A R T I C L E S

Contextuality Within Activity Systems and Sustainability of Competitive Advantage

by Michael Porter and Nicolaj Siggelkow

Executive Overview

Research on the interactions among activities in firms and the extent to which these interactions help create and sustain competitive advantage has rapidly expanded in recent years. In this research, the two most common approaches have been the complementarity framework, as developed by Milgrom and Roberts (1990), and the NK-model (Kauffman, 1993) for simulation studies. This paper provides an introduction to these approaches, summarizes key results, and points to an aspect of interactions that has not found much attention because neither of the two approaches is well-suited to address it: contextual interactions, i.e., interactions that are influenced by other activity choices made by a firm. We provide a number of examples of contextual interactions drawn from in-depth studies of individual firms and outline suggestions for future research.

The importance of fit and consistency among a firm's activities[1] is one of strategy's most long-standing notions (Drazin & Van de Ven, 1985; Khandwalla, 1973; Learned, Christensen, Andrews, & Guth, 1961). While earlier work stressed the consistency among higher level concepts such as "strategy" and "structure" (Chandler, 1962), more recent work has emphasized interdependencies at a lower level, among the various activities a firm is engaged in (Milgrom & Roberts, 1990; Porter, 1996).

Consider the example of Urban Outfitters, a $1.1 billion specialty retail store chain whose sales and profits have been growing at about 30% a year for the last 15 years. It has adopted a set of activities and practices that are highly interdependent and quite distinctive (Bhakta et al., 2006). Its stores create a bazaar-like ambience with eclectic and nonstandardized merchandise, including clothes and home accessories, and the assortment in each store is broad but shallow, underscoring the atmosphere. Each store has a unique design; some occupy buildings previously used as movie theaters, banks, or stock exchanges. Store managers have considerable authority to, for instance, change the store layout, or to experiment with the music being played. Strengthening this shopping experience is a substantial investment of 2% to 3% of annual revenue into visual display teams who change the layout of each store every two weeks, creating a new shopping experience whenever customers return. As a result, customers spend considerably more time in Urban Outfitters stores than in other specialty stores (three to four

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[1] An activity is a discrete economic process within the firm, such as delivering finished products to customers or training employees, that can be configured in a variety of ways (Porter, 1985).

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times as much). To finance this investment, the company shuns traditional forms of advertising such as print, radio, and television.

Urban Outfitters' choices are clearly interdependent. For instance, the unique real estate plays well with the nonstandardized merchandise mix; both in turn make it more beneficial to grant more authority to store managers, as standardized approaches are unlikely to work well. Similarly, frequent changes in store layout are particularly beneficial given the quick turnover of merchandise. Lastly, Urban Outfitters can afford not to use traditional media outlets given the substantial word of mouth its unusual stores generate.

While such interdependencies among a firm's activities are widespread, the strategy field has struggled for many years to find a structured way to analyze the consequences of such interactions. Two fairly recent advances have made it possible to more systematically analyze the strategic and organizational implications of interdependencies among a firm's activities. One is agent-based simulation modeling using the NK model (Kauffman, 1993); the other is the complementarity framework developed by Milgrom and Roberts (1990). In this paper, we provide an introduction to each of these approaches, summarize a range of research findings that have emerged from them, and discuss an important feature of interdependencies among activities that neither approach is well-suited to address.

Both approaches have focused on the *contextuality of activities*—the fact that the value of individual activities is influenced by other activity choices made by a firm (i.e., Urban Outfitters' choice to create a bazaar-like setting influenced its inventory levels and affected its decision to shun traditional advertising).

Using large samples of firms, the empirical work based on the complementarity framework has concentrated on identifying precisely which activities affect each other in many firms, i.e., on understanding where contextual activities tend to arise. The agent-based simulation work has focused on analyzing the consequences that arise as contextuality of activities (i.e., the number of interdependencies among activities) increases.

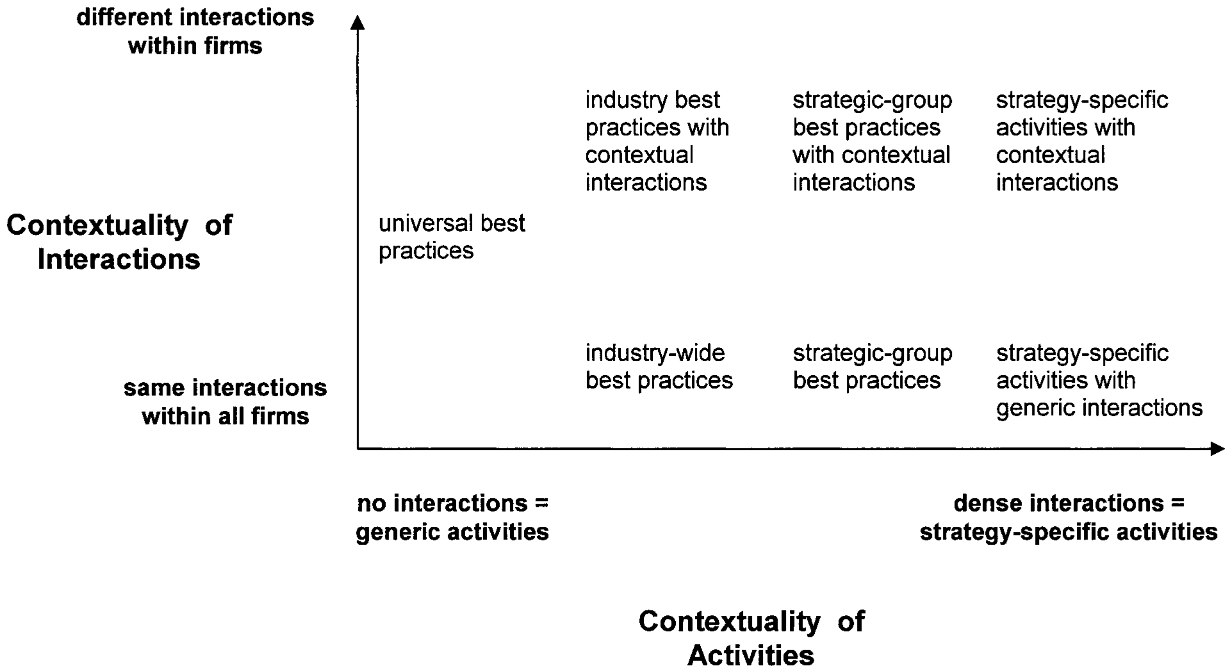
While contextuality of activities is an important phenomenon, our research conducted at the firm level suggests that a second type of contextuality is important to further our understanding of the sustainability of competitive advantage: the *contextuality of interactions*. Whether and how activities interact—for instance, whether they are complements and reinforce each other, or whether they are substitutes[2]—can also depend on other activity choices made by a firm. Thus, the nature of the interaction among activities may not be an inherent property of the activities, but a function of the other choices made by a firm.

As an example, consider a firm such as the Gap that operates a distribution system linking warehouses and stores. Assume that the firm's ordering system is configured to allow stores to order goods once a week. In this case, the benefit of increasing delivery frequency of ordered goods from weekly to daily is quite low (i.e., if the ordering system allows buyers to order goods only once a week, there is little value in daily deliveries). If stores were to order daily, though, the benefit of increasing the delivery frequency from once a week to daily would be higher. Thus, the marginal benefit of increasing the ordering frequency increases as the delivery frequency increases, that is, ordering frequency and delivery frequency are complementary. However, this complementarity is contextual to the firm's in-store information system. It exists only if the firm has relevant information needed for ordering on a daily basis, for instance through a point-of-sales (POS) system that tracks items sold in real time. It is the presence of the POS system that makes the relationship complementary. (Without a POS system, the two activities are not complementary.)

The rest of this paper is organized as follows. In the next section, we provide more detail on contextuality of activities. We continue with an overview of existing work that has focused on contextuality of activities based on the NK simulation model and with empirical investigations that were grounded in the complementarity framework. In the subsequent section, we show several ways in which contextual interactions can arise and pro-

[2] Two activities are complements if the presence of one activity increases the marginal benefit of the other, and substitutes if the presence of one decreases the marginal benefit of the other.

Figure 1
Activity/Interaction Typology



vide examples of contextual interactions drawn from detailed firm-level analyses. Finally, we discuss the effect of contextuality on the difficulty of imitation and adaptation and explore the implications of contextuality for research using simulations and for empirical investigations.

Contextuality of Activities

One way to classify activities is by the degree to which their value is affected by other activities, i.e., the extent to which they interact. Accordingly, activities can be arrayed along a continuum of increasing interdependence (see the horizontal dimension in Figure 1). At one extreme (low interdependence) lie activities that are not affected by any other activity choices. Since their value is context independent, these activities have the same optimal configuration for all firms in the economy. In other words, they are *generic*. For instance, the use of computers for accounting is an optimal activity choice for (practically) all firms in the economy.[3]

At the other extreme (high interdependence) are activities whose value is affected by many other firm choices; consequently, they have firm- or strategy-specific optimal configurations.[4] For instance, the U.S. mutual fund provider Vanguard configured its employee incentive system so that pay was based on the extent of cost savings for fund shareholders. This configuration was particularly beneficial to Vanguard given many of Vanguard's other choices, such as its organizational structure in which fund shareholders were also the owners of the asset management company, its emphasis on funds for which low costs were competitively important such as index funds, and its culture of keeping costs low in all of its operations (Siggelkow, 2002a). Between these two extremes lie activities that have generically optimal configurations within particular industries, or that are specific to a particular strategic group within an industry (Caves & Porter, 1977; Hatten & Schendel, 1977).

Generic activities are not unimportant—quite the contrary. They set the bar for competition. A

[3] Even at the extreme end of genericity one can have gradations. For instance, the use of computers presumes some computer literacy of employees in the accounting department of a firm. For some parts of the world this assumption may not hold, making the use of computers in those areas not a generic activity.

[4] We use the term *strategy* here as a shorthand for *many other activity choices a firm has taken*. Strategy by itself is not a special activity, but it arises from the set of activities a firm has put in place.

firm that does not attain parity on such activities is at a competitive disadvantage. Yet, at the same time, since these activities are beneficial for all firms, other firms have a high incentive to pursue such activities as well. As a result, firms are unlikely to attain a sustainable competitive advantage from these activities. Competitive advantage is more likely to be sustainable if it arises from activities that have more than one optimal configuration, i.e., from strategy-specific activities. Since these activities are more beneficial to the firm than they are to its rivals, incentives for imitation are muted (and more difficult, as we will argue in more depth below). In addition, contextual activities can lead to different strategic positionings within an industry. Consider the following two examples:

In the wine industry, Robert Mondavi and E. & J. Gallo compete successfully with very different systems of activities. Mondavi, the leading premium wine producer, produces high-quality wine with premium grapes, many grown in its own vineyards. Grapes sourced from outside growers are purchased under long-term contracts from suppliers with whom the company has deep relationships, sharing knowledge and technology extensively. Grapes are handled with great care in Mondavi's sophisticated production process, which involves extensive use of hand methods and batch technologies. Wine is fermented in redwood casks and extensively aged in small oak barrels. Mondavi makes heavy use of wine tastings, public relations, and wine tours in marketing relative to media advertising.

Gallo, in contrast, produces large volumes of popularly priced wine using highly automated production methods. The company purchases the majority of its grapes from outside growers via arm's-length relationships and is also a major importer of bulk wine for use in blending. Gallo's production facilities look more like oil refineries than wineries. Bulk aging takes place in stainless-steel tank farms. Gallo spends heavily on media advertising and is the leading advertiser among California wineries. In sum, Mondavi and Gallo have chosen very different systems of contextual activities—activities that fit together and reflect the firms' different positionings.

A second example of different activity sets within the same industry can be found in the automobile insurance industry. There are two broad types of insurance providers: those serving standard (low-risk) drivers, such as State Farm, and those serving to a considerable degree nonstandard (high-risk) drivers, such as Progressive Corporation. As a consequence of their different target customers, these companies have pursued two different systems of activity configurations. Specifically, we look at how the firms differ in terms of settling customer claims. The activity design followed by most standard insurers is to investigate and settle claims deliberately in order to hold down costs and earn further returns on the invested premium. Most standard auto insurers (including State Farm) register operating losses in their insurance business, i.e., claims and operating expenses exceed premiums, and profitability depends on the returns earned on the float before claims are settled.

A different set of interdependent activities, put into practice by Progressive, revolves around paying as quickly as possible. Progressive makes personal contact with more than 75% of claimants within 24 hours and settles more than 55% of all claims within seven days. In many cases, a Progressive adjuster will come to the accident scene and issue a check on the spot. The rationale behind this choice is to reduce the number of lawsuits, which tend to escalate costs but do not ultimately benefit the insured.[5] Many other activities influence the time between an accident and the final issuing of a check. Activity configurations that lead to quicker responses include educating customers to call an 800 number right after an accident, staffing the telephone support system, equipping adjusters with vans and having them on call around the clock, extensively training adjusters and allowing them to write a check on the scene, contacting policyholders very quickly after accidents, and improving back-office processes that allow rapid settlement.

While both approaches to claims settlement

[5] A study conducted by the independent Insurance Research Council showed that after paying lawyer fees, policyholders who hire an attorney end up with less compensation on average than those who do not involve a lawyer (Fierman, 1995).

represent coherent sets of interdependent activities, the profitability of each approach depends on the type of customers served. For Progressive, which concentrates on nonstandard customers who are more likely to be involved in an accident and who generally choose only the lowest coverage levels required by law, a fast settlement process is optimal because the margin for error by adjusters is limited. Moreover, facing less competition to insure high-risk drivers, Progressive can earn operating income on the underwriting and is thus less dependent on the float to become profitable. In contrast, for standard insurers, whose customers choose much larger coverages, this response approach tends not to be optimal.

In sum, the value of individual activities can be dependent on the configuration of other activity choices of a firm; the benefit of activities is contextual. While some activities might be generically beneficial, and thereby form the competitive bedrock of an industry, strategy-specific activities allow firms to create and implement different strategic positionings in the market.

To gain a better understanding of how interactions among activities—i.e., the presence of strategy-specific activities—can create a number of different positionings, the framework of performance landscapes is very helpful (Kauffman, 1993; Levinthal, 1997; Wright, 1931). To illustrate the idea of a performance landscape, consider a simple world in which a firm needs only to make a decision of how much to invest in two activities, A and B. For instance, a firm might invest very much in both A and B, or very little in A and a medium amount in B, etc. On a horizontal plane with two axes, we could capture these choices by plotting along the x-axis the degree of investment in A and along the y-axis the degree of investment in B. Since in our simple world the firm can engage in only two activities, the firm's performance is determined by these two investments. Thus, for every combination of investments there arises a particular performance for the firm. This performance is dependent on all factors that affect the value of an activity configuration, such as customer preferences, available technologies, and competitors' current positionings. For each combination of investments in A and B, we now plot the ensuing performance on the vertical z-axis. This procedure creates a performance landscape, i.e., a mapping from activity configurations onto performance values (see Figure 2a). Conceptually, the idea of a performance landscape can easily be extended to more than two choice dimensions (A, B, C, D, . . .), collectively leading to a performance outcome for a firm. For illustrative purposes, we will continue, however, with two dimensions.

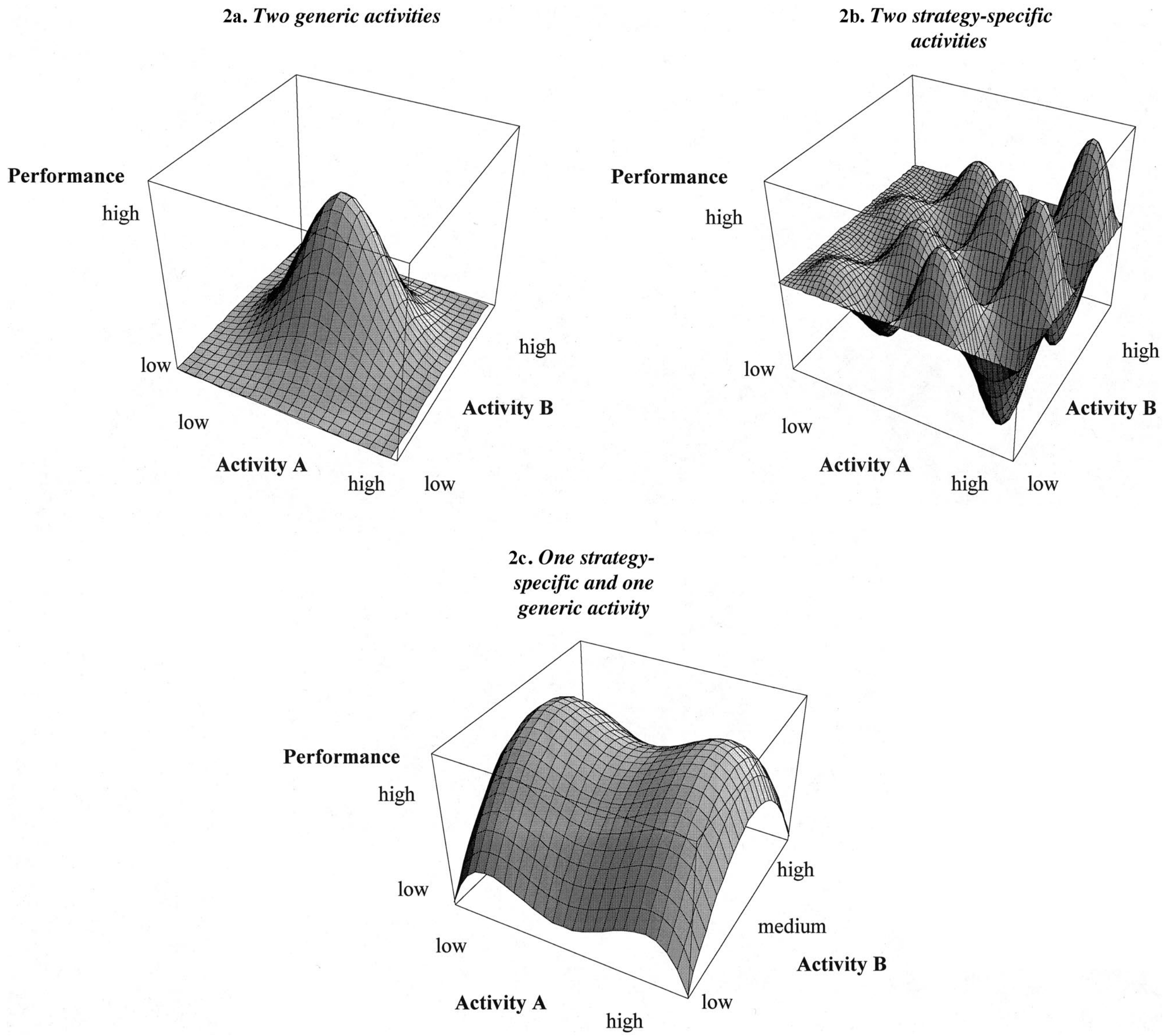
Consistency, or "internal fit" within a set of activities, is represented by a peak in the landscape. A set of activities is said to be consistent if changing any single activity (and not changing any other activity) leads to a performance decline. Thus, consistency of fit among activities is represented by a peak in the landscape: Any incremental move leads the firm to a lower elevation, i.e., to lower performance.

At the same time, the overall shape of the performance landscape is intimately affected by the degree of interaction among the activities. If activities are generic (i.e., have an optimal configuration that is independent of other activity configurations), then the landscape is smooth and contains only a single peak. This peak consists of the optimal configuration of each individual activity (see Figure 2a). The more interactions are present among the activities of firms, the more rugged the performance landscape becomes. With many strategy-specific activities (i.e., activities that are highly interdependent with each other), many peaks arise (see Figure 2b). In this case, not only one "global" (highest) peak exists, but many other "local" peaks exist, too.[6] If a performance landscape represents a particular industry, the presence of multiple peaks implies that several consistent sets of activities, several valuable positionings, exist in the landscape. We illustrated such multiple positionings that arose from contextual activities with our examples of the wine and the automobile insurance industries.

More generally, generic (independent) activities lead to smooth plateaus, to "mesas" in the

[6] This terminology is common in the context of optimization. The performance function, which takes activity choices as arguments and provides performance as output, does not have a single "global" maximum, but also several "local" maxima.

Figure 2
Performance Landscapes



landscape.[7] In a sense, the presence of generic activities reduces the number of dimensions on which firms can differentiate themselves (because all firms have the same optimal configuration for this activity). Figure 2c depicts the case in which Activity B is generic. Regardless of the level of Activity A, the highest performance is achieved for a medium level of B. Thus, a medium level of B constitutes a best practice for all firms and does not provide an opportunity for differentiation.

Contextuality of activities has been the focus of two current streams of research. First, agent-based simulation work based on the NK model has sought to analyze the consequences that arise as the degree of interdependence among the activities of a firm increases, and thus, as a performance landscape becomes more rugged. Second, the work on complementarities has focused on

[7] Assume A is an independent activity that leads to high performance if it is configured as A' (e.g., use computers in your accounting department). Since A is independent, A' always leads to high performance regardless of the configuration of other activities. As a result, the heights on the landscape of sets of activities that contain A' have a high correlation with each other, i.e., the landscape is smooth. In contrast, if A is not independent, the value of A' is changing when the configuration of other activities is changing. In this case, the heights of sets of activities that contain A' are less correlated with each other.

providing empirical evidence for interaction effects among activities in larger samples of firms. In the next two sections, we review each research stream.

Research Based on the NK Model

While the organization literature has a long tradition of recognizing the importance of interactions (e.g., Thompson, 1967), formal studies have only recently come to the fore. A large number of studies have employed simulation techniques based on the NK framework developed by Kauffman (1993) to study the consequences of interaction effects (for an overview, see Sorenson, 2002). Simulation models based on the NK framework have two parts: the creation of a performance landscape and the modeling of "agents" (e.g., firms) that try to find high peaks on these landscapes.

As described above, in our context, performance landscapes represent a mapping between different sets of (more or less interdependent) activity choices and performance outcomes. The challenge for researchers was how to create a parsimonious mechanism that would allow the generation of such performance landscapes and provide the researcher with control over the degree of interdependence among the activity choices. It turned out that a similar problem had arisen in the field of theoretical biology. The fitness of an organism is to a large extent determined by its genetic makeup, i.e., the outcome from a large set of genes. Moreover, many genes interact with each other. Building on prior work by Wright (1931), who had visualized organisms as trying to achieve high locations on fitness landscapes, Kauffman (1993) proposed the NK model to represent possible payoffs to various combinations of genes, i.e., to create performance landscapes. Work by Levinthal (1997) and Rivkin (2000) imported this technique to the field of organizational studies.

As the name implies, the NK model has two key parameters: N represents the number of activities (or genes, in the original setting); K captures the degree of interdependence among the activities. More specifically, if we apply the NK model to business, each firm is assumed to make choices with respect to N binary activities ($a_1, a_2, \ldots a_N$), each contributing to firm performance.[8] For instance, firms need to decide whether to introduce a new product ($a_1 = 1$) or not ($a_1 = 0$), whether to provide more sales force training ($a_2 = 1$) or not ($a_2 = 0$), or whether to upgrade production facilities ($a_3 = 1$) or not ($a_3 = 0$). Each activity, a_i, contributes to the overall performance of the firm. The contribution of each activity, $c_i(a_i, \boldsymbol{a_{-i}})$, is assumed to depend on how activity a_i is configured and how K related activities ($\boldsymbol{a_{-i}}$) are configured. Thus, the notion of contextual activities—the value of an activity is dependent on how other activities are configured—is a central aspect of this type of modeling. Which K activities interact with any activity a_i is specified either by the modeler (e.g., Ghemawat & Levinthal, 2000) or randomly by the computer (e.g., Rivkin, 2000). For each possible combination of activity a_i and its K related activities, value contributions c_i are drawn randomly from a uniform distribution over the unit interval. For instance, assume activity a_1 is affected by activity a_2. Then the model would create four possible contributions for a_1: $c_1(00)$, the contribution of a_1 if a_1 is set to 0 and a_2 is set to 0; $c_1(10)$, the contribution if a_1 is set to 1 and a_2 is set to 0; and likewise $c_1(01)$ and $c_1(11)$. Each of these contributions would be determined by a random draw from the uniform distribution u[0, 1].

The resulting overall performance of a particular activity combination is then given by the average of the contributions, i.e., $V(a_1a_2 \ldots a_N) = \frac{1}{N}\sum_{i=1}^{N} c_i(a_i, \mathbf{a}_{-i})$. For instance, for a case with N = 3, the firm may have chosen the activity configuration 101; then $V(101) = 1/3 * [(c_1(101) + c_2(101) + c_3(101)]$.

The procedure thus allows researchers to create performance landscapes that have a certain degree of ruggedness, which is controlled by the parameter K. If K = 0—i.e., each activity's contribution depends only on how that activity is configured—a landscape is smooth and single-peaked. As K increases, up to its maximum of $N - 1$,

[8] The assumption that decisions are binary is not crucial. The model could easily be extended to have more than two choices for each decision.

landscapes become increasingly rugged. Since contributions are drawn randomly, landscapes with the same level of K still differ in the location of the various peaks on them.

The second part of the simulation models comprises the agents that are "released" on these landscapes. Considerable modeling advances have been made on how to represent these agents in the context of business firms. While early work assumed that firms explore performance landscapes by randomly changing ("mutating") individual activities (Levinthal, 1997), more recent work has put significantly more organizational structure on the firms, modeling, for instance, hierarchy, vertical information flow, and incentives (Rivkin & Siggelkow, 2003; Siggelkow & Rivkin, 2005, 2006), or different cognitive representations of managers (Gavetti & Levinthal, 2000).

A simulation would then proceed as follows: First the researcher specifies the landscape characteristics N and K; then, using the NK model procedure a landscape is created. Onto this landscape firms with various characteristics are released; these firms are observed for a certain number of periods (e.g., until each firm has found a peak and is not moving anymore) and their performance is recorded. Then a new landscape with similar characteristics is generated, and so on. Since each landscape differs in detail (due to the random generation of the contributions), this loop is usually repeated many times (e.g., 1,000 times). Results are then averaged over these 1,000 observations. Lastly, the landscape characteristics—say, K—would be changed. And again 1,000 landscapes with this new level of K would be generated, and firms would be observed on each of these landscapes.

The key focus of this work has been on examining the effects of different degrees of interaction (different levels of K). For instance, Levinthal (1997) found that firms operating on high-K landscapes are subject to high rates of failure in changing environments. Similarly, Rivkin (2000) showed that as K increases, the probability of a firm's reaching the global peak decreases dramatically. As a result, imitating a firm that occupies the global peak within a landscape is very unlikely to succeed if the leading firm's strategy is based on a large set of interdependent activity choices. In an extension of this work, Rivkin (2001) analyzed the problem faced by firms (e.g., franchise operations) that, after finding the global peak, might want to replicate this performance. If a firm's strategy is complex, a firm that tries to replicate itself might encounter similar obstacles to those encountered by other firms that try to imitate it. Assuming that a replicator has a higher probability of correctly duplicating each individual activity than an imitator does, Rivkin (2001) found that the gap between replicability by the same firm and imitability by other firms tends to be greatest at moderate levels of K.[9]

An attractive feature of the NK model is that the degree of interdependence can be controlled by only one parameter, K. The downside of this simplicity is that the modeler has no control over which types of interactions arise. In any given simulation involving a significant degree of interaction, a broad distribution of different types of interactions is present, rendering the study of the effects of particular types of interactions, and of contextual interactions, impossible. For instance, activities A and B might be complements (i.e., the marginal benefit of A increases with the level of B, and vice versa), while the interaction between A and C is one of substitutes (i.e., the marginal benefit of A decreases with the level of C). Unfortunately, the modeler has no control over which of these types of interactions arise. This limitation of the NK model stems from the random assignment of contributions to activities (see Appendix 1 for more details).

In sum, while the studies of the effects of different degrees of interaction have produced a number of interesting insights, it is important to note that these results are mean tendencies across

[9] Further studies employing the NK methodology include McKelvey (1999) and Lenox, Rockart, and Lewin (2006), whose models include interactions between different firms; Levinthal and Warglien (1999), who included interactions among different decision makers; Marengo et al. (2000), who examined the effects of various decomposition schemes; Siggelkow and Levinthal (2003, 2005), who analyzed different sequences of organizational structures; Sommer and Loch (2004), who studied different learning mechanisms; and Ethiraj and Levinthal (2004a, 2004b), who focused on the effects of different degrees of modularity among the activity choices. Empirical studies testing the NK-framework are few. Notable exceptions are Sorenson (1997), Fleming and Sorenson (2001), and Sorenson, Rivkin, and Fleming (2006).

a wide range of different types of interactions, potentially hiding important phenomena. For instance, as Siggelkow (2002b) showed using an analytically solvable mathematical model, the consequences of misperceiving interactions between activities are markedly different when interactions are between substitutes than when they are between complements. With the NK approach, such distinctions relating to the types of interactions cannot be explored.

Research Based on the Complementarity Framework

Besides the simulation work in the organization literature, a large stream of the recent work on interaction effects among firms' activities—both empirical and theoretical—has built on the work of Milgrom and Roberts (1990, 1995). Guided by the observation that many firms in the American economy were shifting from mass production to lean manufacturing, Milgrom and Roberts (1990) proposed an optimizing model of the firm that generated many of the observed patterns in the transition from one system to the other. In particular, the model accounted for the observation that a successful transformation from one system to the other required substantial changes in a wide range of a firm's activities.

Milgrom and Roberts' work contained two key insights, one conceptual, one mathematical. First, they observed that many activities within a given production system were complementary to each other. They defined two activities to be complementary if the marginal benefit of one activity was increased by the level of the other activity. Second, they developed mathematical methods building on the supermodularity work by Topkis (1978) that allowed a particular but exact formulation of the notion of complementarities involving a large set of choices. With these methods, models with an unusually large number of variables and relatively weak assumptions (by economics standards) were amenable to tractable analysis. (We will return to these assumptions at the end of this section.)

The complementarity framework has spurred both theoretical and empirical research. A growing body of literature has continued to develop and apply the mathematical apparatus of supermodularity in a wide variety of formal models, addressing issues such as investments in product and process flexibility, optimal partitioning of design problems, modes of organizing innovation activities, and convergence to equilibria in learning games (e.g., Athey & Schmutzler, 1995; Bagwell & Ramey, 1994; Chen & Gazzale, 2004; Holmström & Milgrom, 1994; Leiponen, 2005; Milgrom, Qian, & Roberts, 1991; Milgrom & Shannon, 1994; Schaefer, 1999; Topkis, 1995; Vives, 2005).

Empirical work in this line of research has pursued two main directions: finding support for complementarity among various activities by studying the performance implications of adopting individual activities versus entire sets of activities, and inferring complementarities by studying adoption patterns of new technologies and practices. For a thorough exposition of the inherent econometric problems involved in identifying complementarities, see Athey and Stern (1998) and Arora (1996). For a testing strategy to detect supermodularity given discrete choices, see Mohnen and Röller (2005).

A notable example of the first type of empirical study is Ichniowski, Shaw, and Prennushi (1997), who studied the effect on the productivity of steel finishing lines of adopting individual human resource management (HRM) practices versus entire sets of HRM practices. They found "consistent support for the conclusion that groups or clusters of complementary HRM practices have large effects on productivity, while changes in individual work practices have little or no effect on productivity" (p. 291). Ichniowski and Shaw (1999) reported a similar finding using an expanded sample including both U.S. and Japanese steel finishing lines. Likewise, MacDuffie and Krafcik (1992) found for firms in the U.S. automobile industry a synergistic payoff between the adoption of "lean" production processes and a set of HRM practices, including shop floor work organization and incentive clauses in employment contracts. MacDuffie (1995) extended this work to a larger set of automobile assembly plants located worldwide, finding a complementary relationship between teambased work systems, high-commitment HRM practices, and low inventory and repair buffers. Also focusing on high-performance work practices, such as profit sharing, formal teams, and job rotation, Colombo, Delmastro, and Rabbiosi (2007), using longitudinal data on 109 Italian manufacturing firms, found that the value of these practices was enhanced by a decentralized organizational structure. Thus, in this case, a complementarity between work practices and an element of organization structure was detected.

Focusing on investments in information technology, Bresnahan, Brynjolfsson, and Hitt (2002) found in a sample of 300 large U.S. manufacturing and service firms that the benefits to information technology investments increase in the level of worker human capital, and vice versa, indicating complementarity. Likewise, the relationship between workers' skill level and organizational changes, such as decentralization of authority and delayering of managerial functions, was shown to be complementary in a sample of French manufacturing plants (Caroli & Van Reenen, 2001).

On a broader organizational level, Whittington et al. (1999) studied the performance implications of 10 distinct changes in organizational structure, processes, and firm boundaries using a survey of 383 European firms. Consistent with complementarities, they found that piecemeal changes (with the exception of investments in information technology) delivered little performance benefit, while exploitation of the full set of innovations was associated with high performance. In particular, a positive performance effect arose only if changes to structures, processes, and firm boundaries were combined. No performance effect, or even a negative effect, was found when changes addressed only two of these areas. For a broader exposition of these results, see Pettigrew et al. (2003).

One should note that not every empirical test of complementarity has yielded confirming results. For instance, Cappelli and Neumark (2001), using U.S. Census Bureau survey data covering 1977 through 1996, found very few complementarities among work practices. In addition, they made the interesting observation that complementarity does not necessarily imply that joint adoption is better than no adoption. While it may be true that adopting practice A alone is worse than adopting practices A and B together, the net benefit of practices A and B may still be zero if the direct effects (e.g., costs) of A and B are negative. They found such a relationship for the practices of job rotation and self-managed teams. These two practices do benefit from each other, yet both have individual negative effects on performance (measured by labor productivity), creating an overall insignificant performance effect.[10]

Similarly, Black and Lynch (2001), studying the effects of work practices in a broad sample of U.S. manufacturing businesses over the period 1987 through 1993, found a significant interaction effect only between unionization and profit sharing for nonmanagerial workers, yet no interaction effects among any of the workplace practices themselves. Lastly, in a detailed study of the effects of improved information technology in emergency response systems (9-1-1), Athey and Stern (2002) did not find evidence for complementarity between information technology investments and investments in the human skills of the call-takers.

Empirical studies in the second stream of literature, examining adoption patterns of new practices and technologies, include Colombo and Mosconi (1995), who investigated the adoption patterns of flexible manufacturing systems, new design/engineering technologies, and new management techniques such as JIT and total quality procedures in the Italian metalworking industry. They observed that all of these innovations tended to be adopted together, providing an indication of complementarity among them. Focusing on the adoption of different types of incentives, Cockburn, Henderson, and Stern (1999) showed in a sample of large pharmaceutical firms that a complementary relationship exists between the

[10] Sometimes the adoption of "practices" may be forced by other considerations. For instance, Van Biesebroeck (2006), studying automobile plants in the United States, found that an increase in product variety led to lower labor productivity. In this case, competitive forces may require a firm to increase its product variety. Moreover, Van Biesebroeck found that an increase in vertical integration (insourcing) and an increase in the use of flexible technology also led to lower labor productivity. However, if the increase in product variety was coupled with a higher degree of insourcing or a more extensive use of flexible technology, the negative effects were muted, thus showing a complementary relationship between product variety and flexibility and product variety and insourcing.

degree to which publications in scientific journals are important for career advancement and intensity of incentives to conduct applied research.

Concentrating on interdependencies among outsourcing decisions, Novak and Stern (2007), using detailed data from the global auto industry, found that contractual complementarities exist. In particular, they showed that the probability that a firm chooses to vertically integrate an automobile system (e.g., the brake system) increases with the number of other systems the firm integrates. Moreover, these complementarities are particularly strong for systems that have tight interdependencies and for which coordination is difficult to monitor.

Hitt and Brynjolfsson (1997), in a study of 273 firms from the Fortune 1000 list, found that firms that were extensive users of information technology tended to adopt a complementary set of organizational practices that included decentralization of decision authority, emphasis on subjective incentives, and greater reliance on skills and human capital. Similarly focusing on the adoption of information technologies, Bocquet, Brossard, and Sabatier (2007), using data on 136 French firms, found that positive reinforcements appeared to exist between Enterprise Resource Planning (ERP) systems and Electronic Data Interchange (EDI) systems, and between ERP and Internet-based exchange systems. At the same time, they concluded that EDI systems and Internet-based exchange systems were independent choices, not affecting each other.

In sum, studies have generally explored activity configurations that are beneficial for many firms and activities that are complementary in the same manner for all firms within an industry or across industries. (For a recent study that starts to address contextual interactions, see Cassiman and Veugelers, 2006, to be discussed in more detail later.) While these are important situations to study, they represent only a subset of the ways in which activity choices can interact and how these interactions affect competition. Moreover, an explanation for sustainable competitive advantage, i.e., for long-term superior profitability, may not be found in such cases. If a particular activity configuration is beneficial for all firms within a given industry, competitors will have strong incentives to adopt this configuration sooner or later.

Similar to the NK model, the complementarity framework is not well-suited to deal with contextual interactions. While in the NK model any and all types of interactions can arise, the complementarity framework, as the name implies, constrains itself to a single and very specific type of interaction. In particular, in the formal analyses that form the background for the empirical studies, two activities, A and B, are said to be complements if and only if three conditions hold (see Appendix 2 for a more general and formal statement of these conditions):

1. The marginal benefit of A has to increase with the level of B, and vice versa.
2. Relationship 1 has to hold for all levels of A and B.
3. Relationship 1 has to hold regardless of how a firm configures its remaining activities.

This definition of complementarity is convenient because it yields robust comparative statics properties: Any exogenous decrease in the marginal cost of any element in a system of complements will (weakly) increase the optimal level of all elements in the system (for more details, see, e.g., Milgrom & Roberts, 1990; Milgrom & Shannon, 1994; Topkis, 1995). This formulation also holds mathematical interest because conditions 1 through 3 describe the weakest sufficient conditions to yield these comparative statics results (Milgrom, Roberts, & Athey, 1996). However, for the central question of strategy—how firms can distinguish themselves and achieve above-average performance—an exclusive focus on complementarities as defined above is less satisfying for three reasons.

First, complementarity is but one case of how activities interact. Activities within firms can interact as substitutes as well.[11] For instance, as a firm increases its investment in quality control, leading to fewer defects in its products, the mar-

[11] The complementarity framework can incorporate only a limited number of substitutes. If activity a_i is a substitute to all other activities of a firm, it can be formally replaced by $-a_i$, thereby making it complementary (de Groote, 1994).

ginal benefits of increasing after-sale service support dealing with faulty products is likely to decrease.

Second, the type of interaction among activities may not be constant for all levels of these activities, i.e., condition 2 may be violated. Two activities might be complementary over a range of their values, but not complementary outside the range.

Third, interactions among activities are not always independent of other activity choices, as condition 3 requires. As a result, two activities might be complementary in one firm and substitutes in another. (For an illustration of how restrictive the complementarity conditions are, see Appendix 3.) Similarly, as a firm changes some of its activities, the nature of the interactions among its activities might change over time.

To summarize, both the NK model and the complementarity framework have been successfully used to study the issue of interdependencies among a firm's activity choices. At the same time, both approaches make it difficult to study *contextual* interactions. In the remainder of this paper, we will illustrate contextual interactions in their various forms and outline implications of contextual interactions for both managers and researchers.

We first describe violations of condition 2, i.e., contextuality that is caused by the level of the activities. Second, we will explore examples of violations of condition 3. In one case we describe how the same activities can have different interactions in different firms because the activities are embedded in different activity systems; in the other case we describe how contextuality can lead to interactions that change their nature over time.

Contextuality Created by Different Activity Levels

To illustrate a situation in which activities may be complementary only over certain ranges of their levels (violation of condition 2), we continue with the example of the auto insurer Progressive Corporation. Progressive's quick-response approach to handling clients' claims allows the company to lower total costs by reducing the frequency of litigation in serving high-risk customers. Let $T = t_1 + \ldots + t_N$ be the total time between accident and issuing a check, i.e., the time required for the N activities that lie between accident and the issuing of a check. For instance, t_1 might be the time until a customer notifies an agent after an accident has happened, t_2 the time between the notification of the agent and personal face-to-face contact, and t_3 the time between agent contact and claim settlement. Let P(T) be the net benefit function of having a response time T. Since shorter response times are beneficial for Progressive, P(T) is decreasing in T. Depending on the shape of P(T), investments in activities that shorten the total time to settlement are complementary, or not. Strict complementarity requires that P(T) is convex over the *entire* range of T. While an argument can be made that P(T) may be convex within a certain range of T, the convexity of P(T) is unlikely to hold over all possible levels of T. For instance, if it takes a relatively long time to settle claims (two weeks is not uncommon in the industry), a reduction in the time it takes for an agent to have contact with the claimant and to start the claims process, say from three days to one day, is quite likely to go unnoticed by customers and creates no benefit for the insurance company (the investments are not complementary). If, however, claims settlement can actually occur within a day, the same reduction in time of contacting a claimant (from three days to one day) may have considerable benefit to the insurance company (in terms of both customer satisfaction and likelihood of involving a lawyer), as the insured party may respond positively to the noticeable reduction of total processing time. (In other words, the efficiency improvement is not swamped by large delays introduced by other parts of the settlement process.) Thus, the investment in one activity increases the marginal benefit of investing in the other activity—the activities are complementary. Finally, once both contact and settlement time have been reduced to very short levels, the marginal benefit of decreasing one even further is likely to decline again, i.e., the investments cease to be complementary. (In other words, as T gets closer to zero, P(T) is not going to infinity but will level out.)

This example also illustrates the empirical challenge of choosing the correct level at which to measure the effects of complementarity. Using the previous notation, a common question would be whether investments that reduce, say, t_1 and t_2 are complementary. Assume that an investment that reduces t_1 does not lead to a reduction in t_2, and vice versa, i.e., reductions in T through investments in t_1 and t_2 are strictly additive. In this case, if the efficiency of the process is measured by T, no complementarity between the investments will be found. At the same time, if P(T) is used to measure the effects and T is in the range in which P(T) is convex, one *would* empirically find a complementarity between the investments.

Contextuality Leading to Different Interactions in Different Firms

An even more interesting departure from the strict complementarity assumptions for company strategy is the case when the type of interaction is affected by other choices (violation of condition 3). A firm's existing set of activities can transform the relationship between activities from one of complements to one of substitutes and vice versa. For example, in the automobile insurance setting, we described two different kinds of strategies with respect to response times. Given a strategy of postponing payments (up to the point when regulators step in), all activities that lead to a reduction in response times are substitutes. Any investment that reduces the time of one activity would lead to a decrease of the marginal benefit of speeding up another activity. However, with a strategy of decreasing total response time, these choices are complementary (at least over a certain range, as discussed in the previous section).

A more elaborate example of contextuality can be found in the mutual fund industry. In 1974, the mutual fund provider Vanguard was formed. Originally, Vanguard, like other mutual fund providers, outsourced investment management to an investment management company, Wellington Management (WM). As was industry practice in the 1970s, Vanguard distributed its funds using the same investment management company that managed the funds.

Vanguard differed from its competitors, however, in various ways. First, administrative services were not contracted out, but were provided at cost by the Vanguard Group itself. Second, the Vanguard Group was owned by the fund shareholders rather than by a separate set of shareholders. Lastly, Vanguard differed from its competitors in its overarching investment philosophy and the type of funds it promoted. John Bogle, Vanguard's CEO, believed that high and fairly predictable long-run investment returns could be achieved by incurring very low expenses and attempting not to outperform the market but to match it. Thus, Bogle introduced the industry's first index fund (based on the S&P 500) in 1976 and increased Vanguard's offering of bond funds. In 1977, Vanguard decided to bring the distribution function in-house and to market its funds as no-loads, i.e., not to charge any sales fees. In the following years, Vanguard also started to bring investment management for all bond funds in-house.

The interplay between the insourcing of investment management and the no-load, direct distribution system reveals the effect of contextuality. For Vanguard, bringing both investment management and distribution in-house was complementary, yet for other fund providers it was not. The benefit of internalizing investment management was much greater after Vanguard had gained control over distribution. It would have been unwise for Vanguard to take away the (very lucrative) investment management business from WM while still relying on WM to distribute its funds. WM would have been much less motivated to sell the funds. If insourcing investment management and direct distribution are complementary, the reverse is also true, i.e., changing from load distribution to direct, no-load distribution is more valuable in the presence of internal investment management than with external investment management. This reverse argument holds for Vanguard, but only in the context of its low-cost strategy, organizational structure, and fund portfolio. Internalization of investment management and distribution each decreased costs. By virtue of Vanguard's mutual structure these cost savings were passed through to the funds, which therefore recorded higher net returns. It has been shown that fund inflows, in turn, respond in a convex manner to higher relative returns (Sirri & Tufano, 1998). Thus, the benefit to Vanguard—in terms of asset growth—from decreasing its costs of investment management became larger when the costs of distribution were also reduced. Moreover, this effect was most pronounced for fund types for which small changes in expenses translated into large relative performance differences and were not swamped by large performance fluctuations. Thus, the complementary relationship arose strongly for the types of funds Vanguard was focusing on and for which it was insourcing the investment management, i.e., low-risk and index funds. Consistent with this contextual complementarity argument, Vanguard did not insource the investment management for actively traded equity funds.

This contextuality can also be inferred from the following observation. Were insourcing investment management and distribution complementary for all firms, regardless of the firms' other choices, then we should always see the choices of in-house investment management and in-house distribution go together. However, we can observe quite a number of "mixed cases," i.e., mutual fund providers that focus only on asset management and outsource distribution, and a number of providers who specialize in distribution and outsource investment management. Thus, insourcing investment management and insourcing distribution do not seem to be context-free complements.

Contextuality Leading to Changes in Activity Interactions Over Time

Violations of condition 3 can manifest themselves not only across firms but also over time in the same firm. Two activities that were substitutes can become complements, and vice versa, as a firm adapts its activity system to changing industry conditions.

An example of how the relationship among activities can change over time can be found at Liz Claiborne, the largest fashion apparel manufacturer in the United States. In the 1980s, Liz Claiborne focused on the apparel needs of the then rapidly growing segment of professional women. Its collection provided high value to customers looking for guidance about what constituted acceptable professional women's apparel and for an array of items that were fashion coordinated. In its early years, given its unique positioning, Liz Claiborne was able to easily sell all of its output to its department store customers and required them to place binding orders at the beginning of the season.

Consider the subset of activities that influences the lead time between design and final delivery of the product. Each of these activities, from design itself to the management of contract manufacturers, involves configuration choices: e.g., conventional design vs. computer-aided design, physical delivery of design and fabric samples to manufacturers vs. using online technology, etc.

When Liz Claiborne was setting fashion trends and was able to sell its entire output, the benefits of decreasing its lead time were small. In fact, lead time did not matter much as long as Liz Claiborne was able to ship its merchandise at the beginning of each season. For firms that were not able to "define" the market, shorter lead times were beneficial since they allowed the gathering of more information about upcoming fashion trends. Hence for Liz Claiborne, improvements in activities that led to a shortening of the total lead time were substitutes. More formally, let $T = t_1 + t_2 + \ldots + t_N$ be the total lead time, with $t_1, \ldots, t_N$ the time of the various activities from design to delivery. If there is no benefit in decreasing T (under the constraint that T is sufficiently small to guarantee shipment at the beginning of the season), then a decrease, for instance, in t_1, would lead to a reduction of the benefit of reducing t_2, i.e., investments that reduce t_1 and t_2 are substitutes. For example, as IT systems improved, allowing faster communications with suppliers, the marginal benefit of investing in design technology (e.g., CAD systems) that would reduce lead time even further decreased for Liz Claiborne. Consistent with this relationship, Liz Claiborne invested very little in upgrading design technology (Henricks, 1995).

In the 1990s, however, Liz Claiborne's competitive environment changed. First, the Liz Claiborne brand became less important, leading to decreased consumer loyalty. With this change, shorter lead times, once unimportant for the company, became valuable, since shorter lead times allowed it to wait longer and discern emerging fashion trends. Second, department stores experienced cash-flow problems as many chains had been involved in leveraged buyouts or mergers involving high levels of debt. As a consequence, department stores sought to reduce inventories to free up cash, and increasingly demanded the delivery of merchandise in small lots and the option to reorder items during a season. To allow reordering efficiently, manufacturers had to move to at least partial production to order (Hammond, 1993). Production to order, in turn, was more effective with shorter overall lead times. Investments that sped up the design process were made more valuable by concurrent investments in information technology. For Liz Claiborne, upgrading design technology and upgrading information transmission technology had become complementary.

Implications of Contextuality for Management Practices

Contextuality has a number of implications for management practice. Here, we focus on the effect of contextuality on the ease of imitation and adaptation. Imitating complex systems of interactive activities is generally challenging because entire systems (rather than individual activities) must be replicated (Porter & Rivkin, 1998). Put differently, interactions cause the imitation-benefit relationship to be convex: If only a few elements of a system are copied, no benefits (or even negative results because of inconsistencies) are generated.

Contextuality further adds to the difficulty of imitating a competitor's activity system. First, strategy-specific activities, as compared to generic activities, are inherently more difficult and costly to imitate because their configurations are observable in fewer firms, and matching them often requires imitators to suboptimize their current activity configurations (Porter, 1996).

Second, and more subtle, contextuality of interaction effects can lead to misguided imitation behavior. Contextual interactions require imitators to learn not only about new activity configurations (e.g., a new practice adopted by a competitor) but also about new activity interactions (i.e., how this practice affects existing activities within the imitating firm). In the presence of contextual interactions, managers who observe that two activities are complementary (or substitutes) for a competitor cannot conclude that the same two choices are complementary (or substitutes) for their firm. As a result, imitating the investment behavior of competitors can backfire. For instance, a competitor for whom two activities are complementary would tend to co-invest in both activities. Imitating this co-investment could be harmful to the imitator if the two activities, due to other activity choices, are actually substitutes in the imitating firm. For instance, while investing in quick response capabilities and faster claims adjusting might be complements for Progressive, they might very well be substitutes for standard insurers.

Similarly, contextuality of interactions implies that the relationship between existing activities can change as new activity configurations are adopted. This means that established strategic heuristics or adjustment routines (Nelson & Winter, 1982) may fail. Consider a firm that is trying to imitate a leading firm. If the imitator could observe the entire set of activity choices taken by the leading firm, and if the imitator were capable of duplicating all these choices, the imitator could imitate perfectly. However, in most cases, the imitator cannot observe the entire set of the leader's activity configurations. Hence, the imitator can duplicate only the observable activity configurations and subsequently attempt to deduce the remaining set of choices, hoping that its system of routines and traditional operating procedures, i.e., its knowledge about how the new activity configurations interact with its old activities, will bring about optimal readjustments. Yet, if the nature of the relationship between existing activities has changed after the adoption of new activities, either no or even counterproductive adjustments will be made.

The fact that interactions can change their type from substitutes to complements, or vice versa, when other activity configurations are altered has consequences not only for imitation but also for the ability of firms to adapt their activity systems, e.g., in response to an environmental change. As a firm starts to incrementally change its activity system, it may not be aware that interactions among its other activities have changed and will therefore operate with mistaken beliefs about interactions, relying on outdated mental maps. For instance, Liz Claiborne's existing management did not fully realize that interactions had changed within its activity system after reordering activities had been adopted—e.g., creating a complementarity between investments in faster design capabilities and better capitalized suppliers—which contributed to its performance decline (Siggelkow, 2001).

Further examples of such consequences of contextual interactions on imitation and adaptation are revealed in the innovation literature (Henderson, 1993; Henderson & Clark, 1990). Incumbent firms have been found to experience severe difficulties in responding to "architectural" innovations that are characterized not by new parts of a system, but by new ways in which the parts of a system *interact* with each other. The interactions among the components of a product, or, more generally, among activities of a firm, leave organizational imprints, such as who communicates with whom, what type of information is gathered and shared, and what heuristics are used to solve problems or to make investment decisions. If relevant interactions change, the existing organizational structures and processes that arose in the context of the old set of interactions can become very misleading.

Recall the example of firms like the Gap that operate distribution systems linking warehouses and stores. For such firms ordering frequency and delivery frequency are complementary, yet only if relevant information for ordering on a daily basis is available, e.g., through a POS system. Existing investment routines that were formed in the old regime (i.e., in the absence of a POS system) will not have incorporated a relationship between ordering and delivery frequency. With these old routines in place, the installation of a POS system (e.g., a salient feature of a competitor that was replicated) may not be accompanied by increased investment in ordering and distribution frequency. Moreover, even if the firm increased investment in one of these activities, the old routines would not lead to a self-adjusting increase in the investment in the other activity.

In sum, the extent of contextual interactions is an important dimension that characterizes systems of activities. While considerable research effort has been extended on the horizontal axis of Figure 1, the contextuality of activities, much less attention has been spent on the vertical dimension, the contextuality of interactions. Combining the distinction between generic and strategy-specific activities and between interactions that are contextual or not creates the typology shown in Figure 1. When no interactions are present optimal configurations can be found that are not different across firms. In other words, these activity configurations represent universal best practices. As the interactions among activities becomes more dense (i.e., the value of activities is more likely dependent on other activity choices), the optimal configuration of activities becomes a function of industry, strategic group, or even firm-level strategy. At each of these levels of activity contextuality, interactions themselves can be either contextual or similar within all firms at the respective level. Given that contextuality of interactions has not been a focus of past research, in the next two sections, we will spell out implications for both simulation and empirical work.

Implications of Contextuality of Interactions for Simulation Studies

Formal modeling can be very useful in trying to understand the often complex effects of activity interactions. Traditional closed-form modeling approaches, however, become quickly intractable when dealing with interactions unless restrictions are imposed, such as the Milgrom and Roberts definition of complementarities. Agent-based simulations building on the NK model can address this challenge. Yet, as noted before, the NK simulation framework is limited because it does not provide control over which types of interactions can arise in a performance landscape.

To study the effects of contextual interactions directly, such control would be very useful. One way to achieve such control would be to start with a performance function, rather than to assign contributions to individual activities. Consider a case of N = 4, where each activity a_i can take on two values, 1 and 0. The following function includes all possible interactions among the activities:

$$V(a_1, a_2, a_3, a_4) = \alpha_1 a_1 + \alpha_2 a_2 + \alpha_3 a_3 + \alpha_4 a_4 + \beta_1 a_1 a_2 + \beta_2 a_1 a_3 + \beta_3 a_1 a_4 + \beta_4 a_2 a_3 + \beta_5 a_2 a_4 + \beta_6 a_3 a_4 + \gamma_1 a_1 a_2 a_3 + \gamma_2 a_1 a_2 a_4 + \gamma_3 a_1 a_3 a_4 + \gamma_4 a_2 a_3 a_4 + \theta a_1 a_2 a_3 a_4$$

By choosing appropriate values, or distributions, for the parameters α_i, β_i, γ_i, and θ, different types of interactions can be created. For example, if $\beta_i = \gamma_i = \theta = 0$, all activities are independent; in this case, landscapes that are generated by drawing random values for α_i have similar properties to K = 0 landscapes created by the NK model. If $\beta_i > 0$, $\gamma_i \geq 0$ and $\theta \geq 0$, all interactions among activities satisfy the Milgrom and Roberts definition of complementarity, as all cross-partial derivatives are positive. If $1 > \beta_i > 0$, $\gamma_i \leq -1$ and $\theta = 0$, all activities have contextual interaction effects.[12]

First exploratory characterizations of performance landscapes created with this methodology show that having control over the types of interactions can create new insights. For instance, one of the main findings of NK models is that as K increases—often interpreted as an increase in interaction intensity (e.g., Levinthal, 1997)—performance landscapes become more rugged (Kauffman, 1993), making imitation more difficult (Rivkin, 2000). Yet, if landscapes are composed entirely of complementary activities, stronger interactions can actually lead to smoother landscapes, making imitation potentially easier (results available from the authors).

[12] To see that all activities have contextual interaction effects when $1 > \beta_i > 0$, $\gamma_i \leq -1$ and $\theta = 0$, consider, e.g., the cross-partial derivative of a_1 and a_2, $\beta_1 + \gamma_1 a_3 + \gamma_2 a_4$. It equals β_1 if $a_3 = 0$ and $a_4 = 0$. Since $\beta_1 > 0$, a_1 and a_2 are in this case complements. Yet, if $a_3 = 1$ and $a_4 = 0$, the cross-partial derivative equals $\beta_1 + \gamma_1 < 0$; thus, in this case, a_1 and a_3 are substitutes. Likewise for $a_3 = 0$ and $a_4 = 1$. In other words, the type of the interaction between a_1 and a_2 is contextually determined by the configurations of a_3 and a_4.

Implications of Contextuality of Interactions for Empirical Research

Contextuality of both activity configurations and interactions poses significant challenges for empirical work because identifying contextuality often requires an in-depth knowledge of the activity systems of each firm, or data point. Such in-depth knowledge is difficult to obtain for large samples. However, our framework suggests practical directions for large-sample research. For instance, assume that the benefit of adopting a bundle of production practices (say, A, B, and C) has been found to yield higher labor efficiency for a sample of firms than adopting the practices separately. Our framework suggests the additional question of whether the configuration is particularly beneficial (or detrimental) for firms with specific strategies, i.e., for firms with certain sets of other activity choices. By pooling across all observations, we know only that the bundle of practices is beneficial on average. However, it may be that A, B, and C are beneficial (and/or mutually reinforcing) only for companies that produce standardized outputs, while they are detrimental (and/or mutually independent or even substitutes) for companies that produce highly customized outputs (or vice versa).

Contextuality of interactions can be explored by testing whether interaction effects are constant over entire samples, including firms with significant differences. Interaction effects are frequently studied by including the product of two variables in a regression model. Thus, if the interaction between A and B is tested, the regression model would include a term such as β*A*B. Contextuality due to the level of activities could be tested by exploring whether β is a function of the level of A and B. This could be explored by splitting the sample into groups depending on their levels of A and B and testing whether β is different across the groups.

Contextuality due to other activities could be tested by exploring whether β is a function of other variables, C. Dividing the sample into subgroups using C and testing for differences in β, or including higher-order interaction terms such as A*B*C, would be a first step to explore this type of contextuality. Similarly, if A and B are shown to be complementary on average, finding variables C that drive the joint adoption of A and B, but not of A or B alone, can point to sources of contextuality. For an interesting test along these lines, see Cassiman and Veugelers (2006). Investigating whether internal R&D and external knowledge acquisition are complementary for firms, they "identify reliance on basic R&D—the importance of universities and research centers as an information source for the innovation process—as an important contextual variable affecting complementarity between internal and external innovation activities" (p. 68).

If no such contextuality effects among a particular set of performance-enhancing activities can be detected, then the range of firms included in the sample speaks to the degree to which these activities are generic. For instance, if the sample includes firms from a broad swath of industries, the set of activities would be universal best practices. If firms from only one industry are included, the set of activities would be (at the minimum) industry best practices. If contextuality effects are detected, the degree of specificity of the contextual variable determines the degree of specificity of this effect. For instance, if the contextual variable is constant for firms within a strategic group, yet differs across strategic groups, the identified activities are strategic-group best practices with or without contextual interactions, depending on the presence of contextual interactions.

As an illustration of how taking contextuality into account can refine empirical findings, we reanalyzed the data from MacDuffie's (1995) study of automobile assembly plants. MacDuffie (1995) investigated the productivity and quality effects of innovative human resource practices, work policies that govern shop floor production activity, and the use of inventory buffers in production. MacDuffie analyzed both the direct effects and interaction effects of these practices and concluded that "plants using flexible production systems, which bundle human resource practices into a system that is integrated with production/business strategy, outperform plants using more traditional mass production systems in both productivity and quality" (p. 218). The results implied that the identified practices were generically beneficial and interacted similarly in all firms, i.e., a case of industry best practices.

Our subsequent analysis of the data reveals, however, that only the work practices, such as the degree to which workers are in formal work teams, were truly industry best practices, showing no contextual effects. The human resource and inventory buffer practices prove to have both contextual benefits and contextual interactions. For instance, the benefit of the human resource practices, such as the level of ongoing training, was higher for plants that assembled relatively new models, i.e., for firms that had shorter product life cycles. Similarly, we found that the complementary interaction between human resource and inventory buffer practices was influenced by the degree of variation among those parts that were required for all models assembled in a plant (MacDuffie & Siggelkow, 2002).

A further important avenue for empirical work is to examine a broader array of measures of performance, specifically measures of overall performance. Many studies of complementarities have employed narrow efficiency measures such as labor input per unit of output (i.e., labor productivity). These measures offer comparability across processes, but have differing relevance for firms with different strategies. Ideally, performance measures should incorporate both the cost and the price elements of the business (i.e., some form of margin or profit contribution measure). For instance, a firm that produces highly customized products may not want to adopt the bundle A, B, and C, if adopting this bundle hampers the ability to customize products and thereby command higher prices. In this case, the firm might pursue a differentiation strategy (Porter, 1985). While a different optimal bundle might result in lower (labor) efficiency in producing standardized outputs, the price premium for the customized products can outweigh the efficiency loss. A focus on narrow measures of efficiency, then, implicitly suppresses strategy differences by assuming that all firms value the measure similarly, i.e., that all firms follow the same strategy. This neglects important dimensions of competition and can create misleading interpretations of empirical results.

Conclusion

In recent years, the idea of firms as systems of interdependent activities has found renewed interest. Both the NK model and the complementarity framework have allowed researchers to approach this topic in a more systematic manner. For future research, we would suggest increasing the focus on sets of activities whose interaction effects are contextual, because these activities are more difficult to imitate and, thus, more likely to represent sources of competitive advantage. More generally, as our examples show, to gain a richer understanding of the role played by interactions among activities in creating and sustaining competitive advantage, research needs to encompass a wider range of interactions than the strictly defined complementarities that have served as the theoretical model underlying many empirical analyses. Similarly, simulation research will need to be extended. To study the effects of different types of interactions and of contextuality, simulation models will have to allow more control than the frequently used NK model grants.

Empirical support for the existence of contextual interactions is so far mainly derived from in-depth field research. Future research on larger samples is needed. Reanalyzing prior studies to look explicitly for contextualities might be a first step. A more ambitious approach would be to assemble data sets in which fuller interaction structures of the activities of firms are documented. Due to the high cost of assembling such data, research treading a middle ground between individual case studies and large-sample research may prove to be the most feasible next step. Incorporating the possibility of contextual relationship in future research is certainly no small task, but will be essential to further our understanding of the role of interactions in competitive advantage.

Appendix 1: Different types of interactions within the NK model

The random assignment of contributions to activities gives rise to a variety of types of interactions, yet provides the researcher with no control over which types of interactions do arise. A simple example illustrates this point. Say activities A and B can be configured in two ways (0 or 1) and B affects A. In this case, the NK model would assign four random contributions to A: $c_A(0, 0)$, the contribution of A when A = 0 and B = 0; $c_A(1, 0)$, the contribution when A = 1 and B = 0; and likewise $c_A(0, 1)$ and $c_A(1, 1)$. Consider the case $c_A(0, 0) = 0.1$, $c_A(1, 0) = 0.4$, $c_A(0, 1) = 0.3$, and $c_A(1, 1) = 0.8$. In this case, when B = 0, the marginal benefit of changing A from 0 to 1 equals 0.3 (= 0.4 − 0.1), and it equals 0.5 (= 0.8 − 0.3) when B = 1. Thus, the marginal benefit of A is increasing in the level of B; A and B are complements. Yet the NK model could quite as likely assign $c_A(1, 1) = 0.5$. Now, the marginal benefit of changing A from 0 to 1 when B = 1 is only 0.2 (0.5 − 0.3), less than the marginal benefit when B = 0. In this case, A and B would be substitutes. Thus, given the stochastic determination of contributions—and thereby implicitly of the types of interactions among activities—it is impossible to control what types of interactions will be present in any given simulation run.

Appendix 2: Complementarity and supermodularity

Milgrom and Roberts define complementarity as follows: Let $f(x, y, \mathbf{z})$ be a (benefit) function where $\mathbf{z}$ is a vector of variables. The variables x and y are complements, if f is supermodular, i.e., has the following property:

$$f(x'', y'', z) - f(x', y'', z) \geq f(x'', y', z) - f(x', y', z) \quad (1)$$

$$\text{for all } x'' > x',\ y'' > y' \quad (2)$$

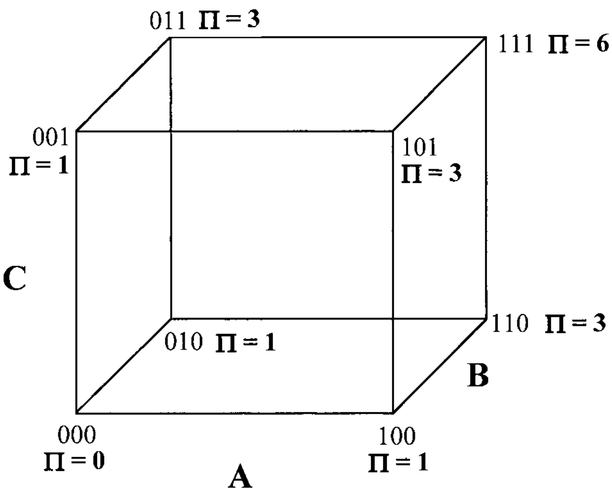
$$\text{and all values of } \mathbf{z} \quad (3)$$

Complementarity is, thus, defined to occur when increasing the variable x from its lower level x' to the higher level x'' is more beneficial when the second variable y is at the higher level y'' than at the lower level y'. Condition 2 states that this relationship between x and y has to hold at all levels of x and y. Condition 3 requires that this relationship hold for all values of all the other variables $\mathbf{z}$. Only if the above conditions hold for all pairs of variables (between x, y, and $\mathbf{z}$ and among the variables constituting $\mathbf{z}$), does the set of variables $\{x, y, \mathbf{z}\}$ form a system of complements.[13]

Translated into our activity terminology, each variable corresponds to an activity, while x', x'', etc. are different configurations of activity x. Note that the Milgrom and

[13] For clarity, we chose to unpack the definition given by Milgrom and Roberts (1990, p. 516): "A function f: $\mathbf{R}^n \rightarrow \mathbf{R}$ is supermodular if for all $\mathbf{a}$, $\mathbf{a}' \in \mathbf{R}^n$, $f(\mathbf{a}) + f(\mathbf{a}') \leq f(\min(\mathbf{a}, \mathbf{a}')) + f(\max(\mathbf{a}, \mathbf{a}'))$." Rewrite $\mathbf{a}$, $\mathbf{a}'$ as: $\mathbf{a} = (x', y'', z)$ and $\mathbf{a}' = (x'', y', z)$ with $x', x'', y', y'' \in \mathbf{R}$ and $\mathbf{z} \in \mathbf{R}^{n-2}$. Since the above definition of supermodularity has to hold for all vectors $\mathbf{a}$, $\mathbf{a}'$, consider $\mathbf{a}$ and $\mathbf{a}'$ that fulfill: $x'' > x'$ and $y'' > y'$ (our condition 2) for any $\mathbf{z} \in \mathbf{R}^{n-2}$ (our condition 3). Then $\max(\mathbf{a}, \mathbf{a}') = (x'', y'', \mathbf{z})$ and $\min(\mathbf{a}, \mathbf{a}') = (x', y', \mathbf{z})$. Substituting into the above definition yields: $f(x', y'', z) + f(x'', y', z) \leq f(x', y', z) + f(x'', y'', z)$, which can be rewritten as $f(x'', y'', z) - f(x', y'', z) \geq f(x'', y', z) - f(x', y', z)$ (our condition 1). ($\mathbf{R}$ denotes the set of real numbers.)

Figure A1
Complementary interactions



Each activity, A, B, and C, can be configured in two ways, 0 and 1. Each vertex of the cube represents one of the eight different possible combinations. The payoff associated with each combination is given next to each vertex.

Roberts framework requires that the possible choices for each activity can be ordered, e.g., small vs. large investments in flexible machinery. All statements of activity "levels" are thus to be understood with respect to such an order.

Appendix 3: Complementarity and contextual interactions

The following example illustrates the concept of contextuality while revealing the restrictiveness of the complementarity conditions. Consider the case of three activities, A, B, and C. Each activity can be configured in two ways, which we denote by 0 and 1. Hence, the firm can consider eight possible combinations of ABC: 000, 001, . . . , 111. We normalize the payoff of the combination 000 to be zero. Figure A1 displays a case in which A, B, and C are complements. In this case, changing one and only one activity from 0 to 1 yields a benefit of 1, changing two activities yields a benefit of 3, and changing all three activities yields a benefit of 6. Thus, the payoffs of the eight combinations are given as follows: $\Pi(000) = 0$; $\Pi(100) = \Pi(010) = \Pi(001) = 1$; $\Pi(110) = \Pi(101) = \Pi(011) = 3$; $\Pi(111) = 6$. To check the complementarity between A and B, for instance, note that changing A from 0 to 1 is more beneficial if B is at 1 rather than at 0. Similarly, changing B from 0 to 1 is more beneficial if A is at 1 rather than at 0. Moreover, note that these relationships hold regardless of the level of C.

For C = 0:

A's marginal benefit is larger at the higher level of B:

$$2 = \Pi(110) - \Pi(010) > \Pi(100) - \Pi(000) = 1$$

B's marginal benefit is larger at the higher level of A:

$$2 = \Pi(110) - \Pi(100) > \Pi(010) - \Pi(000) = 1$$

Similarly for C = 1:

$$3 = \Pi(111) - \Pi(011) > \Pi(101) - \Pi(001) = 2$$

$$3 = \Pi(111) - \Pi(101) > \Pi(011) - \Pi(001) = 2$$

Similar calculations reveal that the interactions between activities A and C as well as between B and C are always complementary. Now consider a single modification to the payoff structure: Assume that changing all three activities yields a benefit of 4 rather than 6, i.e., $\Pi(111) = 4$; changing all three activities is still more beneficial than changing any two, but less so than previously. With this single modification, all three interactions between A, B, and C become contextual. Consider, for instance, A and B. When C is at 0, A and B are still complements, yet when C is at 1, A and B are now substitutes.

For C = 0: payoffs are as given above.

For C = 1:

A's marginal benefit is *smaller* at the higher level of B:

$$1 = \Pi(111) - \Pi(011) < \Pi(101) - \Pi(001) = 2$$

B's marginal benefit is *smaller* at the higher level of A:

$$1 = \Pi(111) - \Pi(101) < \Pi(011) - \Pi(001) = 2$$

The same relationships are found between A and C (both are complements if B = 0 and substitutes if B = 1) and between B and C (complements if A = 0 and substitutes if A = 1). Similar results are achieved for other modifications of the payoff structure (e.g., changing $\Pi(001)$ from 1 to 3 creates contextual interactions between A and C, and B and C, while retaining the unconditional complementarity between A and B). While not every modification to the payoff structure eliminates the generic complementarity among A, B and C (e.g., increasing $\Pi(111)$ to 7 leaves the unconditional complementarity intact), the strict conditions required by complementarity are easily violated, creating contextual interactions.

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