classed or cross-referenced in any one of these locations. Details of the dataset and a list of the 2400 classes are available from the first author.

the firms in the sample during five-year, moving windows.[4] Our analysis spans the period from 1978 to 1992, inclusive. Using a 5-year window allows us to construct three community matrices—each one derived from nonoverlapping years of data—during the 15-year span of our analysis. Thus, we constructed an $\mathbf{A}_{82}$ matrix that is a 10×10 computed from all of the U.S. semiconductor patents awarded to the sampled firms during the period from 1978 to 1982, inclusive. Similarly, the $\mathbf{A}_{92}$ matrix was generated from the patent cocitations in the sample during the years from 1988 to 1992.

ANALYSIS

Although assessing search trajectories requires that we consider all years simultaneously, we begin by examining each year separately. As Equation 3 specifies, we construct a separate distance matrix, $\mathbf{D}_{t_m}$, for each of the years 1982, 1987, and 1992. The three panels of Figure 2 show the MDS configurations for each of these years. The coordinates for these plots were generated by the MDS procedure in SAS, version 6.09. In all cases, the number of dimensions was set to two, which resulted in reasonably good stress levels.[5]

Evolution of the technological landscape

As anticipated by the arguments about the path-dependent quality of organizational innovation, the figures suggest a significant degree of stability in the relative positions of the firms in the period of analysis. In all three figures, the leading-edge semiconductor producers are located to the east of the less technically advanced firms. The firms with the greatest percentage of their electronics end-use business concentrated in consumer electronics products are positioned toward the west end of the figures. This is clearest in panel C, which suggests a two-tier structure. The generalists and technological leaders in 1992 were Toshiba, Hitachi, NEC, Fujitsu, and Mitsubishi. In panel C of Figure 2, these firms occupy positions that appear to be differentiated from their consumer electronics-oriented competitors.

Although Figure 2 suggests a great degree of stability in the structure of the industry, visual comparisons of the panels of the figure are difficult because absolute locations in each of the panels are meaningless and the range of the axes of the panels differ. Therefore, the apparent interfirm distances are not constant across the three panels. To make intertemporal comparisons, we apply MDS to a pooled distance matrix as specified by Equation 5.

Quantifying the amount of niche shift

The result of the MDS of the pooled distance matrix is shown in Figure 3, which confirms that the pattern of niche overlap in the Japanese semiconductor industry was indeed quite stable. Evidence of stability comes from the fact that the position of a firm at time t_m is generally quite close to its position at times t_{m-5} or t_{m+5}. For example, Sanyo in 1987 is relatively near to Sanyo in 1982 and Sanyo in 1992. It is possible to quantify the amount of movement in a firm's position by assessing the change in its column (or row) of the distance matrices specified by Equation 3 at different points in time. One such measure follows this reasoning: if firm i did not change positions over time, then its distance from other firms will be relatively stable (the ith column in the distance matrices at two points in time will be highly correlated).

Following Burt (1988), we assess the stability of a firm's position across time periods by constructing a firm-specific covariance matrix in which each cell represents the covariance between a firm's vector of distances to its competitors across two time periods (therefore, for 10 firms and three time periods, we construct a total of 10 3×3 covariance matrices). The more similar

[4] We selected 5 years because it is roughly the duration of the product life cycle in the semiconductor industry. For many types of products, five years understates the time interval in which the product is manufactured (e.g., each successive generation of computer memory, 64K, 256K, etc., has been in production for about a decade). However, 5 years may overstate the time period during which a particular product, design, or process is on the leading edge of the technology in the industry (e.g., the next generation of computer memory chip has arrived approximately every 2.5 years).

[5] In MDS, stress is a normalized, residual sum of squares that suggests the degree to which the resultant configuration agrees with the n-dimensional distance matrix. Stress is often known as a 'badness-of-fit' criterion because higher values suggest worse fits. For the figure representing 1982, the badness-of-fit criterion was 0.086 for two dimensions; for 1987, the badness-of-fit criterion was 0.092; and for 1992, the stress level was 0.036. These stress levels are considered fairly good (Kruskal, 1964).

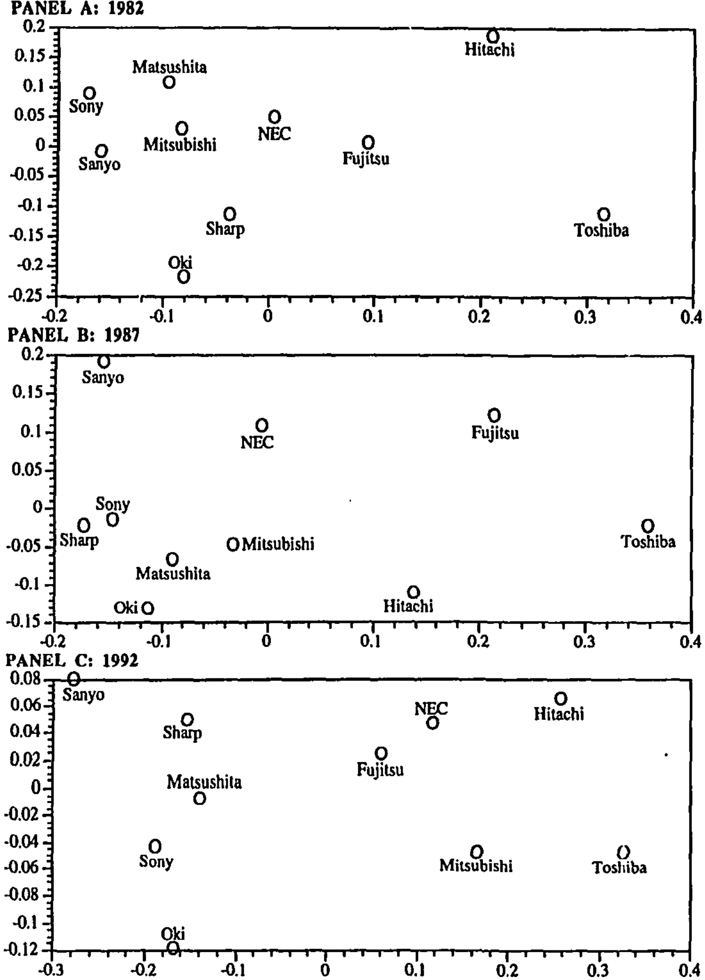


Figure 2. Technological positions of Japanese semiconductor firms

are a firm's distance vectors across all three time periods, the higher is the percentage of variance captured by the first factor of a principal components analysis of each 3 × 3 firm-specific matrix. The results of this analysis are reported in Table 1. The findings show that Toshiba experienced the least movement: 92 percent of the variance in its position vectors for the 3 years is captured by the first principal component. On the other hand, Mitsubishi and Fujitsu were the companies that moved the most: the first principal component captured about 75 percent of the variance in the positions of these two firms. Of all of the sampled firms, Mitsubishi is the only one for which one of the three firm years—1992—had a negative loading on the first principal component. In other words, Mitsubishi moved significantly between 1987 and 1992.

For two reasons, it is remarkable that the pattern of interfirm niche overlap remained so stable during the interval of our study. First, the nature of semiconductor technology is such that a semiconductor device generation change is typically accompanied by significant changes in product

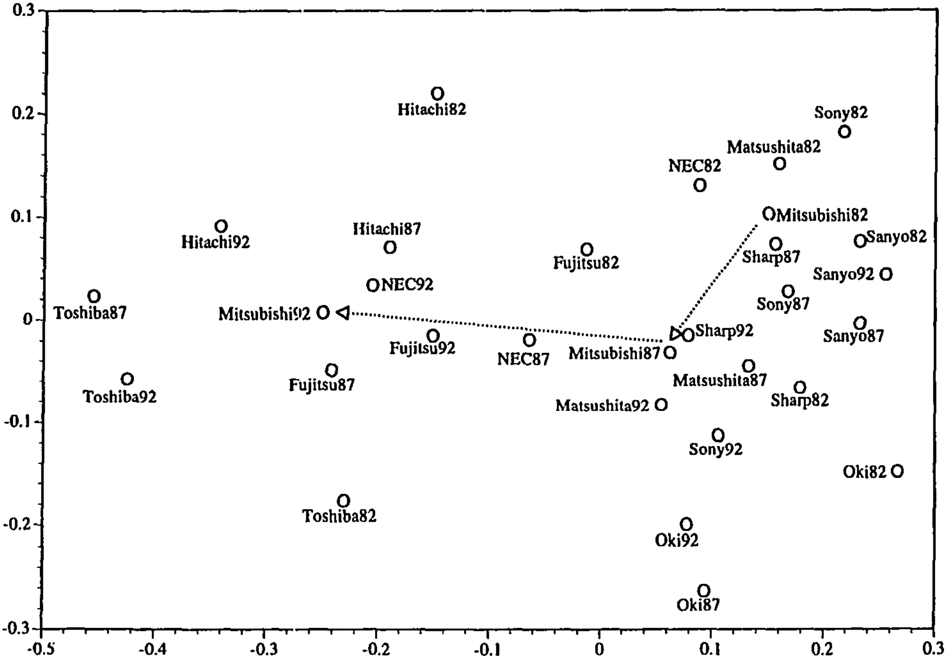


Figure 3. Technological positions of Japanese semiconductor firms: 1982, 1987, and 1992

Table 1. Results from factor analysis to quantify the amount of firms' niche shifts

Firm	Factor 1[a]	Loading: 1982[b]	Loading: 1987[b]	Loading: 1992[b]
Fujitsu	0.75	0.96	0.41	0.79
Hitachi	0.91	0.91	0.88	0.98
Matsushita	0.80	0.95	0.88	0.84
Mitsubishi	0.75	0.95	0.92	−0.70
NEC	0.78	0.93	0.82	0.89
Oki	0.84	0.92	0.90	0.92
Sanyo	0.90	0.97	0.94	0.94
Sharp	0.85	0.94	0.85	0.93
Sony	0.86	0.95	0.94	0.89
Toshiba	0.92	0.98	0.93	0.95

[a]The first factor indicates the stability of firm *i*'s position. The higher the factor, the more correlated are *i*'s distance vectors across time periods.
[b]Factor loadings indicate the extent of a firm's relative movement in a given year.

designs, processes, materials, and manufacturing (it has even been the case that new device generations have required more complex production equipment due to the tighter design rules of more advanced chips). In addition to the fundamental change in the technology from the first year of our data to the last year, we follow the Japanese semiconductor industry during the period when it grew from a comparatively small size to one of global prominence. During the first year of the analysis, the value of their combined production was under $2 billion; by the last year, the 10 sampled firms generated $30.25 billion in semiconductor sales. Despite the dramatic changes in the scope of the sampled firms and in the industry's technology, the pattern of interfirm technological overlap has remained relatively stable.

Interpreting the configurations

The discussion of movement in different directions in Figure 3 begs the question: What are the implications to a firm of being located in different regions of the technology space? Descriptive accounts of the Japanese industry (e.g., Kimura, 1988; Langlois *et al.*, 1988) help to interpret different neighborhoods of the configurations. The semiconductor operations of Matsushita, Sony, Sharp, and Sanyo were catered to their consumer electronics products businesses. Thus, these companies focused on linear integrated circuits and discrete devices, and so it is not surprising to find that they cluster in one neighborhood of the configurations (see Figures 2 and 3). The technological leaders of the sample were NEC, Hitachi, Toshiba, and Fujitsu. These firms were all broad-line semiconductor producers, but they concentrated on complex devices such as logic circuits and MOS memories to support their operations in computing. In Figure 3, these firms appear to be differentiated from the consumer electronics products companies.

Oki and Mitsubishi are interesting cases because they do not fit neatly with the technological leaders or the consumer electronics products firms. Oki manufactured telecommunications equipment and an array of peripheral equipment for data-processing systems and computers. Therefore, its end-use businesses were close to those of NEC. Nevertheless, Oki possessed neither the breadth nor the level of leading-edge technology of NEC, Hitachi, Toshiba, or Fujitsu. For these reasons, Oki occupied a relatively isolated position in the technological structure of the industry: although the foci of its operations paralleled those of the technology leaders, it played a more peripheral role in the evolution of the industry's technology.[6]

Because Mitsubishi was the firm that sold the greatest percentage of its semiconductor production on the merchant market (according to Kimura, 1988, Mitsubishi consumed only 30% of its semiconductor production in the mid-1980s), its semiconductor focus was not as strongly tied to its production of electronic end-use systems. During the 1970s, Mitsubishi focused on discrete devices and integrated circuits for consumer electronics products. However, following a strategic assessment near the end of the decade, Mitsubishi targeted semiconductors for computer and industrial applications and it augmented its capital and R&D expenditures (Langlois *et al.*, 1988). Around this time, Mitsubishi moved into the DRAM market, developed complementary MOS technology, and began to second source Intel's microprocessors. Figure 3 suggests that the company succeeded in its strategy. Mitsubishi was the single company to exit the group of consumer electronics products firms and join the technological leaders. In Figure 3, the trajectory of Mitsubishi's position shift is highlighted by the arrows that display its movement between each of the time periods.

It is a simple extension of the methodology that we propose to generate 'egocentric' representations of each firm's position. Figure 4 illustrates egocentric perspectives of Mitsubishi's position for each of the three time periods. To generate this figure, we constructed three 9×9 matrices for the years 1982, 1987, and 1992. The 'space' that these matrices represent spans only Mitsubishi's patent citations. In other words, the configurations are representations of how the nine other firms in the sample are distributed through the areas of Mitsubishi's inventive activities in each of these years. In the data matrices for Figure 4, the distance between the firms comprising any particular dyad (e.g., Sharp and Matsushita) is a function of the level of cocitations among those two firms, subject to the limitation that the cocitation must have been of a patent that was also cited by Mitsubishi. Clusters in the panels of Figure 4 represent concentrations of firms that overlap with Mitsubishi's niche in a similar fashion (e.g., they overlap with Mitsubishi in similar technological areas).

The successive panels in Figure 4 illustrate the significant amount of change in Mitsubishi's relative position. In the first panel (1982), NEC, Oki and Sony are isolates: they have no overlap

[6] For this reason, Oki appears to be less of an isolate in MDSs of a correlation matrix (instead of a Euclidean distance matrix) because correlations eliminate scale effects (i.e., the correlation between the elements of two firms' rows and columns of the community matrix does not reflect differences in their means). However, we believe that it is undesirable to generate the configurations from correlation matrices because scale is an important attribute of firms' positions.

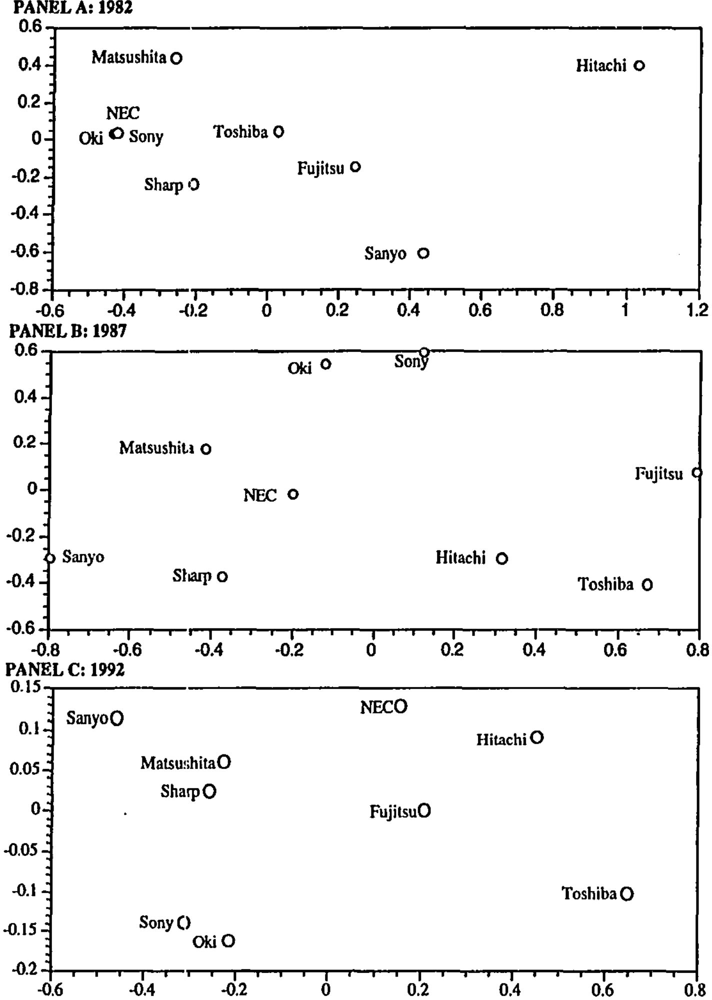


Figure 4. Competitors in Mitsubishi's technological space: 1982, 1987, 1992

at all with Mitsubishi, and so they cluster in the figure. All of the other firms have some overlap with Mitsubishi, but by and large they do not form any discernible pattern based on firm characteristics. By the time of the second panel (1987), all of the nine companies have some overlap with Mitsubishi, so there are no longer any isolates. However, there are still no salient competitive groupings and companies are relatively dispersed in the space. In contrast, in the configuration for 1992 the consumer electronics/broad-line producer distinction is evident along the east–west axis in panel C of Figure 4. By 1992 the egocentric snapshot of Mitsubishi's position reveals two general groupings of competitors: on one side are the consumer electronics products-focused firms (Sanyo, Sharp, Sony, Oki and Matsushita) and on the other are the broad-line producers (NEC, Hitachi, Toshiba, and Fujitsu).

Returning to the 3-year configuration represented in Figure 3, it is possible to draw axes

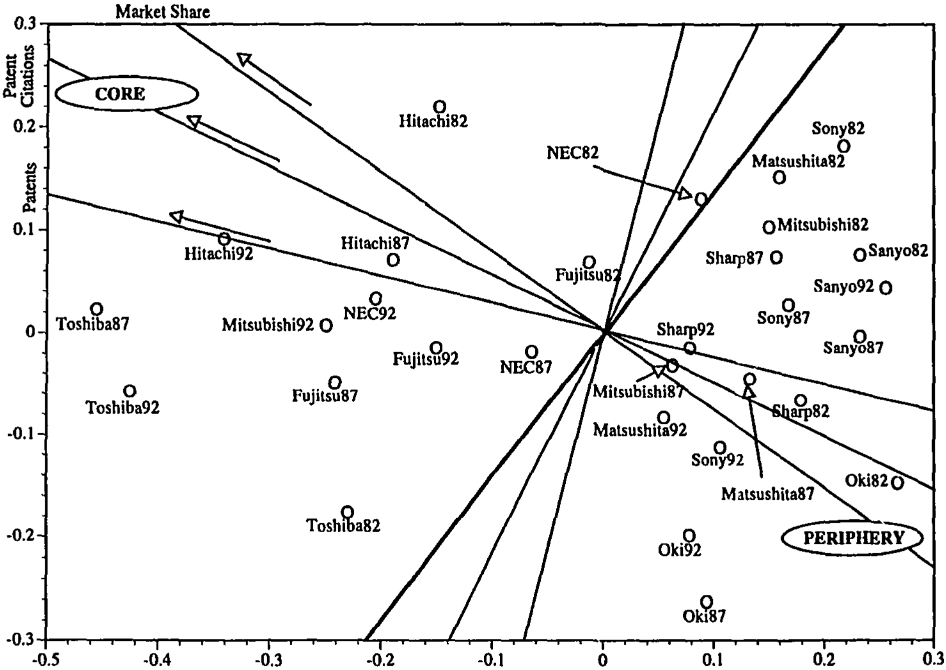


Figure 5. 'Regions' in the technological map of the industry

through the figure that associate characteristics of the firms with their positions in the configuration. Specifically, directions in an MDS configuration can be interpreted by regressing variables over the coordinates of the configuration. Figure 5 adds to three regressions over the coordinates; one is for patents, a second is for market share, and a third is for patent citations.[7] Precisely, the following three regressions were estimated:

$$\text{Share}_{it_m} = \beta_1 \cdot \text{Dim1}_{it_m} + \beta_2 \cdot \text{Dim2}_{it_m}$$

$$\text{Patents}_{it_m} = \beta_1 \cdot \text{Dim1}_{it_m} + \beta_2 \cdot \text{Dim2}_{it_m}$$

$$\text{Citations}_{it_m} = \beta_1 \cdot \text{Dim1}_{it_m} + \beta_2 \cdot \text{Dim2}_{it_m}$$

where Dim1 and Dim2 are the MDS coordinates of firm i at time t_m. All three regressions had significant F-values and high coefficients of multiple correlation.

The regression analysis corroborates that the firms with the largest number of patents, the highest market share, and the most technologically important inventions are located in the western half of the configuration, angled slightly toward the north. The proportion of all patents received by the firm is the axis with the gentlest slope relative to the horizontal plane; the proportion of patent citations received by a firm is the adjacent axis; and market share is the steepest axis. Bisecting each of the regression lines with a perpendicular divides the configuration into halves. We use this technique to bifurcate the competitive space into two regions, which are quite consistent with the descriptive accounts that distinguish the technological leaders from the consumer electronics products firms. The 'core'

[7] The number of citations received by a patent is a commonly employed measure of the commercial and technical importance of that innovation (Albert *et al.*, 1991). Therefore, the frequency at which a firm's patent portfolio is cited is a combined (i.e., summed) indicator of the importance of its individual inventions. All of these variables (sales, patent cites, and total patents) are measured as proportions to prevent escalation in their values simply as a function of time. Thus, sales are included as market share, patents as the proportion of all patents awarded to a focal firm, and cites as the proportion of all citations that are received by the patent portfolio to a focal firm.

segment is the one that includes the most innovative firms and those with the largest market share. We delineate the two-tiered structure by the bold-faced line in Figure 5 (the market share axis)—this line segments the industry such that the firms with the highest market share are northwest of the bold-faced market share axis.

Strategic positions and interfirm alliances

A number of scholars have suggested that the competitive position occupied by a firm influences its strategic behavior. Specifically in the domain of technology strategy, Kimura (1989) argued that technological position may explain variation across firms in their foreign direct investment activities. Eisenhardt and Schoonhoven (1996) and Shan (1990) hypothesized that the technological position of firms affects their incentives and propensities to engage in interfirm strategic alliances.

We briefly consider the relationship between competitive position and alliance behavior. During the period of the analysis, an exhaustive literature search uncovered 35 alliances involving some type of technology exchange among the semiconductor operations of the firms in the sample.[8] In Figure 6 we illustrate the pattern of alliances as it relates to the technological positions of the sampled firms. In the figure, the positions of two firms in 1982 were connected with a line if they formed an alliance during the period from 1982 to 1986 (e.g., NEC82 and Oki82). Similarly, two firms in 1987 were linked if they established an alliance between 1987 and 1991 (e.g., Toshiba87 and Hitachi87). Companies that formed a partnership in 1992 were connected for that year, the last year for which we possess this data. Bold lines join firms that engaged in two or more alliances during a time period.

A number of findings emerge from Figure 6. First, it is remarkable the degree to which the 'core' firms—NEC, Fujitsu, Hitachi, and Toshiba—are central in the alliance network. In total, 31 of the 35 partnerships involved one (or two) of those firms. In other words, the pattern of ties is nearly exclusively core-to-core or core-to-periphery. Moreover, each of the four alliances among the noncore firms included Mitsubishi in 1987. This was the year just prior to the time that Mitsubishi moved into the region of the configuration occupied by the core producers. A related observation about the pattern of intercorporate alliances is that NEC in 1982 and Mitsubishi in 1987, two firm-years that were near the core–periphery border, were particularly active participants in the alliance network. These two firms participated in the greatest number of partnerships among all of the sampled firms in all three years.

Clearly, there is a relationship between position in the configuration of Figure 6 and the decision of a firm to participate in the alliance network. In addition to the fact that alliances appear to bridge the core–periphery border or to join core firms, change in position has a clear relationship to active participation in the recorded technology-exchange and technology-development alliances. For the first period, the correlation between the number of alliances formed by a company and the amount it moved from 1982 to 1987 is 0.13 (not significant). However, for the period from 1987 to 1992, this correlation is 0.71 and statistically significant.[9] The high magnitude of this correlation suggests a positive association between the propensity of a firm to form alliances and the degree to which it innovates in technological fields that are not directly related to those in which it has developed technologies in the past (Stuart, 1995, presents more systematic evidence of this). The decision to branch out from a firm's existing fields of innovation is the most likely source of its movement in the configurations.

DISCUSSION: TECHNOLOGICAL POSITIONS, INNOVATIVE CAPABILITIES, AND STRATEGIC GROUPS

The core imagery that underlies this work is the conception of the technological base of an indus-

[8] We coded patent license and cross-license, second source, joint ventures, joint product development, and technology exchange agreements for this analysis.

[9] In a comprehensive data base on strategic technology alliances, Hagedoorn (1993) reported that the Mitsubishi Group had the highest total number of technology partnerships among all firms worldwide. Hagedoorn found that Mitsubishi formed 157 alliances in the 1980–84 period, and 293 alliances in the 1985–89 period. Hitachi and Toshiba were also among the world's 10 most frequent technology partners.

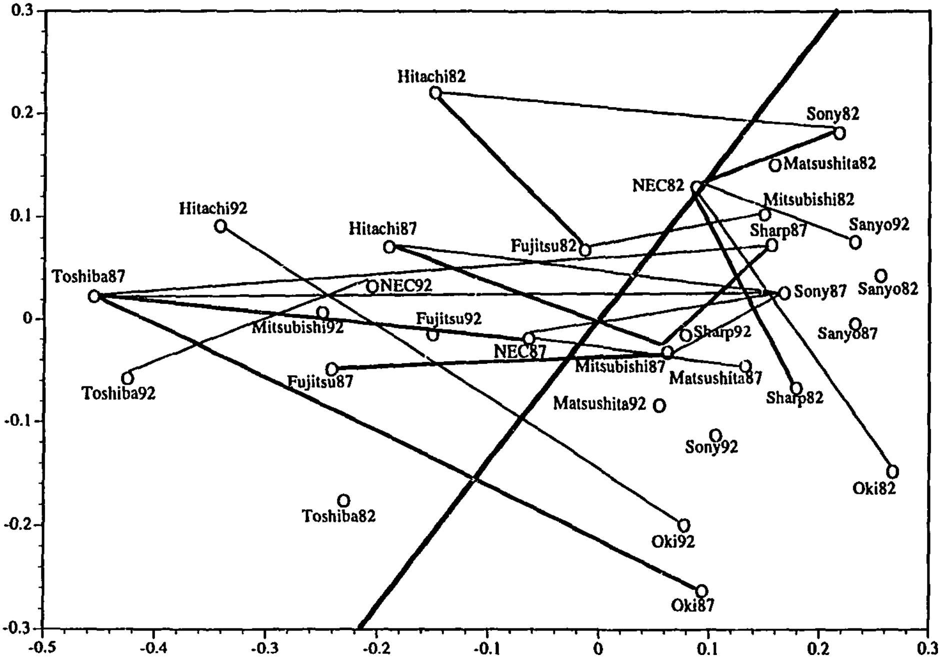


Figure 6. Technological positions of Japanese semiconductor firms and strategic alliances: 1982, 1987, and 1992

try as an evolving network. Discrete inventions, which for the most part belong to corporate innovators, form the nodes of this network. Technological commonalities among the inventions in the network are the ties that connect nodes. In an ongoing research program, we suggest that patents and patent citations can be used to represent this expanding 'technological network' for a select number of high-technology industries (Stuart, 1995; Podolny and Stuart, 1995). Collecting all patents in particular technological areas and aggregating firms' inventions allows the computation of network-theoretic attributes of firm-level positions in this technological network. Like the measures and methods used in this study, ideas and techniques in the network literature lend theoretical insights to the computation and behavioral implications of different attributes of firms' technological positions.

In the analysis of this paper, the proximity of two firms' positions depends upon the degree to which they are structural equivalents. Two actors who are perfect structural equivalents are also assumed to perform the same role in the relational structure in which equivalence is measured (i.e., they are role equivalents). Generalizing this insight to the empirical context of this article, two firms that occupy structurally equivalent positions in the technological network do so because they perform similar roles as innovators. Two such firms would appear very near to one another in the positional maps of this paper. In principle, they could substitute for one another in their innovative roles.

Assume that the ability to develop the inventions that form the basis for a particular innovative role rests on the incumbent's accumulation of difficult-to-imitate innovative skills. This is not a Herculean assumption: following the discussion of the broad literature that characterizes innovation as a path-dependent process, it is quite plausible that firms' positions derive from skills that are in fact quite difficult for competitors to replicate quickly. Moreover, it is also the case that a well-honed innovative capability can be an extremely valuable resource to high-technology firms. In this case, the configurations of firms can be viewed as maps of innovative capabilities.

We believe that the analysis in this paper has an obvious link to the resource-based view of the firm: the configurations of Figures 1–6 represent one approach to positioning firms on the basis of inimitable, valuable resources that are potential sources of sustainable competitive advantage.

In addition, the analyses of this paper are pertinent to the literature on strategic groups. If positions cohere because the firms that hold them perform similar innovative roles, then clusters of firms can be viewed as grouping based on similar innovative capabilities. To date, scholars have usually identified intraindustry group structure by categorizing firms according to their product market positions, or else by general descriptors of their corporate strategy. However, as a number of scholars have suggested (McGee and Thomas, 1986; Dierickx and Cool, 1989; Barney, 1991), one point of contact between the resource-based view of the firm and work on strategic groups is to define intergroup mobility barriers in terms of heterogeneities among groups of firms in their possession of strategically valuable resources.

The findings of this paper do suggest that mobility barriers segregate technological positions. Furthermore, as other researchers have argued, the technological areas targeted by a firm's inventions in large measure circumscribe the expertise that it develops in manufacturing, marketing, and other core business functions (Teece, 1988). It is therefore compelling to use similarity of technological position as a basis for identifying groups whose capabilities are not easily imitated.[10] To identify groups in the square matrices of interfirm technical proximity scores (the community matrices), one would apply a hierarchical clustering algorithm to partition the sample members.

[10] It is important to note that intergroup mobility barriers may be asymmetric, even when firms' group affiliations are determined by their innovative capabilities. For example, hierarchical cluster analyses suggest that the firms in the region labeled 'CORE' in Figure 5 comprise one group, and those in the region labeled 'PERIPHERY' form a second group. The actual technological areas that comprise the basis of the inventive activities of the 'PERIPHERY' firms (e.g., linear ICs and discrete devices) are less complex than those that are the focus of the 'CORE' producers (e.g., optoelectronics and MPUs). In fact, most of the core firms produce linear ICs and discrete devices, in addition to more complex devices. Therefore, mobility barriers are asymmetric: it would be easier for the core firms to move into the periphery region than vice versa.

CONCLUSION: DIRECTIONS FOR FUTURE RESEARCH

The objective of this paper has been to develop a generalizable methodology for quantifying the evolution of firms' technological positions. Our approach conceptualizes the context of search in terms of the actual technologies developed by a sample of innovators, and the outcome of search in terms of its impact on firms' technological positions. From our perspective, an important and underemphasized component of the dynamics of technological change is that firms do not search in isolation; rather, they search as members of a population of simultaneously searching organizations. The methodology that we have suggested in this paper implicitly recognizes that a firm may come to occupy a differentiated technological niche not necessarily as the result of its own R&D, but as the result of the R&D of its competitors. In effect, a firm's position depends as much on the trajectories adopted by other firms as it does on its own trajectory.

A contribution of this research is that it offers a systematic conception of the context of search. The absence of such a method is surprising, particularly considering that the characterization of the search process is an essential step in the construction of evolutionary models of industry dynamics (Nelson and Winter, 1982; Winter, 1984). A direct consequence of the lack of a generalizable approach has been the inability to empirically test the basic assumption of local search in a convincing manner. For example, there have been no empirical tests of the Markovian assumption that the innovative direction of a company at period t_{m+1} depends critically on the state that it occupied at period t_m, but not on its prior history (Nelson and Winter, 1982). Additionally, it has been difficult to understand how the search environment and the history of search explain current technological positions and constrain future shifts in innovative directions.

An important influence on the findings of this study was the choice of setting—the semiconductor industry. Semiconductor technology is known to be cumulative, and because of its great complexity the technology is notably domain-specific. With few exceptions, the fact that a firm excels at innovating or producing in one market niche does not imply a similar expertise in a different niche. With the proposed methodology, however, it would be possible to make intersample comparisons. Because the community matrices contain information on the global positions of all of the members of a system, metrics of the stability of the community matrices are comparable across systems of the same size. For example, it would be possible to compare the 10 largest Japanese firms to the 10 largest U.S. firms during the same interval of time to determine which group experienced the most change. It would also be possible to compare, for instance, the community matrices representing the 50 largest semiconductor firms to those representing the 50 largest pharmaceutical firms during the same time period. An analysis like this could assess the degree to which 'localness' characterizes the search trajectories of firms in different industries. A prior expectation would be that semiconductor firms are substantially more locally bounded in their innovation than pharmaceuticals because semiconductor technologies are more cumulative than are drug discovery techniques.

Innovation can be considered to encompass a broad array of technical and commercial functions, ranging from basic R&D to marketing. Our concern with firm trajectories in knowledge creation has led to our focus on the invention-generating stages of the innovation claim. However, we believe that the methodology that we have presented can be generalized to other stages of the innovation chain. For example, there exist several data sources that provide information on firms' participation in different product market niches in the semiconductor industry. Using such information and distance metrics like those employed in this paper, it is straightforward to measure the distance between firms in product space, just as we have measured the distance between firms in technology space. With this additional information, it would be possible to map evolving market positions and to explore the relationship between market and technological positions.

One of the most suggestive findings of the analysis is that Mitsubishi's movement into the 'technological core' was preceded by alliances with firms in that position. This association suggests the possibility that considerable shifts in technological position are facilitated by efforts to assimilate the technological developments of the firms in the areas to which a firm seeks to move. Alliances and acquisitions represent possible strategies to bring about significant shifts in technological focus. One possible direction for future research would be to more systematically investigate the effect of alliance strategies and other strategic undertakings on the amount and direction of firms' search. In effect, one could investigate the impact of alliances or acquisitions on the distance of a firm's movement as specified by Equation 4. Similarly, it would be a simple extension of this research to model the effects of organizational characteristics—such as age or size—on the stability of a firm's technological position. The central question guiding this type of analysis would be: How do variables that proxy for the institutionalization of organizational routines affect the degree of inertia in the direction of firms' innovation?

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