Capabilities as Real Options

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Strategy research consists of a balance between positive and normative theory. In recent years, normative theory has drawn heavily from industrial economics for its positive justification. Resource and knowledge-based theories of strategy, however, rely on research on organizations as a complementary foundation to industrial economics. This paper explores the joint connection of organizational theories and financial economics by developing the argument that capabilities, or core competencies, are strategic options that provide platforms for the exploration of market opportunities. Investments in these capabilities have an irreversible character because of the complex interdependencies among organizational and technological elements. These interdependencies are rooted in the impediments to organizational adaptation and change. Yet, this inertia is exactly why organizational capabilities have an irreversible quality, and it is this irreversibility that defines the value of capabilities as strategic options.

We formally motivate these ideas for the evaluation of capabilities as strategic options through a formal descriptive model. The valuation of core capabilities is derived from observing the price dynamics of correlated strategic factors in the market. Because of inertia, managers cannot easily adjust the wrong set of organizational capabilities to the emergence of market opportunities. However, firms that have made investments in capabilities appropriate to these opportunities are able to respond. From this description, we define core competencies as the choice of capabilities that permits the firm to make the best response to market opportunities. The heuristic framing of capabilities as strategic options guides the normative evaluation of balance the balance between exploitation and exploration.

[Key words: strategy, options, capabilities, heuristics]

Strategizing is the application of heuristic frames to analyze the world and to generate normative evaluations of potential avenues of implementation. The most eminent names in strategy are often associated with a heuristic, e.g. Porter and industry analysis, Hamel and Prahalad and core competence. Yet, like many professional schools caught between academics and application, strategy research is often ambivalent about the implications of valuing the development of heuristics. Because a test of a good heuristic is its application, the relevant community by which to evaluate such contributions appears often to be the commercial world.

This tension is probably more functional than commonly realized. Professional schools of business share, as Simon (1969) noted, commonalties with schools of design, e.g. engineering or architecture. Strategy research reflects competing ideas about how the world looks, or what the world needs.[1] However, like their counterparts in engineering or architecture, strategy researchers distinguish themselves from practitioners by their attention to an articulation of theory and evidence.

Ned Bowman (1995) has made the distinction between strategies that look in the mirror and those that look through the looking glass. In the parlance of contemporary strategy research, resource and knowledge theories of the firm are inward looking, whereas market positioning and industry analysis are outward looking. It is not surprising that during a time of restructuring and re-engineering, strategy researchers should shift the emphasis from industry analysis to the internal sources of competitive advantage. The international competition and the introduction of information technologies have, as the extensive literature on American competitiveness has documented, generated considerable competitive pressures on corporations.

The current emphasis on looking in the mirror begs the question of how to choose among

[1]Mintzberg (1990) suggests there are no less than 10 schools of strategic planning.

alternatives. The resource based and knowledge theories view the unique capabilities of the firm as the cornerstone of sustainable rents. These approaches share the common insight that a chosen strategy presumes the capability of implementing the vision. A heuristic appropriate to identifying capabilities required to support a strategy is provided by the notion of core competence, as proposed by Hamel and Prahalad (1994). And yet, it is often overlooked that Hamel and Prahalad (1994) essentially invert the framing of a resource-based view of strategy by arguing for the analysis of white spaces in the topography of existing businesses to identify valuable avenues of exploration.

The ideas of core competence and white spaces share strong parallels with the heuristic application of real option theory to strategy, whereby investments in exploration create capabilities to address future opportunities. In this regard, a real option is strongly reminiscent of the distinction between exploitation and exploration.[2] Firms, as adaptive systems, strike a balance between refinements of existing processes and explorations of variations on new techniques. The static analysis of deciding to allocate effort to each of these activities is especially complicated, because current efforts result in short-term efficiencies that can overwhelm long-term efforts of exploration (March, 1991). Thus, the dynamics by which capabilities interact and are learned pose a complex combinatorial problem.

We propose that the theory of real options provides an appropriate theoretical foundation for the heuristic frames suggested as ways to identify and value capabilities and exploratory activities. Since capabilities are platforms that create a generic set of resources, they represent investments in future opportunities. The distinction between exploitation and exploration has an exact correspondence in the difference between net present value and option valuation. The superficial attractiveness of real option thinking is in the obvious characteristic of forcing managers to think about the value of flexibility in response to uncertain events. The more fundamental contribution is to require that the valuation placed upon a strategy is derived from dynamic equilibrium prices in the market. In effect, real option valuation marries the resource-based view with industry positioning by disciplining the analysis of the value of capabilities by a market test.

The advantage of establishing the theoretical foundations to heuristic approaches is the ability to resolve contradictions and to link seemingly unrelated phenomena. In the discussion below, we address three paradoxes and show their interrelations. These are:

1. Strategic heuristics involve a combination of inward-looking (i.e. mirror of resource-based theories) and outward-looking analyses (i.e. window into market positioning).
2. Organizations are inert and yet success depends on flexibility.
3. Organizations have the property of "uncertainty avoidance" and yet their growth depends upon exploration in high-risk environments.

We proceed by first characterizing what are heuristics and how real option theory and core competence are related through the concept of capabilities. A central concept in organizational theory is inertia, which is similar to the notion of "irreversibility" that is critical to the definition of a real option. The argument that we develop is that capabilities reflect irreversible investments, because of the costliness of rapidly transforming the organizational knowledge in a firm. This knowledge can be considered as a composed set of technological and organizational complements, very much in the spirit of the socio-technical tradition. The difficulty facing a firm is that improvements in complements provide a competitive advantage, while also generating a high level of inertia that inhibits the firm from radical change.

We examine these ideas through a stylized mathematical *description* of the problem of

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[2]See Hedlund and Rolander (1990) and March (1991).

adopting radical change. This formalization clarifies that the benefit of a real options heuristic is the imposition of a market test to derive the valuation of capabilities. It also allows for a precise definition of a core competence as derived from the valuation of inert resources from the perspective of the market. Our intention in this description is not to resolve the many important challenges to the practical implication of valuation, but rather to show that the theory of real options leads to insights into the above paradoxes that lie at the heart of the overlap between organizational theory and strategy.

Heuristics:

Following distinctions made in cognitive science, we separate a heuristic into its cognitive frame and the rules of search. A cognitive (or heuristic) frame refers to the 'representation' of the problem and solution space. The heuristic rules of search are the algorithms by which solutions are found in the represented solution space.[3]

Simon (1969) introduced both of these elements by defining heuristics as procedural search in distinction to the substantive rationality of economics and operations research. Simon noted that the solutions to many problems are not computable, that is, the search algorithm cannot in finite time determine the optimal answer. The problem of computation is classically illustrated by the traveling salesman problem in which the objective is to minimize the travel costs of a salesperson who has to visit 50 cities. The 50! calculation is computable, but not within any reasonable horizon.

Strategy often has this level of complexity. In order to know whether a firm should enter into a particular business, it is important to understand the costs and quality of the product or service that can be delivered. And it is also important, consequently, to understand the response of competitors to the

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[3] See Minsky (1985:74, 243-253) for an example. The definition of heuristic search is discussed in Bowman and

competitive entry of an innovation and its embedded bundle of attributes (e.g. price, quality). There are, then, two embedded decisions, one determining the capabilities, the other the market strategy. The dimensional problem of identifying all these elements and understanding their interactions quickly defies a declarative analysis (i.e. net present value) or an exhaustive procedural search across all combinations.

Heuristics are procedural descriptions of how better, as opposed to optimal, decisions or actions may be taken in the context of an organization. It implies a cognitive frame, or what Simon calls a "representation", of the problem as well as a procedure to identify satisfactory solutions. It may be explicitly or implicitly derived from a theory. For example, the procedure by which a firm generates the data for a formal financial evaluation is derived from the theory that discounted cash flows is the appropriate valuation of an investment decision. Elements to this theory include the separation theory of ownership and control in financial markets that permit efficient trading of investment opportunities. Rarely, however, would this theory be explicitly evoked in order to justify the implementation of an organizational process to collect and analyze data for investment decisions.

We claim that a good heuristic has four qualities: it is easy to use, easy to communicate, provides a better direction than ones currently employed, and motivates people who have to implement the strategy. The Boston Consulting Group growth matrix is an example of a heuristic. It requires only two data inputs of market growth and relative position. The famed ideograph of stars, dogs, question mark, and the cash cow have an Orson Wells "Rosebud" value, i.e. they are comprehensible and memorable. (In world characterized by what Brown and Duguid (1991) call a "community of practice", ideographic and metaphoric communication is critical to the success of information technology implementation and performance.) The implementation of the matrix leads to a clear

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Moskowitz (1997).

motivation to grab market share. However, the not-so-minor drawback is that the heuristic often gives the wrong direction.

Because heuristics are intended to be used, they have many qualities that upset the norms of academic research. The objections come from all quarters. Sociologists point out that such heuristics reflect prevailing norms of style or conceptions of control. Cognitive psychologists note that heuristics are prone to type 1 and 2 errors, that is, managers ignore evidence of misfit and overstate the possibility of success. Social scientists are quick to criticize the absence of formal theory and empirical evidence.[4] Ad hoc field research indicate that well-educated Ph.D. business faculty frequently moan over the humiliation of teaching heuristic frames that are not clearly derived from their formal education.

Heuristics are useful because formal theory often does not suggest operational rules, or is not credible, for the problems decisions makers confront in actual conditions. Since they are intended to guide action, heuristics are designed to motivate. From a normative perspective, overestimation is an evolutionary attractive property for assembling human effort; an emphasis on sober assessment screens out people who are most likely inclined to act. Because they are meant to influence action, they are biased toward current conceptions of the world; they are also liable to be dispensed as these conceptions change.

Heuristics have the advantage of countering some cognitive biases, but at a cost. In a study on plant scheduling, Bowman (1963) found that managers would do better if they used linear estimates from their experience rather than tried to optimize in response to each situation. The implication is that managers would do better to rely upon experiential heuristics than seek to optimize each situation.

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[4]For styles of thought, see Guillen (1997) and managerial control, Fligstein (1990); for overestimation bias, see Kahneman and Lovallo (1993); for a discussion of a lack of theory, see Simon's (1969) discussion of the

In real time, the search for optimal strategies can be too costly or liable to be influenced by recency effects (e.g. the arrival of new information). Kunreuther (1969) modified these findings that rules cued to selective environmental information improve actual decision making. This finding implies that there may be certain meta-heuristics that identify the environment and, thereby, indicate the application of less robust but more appropriate decision rules.

One of the merits of a heuristic is its real-time utility. Studies on innovation show remarkable tradeoffs between costs and time for innovations (Scherer, 1967; Mansfield, 1988). Field research and experimental evidence show ample evidence that people rely upon rules of thumb and known routines in situations constrained by time, even for simple problems for which there exist optimal rules. Because decisions must be made, managers and firms often transfer these sub-optimal rules to settings that are poorly suited to these proven heuristics. The limits to the robustness of a heuristic are usually experiential, because the theory is rarely explicit or is ignored.

The Cohen and Bacdayan (1994) experiments illustrate these tradeoffs between implicit heuristics and misapplications. Their study of the emergent rules in a simple card game showed that simple heuristics, labeled as routines, guided the behavior of play. Better routines, of course, were associated with better outcomes. When the game changed, the players tended to engage in "negative transfer", that is, they transferred the acquired heuristics to the new game even though inappropriate. This negative transfer is an instance of a competency trap. Or in the words of Burke, one can be made "unfit by a too fit fitness."

Strategizing is, then, the application of explicit heuristics to problem solving and implementation. Unlike the implicit heuristics that represent what Argyris and Schoen (1978) call "theories in use", strategizing applies explicit schemas to search for appropriate decisions.

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professional school.

Nevertheless, the underlying theories to these heuristics are often only implicit. Consequently, even explicit heuristics are liable to be applied to the inappropriate setting if hidden assumptions prove to be wrong.

Heuristics, Strategizing, and Real Options:

The history of strategic planning tools documents the applicability and limitations of heuristics. That this history shows the waning and waxing of certain rules suggests that heuristics are integrally tied to context. Fligstein's (1990) thesis is that particular eras are marked by specific "conceptions of control". Whereas the 1960s and 1970s were concerned with choosing the right businesses for a portfolio, strategic analysis of the early 1980s stressed the undesirability of competition in mature markets. More recently, the growth of institutional investors and venture capital have lead to a few of the firm as consisting of assets that can be stripped and recombined.[5]

The BCG cash flow matrix "works" to the extent that the theory of scale and experience driving down cost is the proper characterization of value creation. From the initial data, it bootstraps from observations on market growth and relative positions to evaluate whether a firm can dominate a market. Though a fairly simple heuristic, it shared the common bias of its times that size drives success, as opposed to the more modest inference that size is the outcome of success.[6]

Porter (1980) developed his industry analysis in the immediate aftermath of the oil shock and during a period of depressed corporate profitability. Its theory is derived from an industrial economics

[5] For an analysis of institutional investment on firms, see Useem, 1996.

[6] For examples of this bias, see Chandler (1962) and Servan-Schreiber (1969). Only in light of this backdrop is it possible to understand the contribution of Piore's and Sabel's (1984) counter-revolution in thinking about size and performance.

that appears as antiquated by contemporary advancements, but reflects the preoccupations of a time when the historical peaking of oligopolistic measures of concentration suggested that industry structure deeply influenced corporate performance. It is, in many ways, an inevitable implication of the BCG analysis that a world in which a few firms grow to dominance should lead to a focus on how to attain the conditions of structural stability. The initial data on industry forces serves to inform the choice between low-cost and differentiation strategies. The implementation proceeds through an evaluation of the value-chain, with the criterion being contribution to profit. Compared to the requirements of the BCG growth matrix, the methodology is intensive in the use of data.

The core competence concept arose in the late 1980s during the height of re-engineering propelled by acquisitions and new information technologies. It is a direct response to the reputed financial pressures from financial markets dominated for the first time by institutional investors. The formulation by Hamel and Prahalad (1994) suggests that the initial data are in the spirit of understanding the intended strategy of the firm that should be grounded in a distinctive competence.[7] This competence is defined by three attributes: it should be ‘extendable’ to multiple markets, it should be hard to imitate, and it should satisfy a derived customer demand (Hamel and Prahalad, 1994: 202-207).

The theoretical foundations to this view are several, from the reasoning on why knowledge is hard to imitate to the evolutionary theories of firm growth. From a decision theoretic perspective, the core competence framing lends itself readily to a real option interpretation. A real option is defined by an investment decision that is characterized by uncertainty, the provision of future managerial discretion to exercise at the appropriate time, and irreversibility.

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[7]Selznick (1957) was one of the first to develop the idea of distinctive competence, which was absorbed into the

These three elements are jointly required for the application of a strategic options heuristic. An option has value only if there is uncertainty, though defining the relevant source of the uncertainty is not trivial. An operationally important element of design is the provision of discretion, such as the staging of an R&D project to correspond to discrete points of go-no go decisions.

Irreversibility is an easily overlooked feature and signifies the inability to costlessly revisit an investment or decision. Irreversibility is a subtle idea that carries the notion of the arrow of time.[8] For example, the decision to make an investment today bears the risk that the invested assets can only be sold later at a discount. In fact, the decision to divest is likely to be coupled with the realization known to the market in general that the original expectations have been disappointed. A classic example is the BCG categorization of the "dog" product division which a firm should divest, assuming there is a market. However, the ability to divest a poorly performing division is, as Winter (1987) observes, rarely exercised without incurring a loss on the original investment. In this context, irreversibility is the inability to recover the investment costs already expended for the product division. Irreversibility is accentuated if the divesting of an investment also engages costs attached to the unbundling of integrated and coupled assets.

Capabilities as Strategic Options:

The concept of irreversibility is critical to understanding the argument why inertia of organizational capabilities is the source of the value of strategic options. Because time has an arrow, the decision to delay making investments in knowledge needed to enter a new market has a time subscript. The value of this decision will be different if it is considered next year; other firms may

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language of the early business policy literature, as well as of writings on the value-added chain.

[8] Georgescu-Roegen (1971: 196ff.) provides an explicit and early discussion of irreversibility, hysteresis (as discussed

have entered and the early rents are now dissipated. Since strategy entails a decision to invest in capabilities in order to sustain a market strategy, foregoing this investment means that the firm does not have the option to launch the strategy if the market becomes favorable. However, not all capabilities are irreversible. The failure of a firm to invest in information technologies at one point of time does not preclude contracting out for such services in the future. But more likely, the opportunity to invest will diminish in time, as others come to build or acquire the necessary capabilities. Thus, irreversibility has the implication that the asset should be "scarce" and difficult to replicate in a timely way in order to support a strategy at a particular time.

A core competence is, by definition, a sub-set of the capabilities of a firm. A firm consists of many capabilities, ranging from functional expertise to highly defined skills in the development of certain kind of technologies. It is, however, an exalted sub-set insofar that it is highly valued in the market. A core capability is a scarce factor, as Barney (1986) defines it, which also embeds complex options on future opportunities. The scarcity of a resource at a given point in time implies irreversibility. If, through imitation and substitution, this factor will be more abundant in the future and its value will be less, the option value is only realized through the current investment to exploit transient opportunities.

The definition of a core competence as a strategic option captures this notion of irreversibility and scarcity. In spirit, it is close to the argument put forth by Barney (1986, 1991) regarding the resource-based view of the firm. To Barney, the creation of entrepreneurial rents is fortuitous. If managers understood the value creation process, the knowledge through imitation would lead to the

later), and the arrow of time. The arrow of time and evolution are central themes in Prigogine and Stengers (1984). A volume of essays on irreversibility (with little closure on definition) is Boyer, Chavance, and Godard (1991).

immediate erosion of these rents.[9] The presence of a strategic factor market allows the arbitrage of these assets to guarantee a competitive return in financial markets.

The important difference between this early statement of the resource-based view of the firm and core competence is the latter's insistence on the value of a resource as derived from its future but uncertain use. In the sense that Barney relies on market valuations to back into his identification of unique assets, he is consistent with the view that the market values the use of these assets in reference to their potential use by firms bidding for their ownership. Dierickx and Cool (1989) note that Barney makes the incomplete inference that these firms must have differential information by ignoring the arrow of time (or what they call "time compression"). An equally plausible insight is that firms differ in their opportunity set, inclusive of the organizational assets that are costly and time consuming to acquire. Consequently, some firms will discover profitable projects, where the 'excess rents' are earned on their organizational, not physical capital, assets.

Real option theory bridges, then, the positioning and core competence schools by dynamically deriving the value of capabilities simultaneously from two discrete operating states: their value as "is" and as "could be". The "as is" evaluation is a net present valuation based upon an evaluation of the range of possible payoffs by *exploiting* operations currently in place. The option value is derived from *exploration* of new operations to take advantage of future opportunities. In this simultaneous valuation of both operating states of exploitation and exploration (they are clearly dependent), the analysis derives the valuation by creating a shadow security whose value can be derived from the market value of the strategic factor.

It is the identification of the future opportunity set, as established through market valuations,

[9] For a discussion, see Kogut and Zander (1992) on knowledge and combinative capabilities as options, and Zander and

that should drive the identification and valuation of core competence. Some writers fail to make this observation altogether. For example, Teece, Pisano, and Shuen write:

> We define those competences that define a firm's fundamental business as core. Core competences must accordingly be derived by looking across the range of a firm's (and its competitors) products and services…The degree to which a core competence is distinctive depends on how well endowed the firm is relative to its competitors, and how difficult it is for competitors to replicate its competences. (1997: 516).

This statement is, however, rather problematic. It derives a core competence from the description of a firm's businesses, and in comparison to competitors. Finally, it notes that distinctiveness depends on a firm's endowment and the difficulty for the assets to be copied.

The missing element in this analysis is, of course, value. A firm may be well endowed with patents making it difficult for competitors to imitate. However, the important question is whether these endowments, which we might also call more generically the knowledge of the firm, is useful not only to current, but also to future applications. This question is not answered by a notion of dynamic capabilities, or of combinative capabilities, unless the normative criterion is the identification and investment in core competence in reference to potential uses. This objection is not petty, for it is easy to imagine that without market discipline on the analysis, the potential candidates for core competence quickly multiply.

There is another way to think about this problem, suggested by Winter (1987), as a broader formulation along the lines of optimal control. Winter (1987: 180-181) states, "From evolutionary theory comes the idea that a state description may include organizational behavioral patterns or routines that are not amenable to rapid change, as well as…more conventionally defined assets. It is by this route that a variety of considerations that fall under the rubrics *knowledge* and *competence* may

Kogut (1995) and Szulanski (1995) for empirical studies that measure inimitable as tacitness.

enter the strategic state description."[10] This suggestion seems odd, for optimal control requires an excessive belief in the rationality and knowledge of decision-makers, a belief that Nelson and Winter (1982) have strongly criticized. However, it is not a bad heuristic (Winter uses this term) if some of the insights of a capabilities approach is properly specified. A conventional formulation is to describe the characteristics of the state description and allow the decision maker discretion over a few control variables, e.g. technologies or output. A transformed formulation deprives the decision maker of control over some variables and, in effect, captures the constraints and opportunities of capabilities through a richer description of the given state in a decision context.

It is, consequently, reasonable to think of a firm's technology and organization as forming a coherent and dynamic set of capabilities whose value is derived from their value in future and stochastic states of the world. Such capabilities as speed of production or the ability to produce a particular quality are created through the possession of a set of technologies and of organizing principles. Given these capabilities, the firm is endowed with the resources that may be exploited strategically in the market.

Capabilities as Irreversible Investments

Leonard-Barton (1992) notes that core competencies are also core rigidities. In this paradox lies, however, the realization that rigidity is a necessary attribute to competitive advantage. As many have noticed (e.g. Barney, 1991, Yao, 1988), organizational assets are the most valuable sources of competitive advantage because they are rigid and difficult to imitate. Since only scarce assets earn excess returns, assets that are difficult to change and imitate are candidates to provide enduring

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[10] Winter (1987) suggests net present value as a measure, which is appropriate for the case without uncertainty. Most surveys on the use of capital budgeting techniques show that almost all large corporate firms use net present value calculations for investment decisions. See Kogut and Kulatilaka (1992) and Baldwin and Clark (1992, 1994) for a

sources of rents. Incumbents cannot easily change their organizational composition to imitate better performing firms. And innovating firms who invest early in these capabilities have future opportunities for market expansion that they may not have if they delayed these investments. Thus, it is the tight coupling inherent in organizational capabilities that is the source of value.

This view on the value of inertia appears to conflict with the standard interpretation of the demerits of inertia, which is usually seen as a detrimental property to the organization. Notions of "tight coupling" or complementarities imply that a firm's ability to adapt quickly to environmental change is restricted by inertia. Yet, as Hannan and Freeman (1984) recognize, firms may encourage inertia in order to promote routinized expectations among customers and suppliers. Thus, inertia is again a double-edged sword, both crippling the firm and yet a necessary component to establishing a stable reputation for routine behavior.

The claim that investments in capabilities are irreversible because of the tight coupling of technology and organization is critical to the argument that capabilities are irreversible investments. Without complex complementarities inside the firm, managers would not need to worry about their choice of new technology. They could choose instead to wait and exploit their current technology until the uncertainty around technological evolution should be resolved. If, however, technology and sticky organizational assets are compliments, then it would pay to explore new investments in technologies and organizational capabilities even if current knowledge could best exploit the immediate market opportunities.

Understanding investments in new capabilities as exploration resolves some of the classic conflicts in defining radical innovations. An area of debate has been whether to treat major technological innovations as radical or incremental. The organizational literature, especially Tushman

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discussion why investment in capabilities is not a net present value of cash flows but a real option valuation.

and Anderson (1986), has offered the resolution that these innovations can be characterized as radical or incremental depending upon whether they destroy or enhance a firm's competence. (See also Henderson, 1993.) This resolution raises the more fundamental problem that a firm, by its ability to recruit new engineers and managers, should have the capacity to alter its technological competence. The costs of switching to a technology should, by this reasoning, consist of the costs of hiring new individuals trained in the new science or engineering technology. Yet, clearly, the difficulty of adopting of new capabilities cannot be explained by the relatively open recourse to the labor market in most advanced capitalist countries.

This reasoning ultimately leads to the consideration that the radicalness of an innovation has less to do with the novelty of the technology than its conformity with existing knowledge of the firm, i.e. the ways by which work is organized and power is distributed. Since the way work is organized will vary by firms, then the radicalness of a technological innovation can not be determined independent of a particular organizational context. Switching, or adoption, costs are strongly contingent on the current organization of work.

If radicalness of a technological innovation is a question of the organization, it follows that the potentially most radical kinds of innovation are those which alter directly the method by which work is organized. It is an organizational innovation that poses potentially the greatest discontinuity. New ways of doing things are often difficult to understand and implement.

To draw out why, consider the very important literature in organizational behavior concerning the suitability of particular organizational and technological combinations. One of the most perplexing questions in organizational behavior is the failure to identify clear matches between technologies and organizational structures. Yet, the findings are rather ambiguous in this regard. The line of work begun by Woodward and later the Aston school that linked performance to particular technological and organizational combinations has not resulted in clear relationships. Indeed, the most robust finding appears to be between organizational size and output volume rather than between particular structural and technological configurations. Indeed, even the findings between size and authority relations have been found to be sensitive to contextual variables, such as culture.[11]

Dosi and Kogut (1993) proposed that the failure to find robust relationships has been due to the tendency to theorize element to element correspondence, such as high volume production with vertical hierarchy.[12] (See 1a.) The empirical results do not show that these are complements when other factors are controlled. Alternatively, the correspondence might be set to set, where a set of organizational practices maps onto a set of technologies. The data might not reveal that A and B exist as complements; all we observe is A and C and D and B. Complementarities need not be unique between any given technology or organization, but they still should be relationally bounded. The recent findings by MacDuffie (1996) on "bundles" of human resource practices in auto plants indicate that there is a logic that relates organizing practices to each other, and to technologies. (See figure 1.) The experience of General Motors and other car manufactures is that adopting the new capabilities of flexibility and speed requires changes in automation and organization. Between these two sets, there are many functionally equivalent complements, but there are no unique element-to-element correspondences.

This description captures also the idea of co-evolution of technology and organization through

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[11] See the review given in Dosi and Kogut (1993) and the summary of the work comparing U.S. and Japanese organizations (Lincoln, 1993).

[12] This point is implicit in the lattice formulation of Milgrom and Roberts (1990), where a firm's choice is constrained by technical complementarities.

two key features. First, technology and organization do not represent random assignments, nor is their coupling simply at the discretion of managers. Rather, the matches of a technology and organizing principle are constrained to reasonable set-to-set correspondence. However, within these 'developmental' constraints, improvements in technology and organization are correlated through experiential learning. For example, the introduction of mechanical equipment to move the incomplete chassis from one line to the next required the organizational innovation to increase the 'tightness' of the coupling of serial work processes in the factory. In other words, technology and organization are dynamically coupled in their evolution.

The costs of altering tightly-coupled components of technology and organization imply that firms will persist in their old ways beyond the recommendation of the net present value. This persistence defines a range of inertia, or what is called a hysteresis band. Because organizational change is disruptive and hence discontinuous, managers hesitate to change radically their organizations, hoping perhaps that future states of the world would provide more appealing environments.

Figure 2 provides a simple illustration of this point. A firm can choose between two complementary systems, called low and high variety. The important issue is whether the relative value of gaining the capability of variety is enough to offset the costs of discontinuous change. The choice of capabilities is, as we depict it, derived from the market price placed on variety. Because of uncertainty over the evolution of the value of variety and the costs of adoption, managers rationally might choose to persist with inferior techniques before they are confident of future developments.

The concept of core capabilities as embodying exploratory options on the future runs counter to some streams of thought on organizational design. By proposing the idea of "uncertainty avoidance", March and Simon (1958) suggested that an organization's design serves the function of eliminating variance. This idea appears also in Thompson's (1967) landmark book that analyzes the many ways that firms buffer themselves from uncertainty. Similarly, Pfeffer and Salancik (1978) motivate the theory of resource dependency as the creation of organizational mechanisms to reduce uncertainty. Given the supposition that firms are essentially cybernetic programs that enact inert routines or consist of stable technologies, it follows that an important property of survival is the absorption and reduction of environmental uncertainty.

But the problem with this view is the over-emphasis on the inertia of the firm relative to its adaptive exploration of new opportunities. In Ashby's (1960) proposal of a second-order learning, an adaptive system seeks to generate an internal "requisite variety" to insure a robust probability of survival across many states of the world. Hannan and Freeman (1977) acknowledge the potential of an internal requisite variety by identifying a generalist strategy that improves survival chances for high environmental uncertainty.

Yet, to a surprising extent, organizational ecology has been reluctant to recognize the strategic implications of its own logic. Its critical contribution was the insistence that a firm's success (even if measured by satisfying the boundary condition of survival) is determined by external environment. However, the straightjacket of assuming inertia (albeit sometimes limited only to a "technical core") denied the innovative capacity of organization and firms.

When organizational theorists move toward the implementation of their ideas, organizations appear less as passive mechanisms to dampen environmental variance than as agents that desire to generate it. For example, Tushman and O'Reilly (1997: 14) clearly identify the contradiction between the forces for stability and for active adaptive change and yet suggest that certain organizations, which they label as “ambidextrous”, can cut this Gordian knot. They write:

> Long-term organizational success requires streams of innovation –systematically different kinds of innovation over time. These *innovation streams* run counter to forces for organizational inertia. Give these contrasting forces for change and stability, managers need to create ambidextrous organizations –organizations that celebrate stability and incremental change as well as experimentation and discontinuous change simultaneously.

There are two important elements in the above quote. First is that stability and incremental change are linked, that is, firms learn to be more efficient in the exploitation of current activities. Second is that experimentation allows a firm not only to adapt to discontinuous change, but even to introduce radical innovations.

In a normative vein, it stands to reason from the point of view of an organizational ecology that a firm should experiment in activities that promote its future survival. In this sense, organizational ecology offers an escape from the inward-looking bias of the resource-based view of strategy. For enhancing future survival, a firm should invest in those resources that correspond to some expectations regarding the evolution of the external environment. It is exactly the evaluation of this correspondence between exploration of new capabilities and the evolution of the market environment that is provided by the application of a real options heuristic.

A Formal Description

The real option perspective seeks to bridge the understanding of organizational assets as competitive resources with the market valuation of their deployment through particular product strategies. To examine the inward-looking conflict of allocating between becoming good at exploiting knowledge as opposed to exploring new capabilities, we introduce the concept of a capability family that consists of a pairing of organizational and technological elements. A firm learns to improve the efficiency of these capabilities, yet at the risk of increasing its inertia. Simultaneously, a firm can divert some resources to exploration by experimenting with a new family of capabilities.

More importantly, the formal description permits for a precise definition of core competence as determined by their evaluation in the market. The problem facing the firm is to choose the capability set such that it tries to maximize its value in reference to its expectations on the evolution of prices and innovations in capabilities. In this formulation, the nature of the environment and strategy play an important role in shaping the capabilities of the firm. This problem is dynamically complex, as the firm must consider not only how its choice influences current profits, but also the *learning* of future capabilities.

This *descriptive* formulation clarifies two central claims. The current capability set and prevailing environment and market influence the choice and performance of a set of capabilities. In other words, from the option perspective, a strategy considers both the internal resources of the firm and the external market. The second claim is that there is a set to set correspondence within families of technology and organization that bound the feasible bundles of practices. Thus, firms are relatively inert in switching across families, even if adaptive within a given family. As a result, acquisition of flexibility requires irreversible investment in exploration.

We seek below to offer the theoretical underpinnings to understanding core competence as an option, not to value explicitly a real option. (Dixit and Pindyck (1994) and Amram and Kulatilaka (1999) provide a thorough collection of such applications.) For many applications, there exist reasonable avenues of valuation. Capabilities clearly pose challenges to identifying appropriately the market valuation; it is a frontier question to derive the appropriate price dynamics by which to value a capability. However, the formal description has the important advantage of clearly defining a core competence in reference to a market valuation, as well as providing a clear statement of the tradeoffs between learning and exploitation, on the one hand, and experimentation and exploration on the other.

Looking Outside the Firm: Market Pricing

How should we value an investment in new capabilities? Clearly, the value of a capability depends not only on the internal assets but also on how those assets are deployed and the external market conditions. The exploitation value of a capability will be based on following a known strategy in a particular market. One the other hand, the exploration value will depend on choosing a suitable strategy in a market not yet known.

The market price of equity of a firm similar to the capability itself provides the most direct link between the performance of a capability set and prevailing market conditions. This market price is, however, not the value of the future core competence, for if two firms should have the same capabilities, then in what sense does it reflect a comparative advantage to the firm? The problem of finding a replicating asset is directly apparent in Barney's appellation of the competitive asset as "scarce."

But whereas the value of a core competence cannot be determined so easily by reading the daily stock prices, the price of a correlated asset in the relevant 'scarce factor' market represents the initial point of departure. The value of a capability is then inferred (at times calculated) from the observed price dynamics that replicate the payoff to the real option. This replication is the device through which market discipline is imposed on the identification and selection of core capabilities. It is not the static comparison of the capability and strategic factor that matters, but rather the information that is gleaned in the changes in prices over time.

To elucidate the intuition, consider again the framing of a real options problem. The organizational assets of a firm provide an option to spend a fixed amount to procure a new capability by purchasing a physical asset at the end of one year. If the option is exercised, then the resulting project value has the risk characteristics of an existing traded firm. For example, a pharmaceutical firm is considering an entry into biotechnology. It currently has a strong capability in conventional drug development that provides an option to enter into biotechnology at an estimated cost. This cost is idiosyncratic to this firm. However, once it enters into the market, its new business carries a market risk similar to other biotechnology firms. This example illustrates why the price of other firms does not give the value of the core capability, since the cost of entry is idiosyncratic to each firm. However, the price dynamics of other firms provide information on the factors (e.g. risk) that drive the value of the option to enter in this market.

The value of a financial option depends on the current share price. Since the source of this exogenous uncertainty is the market price of a frequently traded market financial security (the share of stock), financial options can be dynamically replicated with a portfolio of stocks and risk-free investments. As a result, derivatives can be valued without knowledge of the expected return earned by the underlying financial asset.

For a special but important case, Black, Merton, and Scholes derived this value through an option pricing formula. The simple, but critical, innovation was their eventual recognition that by composing a replicating portfolio, the value of the option could be perfectly tracked by a levered position in the traded stock. Therefore, a risk-free portfolio can be constructed by holding a combination of the stock and options. This construction has the important implication that option price, relative to stock price, can be obtained without regard to individual risk preferences. Hence, once the range of possible future stock prices is modeled (using its volatility), the market price of the option can be inferred by risklessly discounting the possible option payoffs.

It is, however, unlikely that real options can be perfectly replicated with traded assets. The replication may require the use of product or factor prices. Even when widely traded, the prices of such real assets need not appreciate at a rate equal to its equilibrium risk adjusted return. Instead, owners of real assets will reap various convenience benefits and incur carrying costs that affect the total returns. In such cases, valuation requires knowledge of the actual price dynamics of the factor price and the equilibrium risk adjusted return.[13]

As an initial proposal, we suggest that the theoretically most interesting way to identify the appropriate correlated asset is to decompose the market price into a bundle of attributes that pierces the revenue veil of the firm to see the underlying assets. Whereas this analysis is unquestionably hard, it should be recalled that it is consistent both with the financial market pressure to understand (i.e. strip) assets and the growth of derivatives to hedge specific components of a firm's risk. From this angle, the value of the capability depends on its contribution to the price of product or factor prices whose risk is spanned by traded assets in the economy. The value of the capability is, thus, obtained by explicitly specifying the profit function using these prices as an argument.

A simple example is a microprocessor, whereby a quality-adjusted price can be expressed as the ratio of price to the processing speed (or "mips" for millions of instructions per second). An increase in processing speed implies that the price for one 'mips'' has declined. This quality-adjusted price of the output enters the profit function of a chip producer. Thus, the price dynamics of chips directly drive the expected cash flow from operating the 'as is' assets and from possibly exercising the

[13] If there is a futures market for this factor price (like in the case of commodity markets) we can infer the net convenience yield which will be the shortfall from the equilibrium return. Then again, we can apply the risk neutral valuation.

option to exploit the ‘could be’ investment. The price of the “strategic asset” is not, however, the value of the option. Rather, because of the correlation in their price dynamics, observations on movements in the price of the strategic asset is useful for valuing the assets of the firm. Thus, publicly known information of the strategic asset does not eradicate the value of the firm’s options, because the organizational capabilities cannot be replicated by knowing simply their price. And yet, it is through knowing the price of correlated strategic assets in the market that managers can infer the value of the strategic options embedded in the organizational capabilities.

In order to identify and value a core competence, we must specify the evolution of the quality-adjusted price that we call, θ. However, since θ is not a pure security but is the observed price of a scarce factor, its price characteristics need not necessarily evolve according to its equilibrium risk characteristics. Local supply and demand conditions and technological innovation determine the evolution of θ.[14] We assume θ to be exogenously determined and characterize its evolution by stochastic process

$$\Delta\theta_t \quad = \quad \underbrace{\mu(\theta_t, t)\,\Delta t}_{\text{Deterministic Growth}} \quad + \quad \underbrace{\sigma(\theta_t, t)\,\Delta Z_t}_{\text{Smoothly evolving uncertainty}} \quad + \quad \underbrace{\kappa\, dq}_{\text{Discrete innovations}}$$

where μ is the expected growth rate of θ, σ is its instantaneous volatility, ΔZ_t is standard Normal distributed, d*q* is a Poisson process with intensity parameter λ and κ is the random percentage jump amplitude conditional on the Poisson event occurring (Merton, 1976).

This discrete-time process captures the main features of the notion of a scarce factor market with technological innovation. The drift term reflects the expectations regarding technological progress. For example, the performance of memory semiconductors follows a fairly predictable path, with performance improvements occurring every few years and prices declining subsequently.

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14 The expected rate of appreciation of θ may be different from its risk-adjusted equilibrium rate of return. Hence, the risk-neutral dynamics of θ will depend not only on the risk-free rate of interest but also on the difference between the observed price of the strategic asset (assumed to reflect an equilibrium) and the actual growth rates of θ. See McDonald and Siegel (1984), chapter 13; Hull [1997] for a general model on valuing derivative securities.

Changes in the quality-adjusted price may also reflect unpredictable shifts in consumer preferences. For example, an increase in oil prices would lead consumers to prefer cars which save in fuel consumption. As long as these changes are fairly smooth, it seems reasonable to capture this uncertainty in volatility.

Other changes may be more radical and appear as discontinuous Poisson jumps, such as the arrival of new organizational innovations. These changes would appear as a sudden jump in price to a firm. Recall that these are quality-adjusted prices. The introduction of assembly-line methods at Ford appeared to competitors as a sudden decrease in price. However, as Raff and Trajtenberg (1997) show for the history of the automobile, part of the competitive effect of new techniques was accomplished through changes in quality, holding the nominal price the same. They estimate that quality-adjusted prices fell by 5% a year from 1906 to 1940; about 60% of this decline was to due to falling production costs and 40% to improved quality. We capture these impacts of innovative change by allowing price to evolve in response to quality and process innovations.

Valuation further calls for the equilibrium risk adjusted return of θ. This requires assuming an equilibrium asset pricing model and knowing the parameters of the priced risk for the underlying asset price. For example, if we use the CAPM, we can calculate the equilibrium return as $\mu^* = r_F + \beta(r_M - r_F)$. Then the short fall from equilibrium, δ, will be equal the $\mu^* - \mu$. Note that this still enables the capability to be a scarce factor. Although the risk characteristics of the θ are spanned by the market, its valuation is specific to the unique capability.

Looking Inside the Firm: Capability Sets

Even if two firms are competing in the same industry and market, movement in prices of the strategic asset influences differently their value because of the relationship between the capabilities of the firm and the profit opportunities. To describe this formally, we develop first the notion of a capability set and then define the profit function of a firm in relation to its set of organizational and technological practices.

A firm has the set of capabilities ***c, where c Î C*** is the set of all feasible capabilities. As an example, consider the case where ***C*** contains “mass” and “lean” production families with their associated organizational structures. Each family of production techniques can contain many distinct technologies. They are, however, coupled with the same organizational structure. Hence, a technology family refers to all technologies that can be operated within a single organization.

Suppose the firm is currently employing technology in the “mass” production family, i.e., $\boldsymbol{c^i_m}$ ***Î*** $\boldsymbol{c_m}$ ***Î C***. The firm's problem is to decide what capabilities it should use in the current period. Specifically, its choices are (a) continue using c^i_m (b) continue in the same family but make incremental technological improvements by employing a better mass production technique, c^i_m, or (c) make discontinuous organizational switch and employ lean production technique, c^k_l. Choices a and b reflect ‘as is’ evaluations; only c involves a ‘could be’ alternative.

Furthermore, a capability provides a dynamic representation of the firm. A firm’s capabilities not only serves to meet the current demands but also places it in a position to make further investments to launch new products to meet changing demand conditions. A capability endows the firm with an ability to change, but at a cost. In other words, we capture the idea of inertia through the reorganizing costs incurred by switching from one capability to another, be it from mass into lean, or conventional pharmaceutics to biotechnology. We denote these large organizational costs of switching as Δ_{ij}. For example, the cost of switching from $\mathbf{c}_n$ (mass production) to $\mathbf{c}_l$ (lean production) can be denoted as Δ_{ml}.

Within an organizational capability, however, switching costs are small, but not insignificant. At the same time, continuing within the same family enables the firm to capitalize on local learning effects. If the firm continues in $\boldsymbol{c^i_m}$ or moves to a better mass technique $\boldsymbol{c^j_m}$ then it will subsequently learn by doing. However, switching from the i^{th} to the j^{th} technology may still incur technological costs. We define the local learning benefits in mass production as $-\delta_{mm}$ and technological switching costs δ_{ii}.

To summarize the magnitude of switching costs between all combinations of capabilities and technologies, we denote the cost of switching from $\boldsymbol{c_m^i}$ capability to $\boldsymbol{c_l^j}$ will be

$$d_{ml}^{ij} = \underbrace{T_{ij}}_{\text{Technological change}} + \underbrace{\Omega_{ml}}_{\text{Organizational learning}}$$

where

$$T_{ij} = \begin{cases} \overbrace{d_{ij}}^{\text{technological cost}} & \text{if } i \neq j \\ \underbrace{-d_{ii}}_{\text{technological learning}} & \text{if } i = j \end{cases} \qquad \Omega_{ij} = \begin{cases} \overbrace{o_{ml}}^{\text{organizational cost}} & \text{if m} \neq l \\ \underbrace{-o_{mm}}_{\text{organizational learning}} & \text{if m} = l \end{cases}$$

Consider a special example where mass production family $\boldsymbol{c_m}$ contains two technology modes $\boldsymbol{c_m^1}$ and $\boldsymbol{c_m^2}$ and lean production family $\boldsymbol{c_l}$ contains a single technology mode $\boldsymbol{c_l^3}$. Table 1 presents the switching matrix containing the technological and organizational cost pairs. A negative entry indicates learning value from continuing to use the same technology or organization. A larger sign reflects a larger value.

Table 1
$\boldsymbol{T_{ij}}$ and $\Omega_{\boldsymbol{lm}}$ Switching Cost Pairs

		$\boldsymbol{c_m}$		$\boldsymbol{c_l}$
		$\boldsymbol{c_m^1}$	$\boldsymbol{c_m^2}$	$\boldsymbol{c_l^3}$
$\boldsymbol{c_m}$	$\boldsymbol{c_m^1}$	[- -]	[+ -]	[+ +]
	$\boldsymbol{c_m^2}$	[+ -]	[- -]	[+ +]
$\boldsymbol{c_l}$	$\boldsymbol{c_l^3}$	[+ +]	[+ +]	[- -]

More generally, the diagonal elements in the switching cost matrix will contain negative entries indicating the learning accumulated by exploiting existing capabilities.

Linking the Inside and Outside: Profit Functions

We can now write down the firm's objective. Each set of capabilities $\boldsymbol{c_m^i}$ has an accompanying profit function that is obtained by solving the usual profit maximization problem:

$$\Pi(q, c_m^i) = \max_{y \in c_m^i} \quad q.y$$

where θ is a vector of quality adjusted input and output prices and *y* is the vector of input and output levels that are determined by the capability set. This simple expression indicates that the firm’s ability to choose the best strategy is contingent on its organizational resources.

Critical Capability Set

Static Profit Maximization when there are no Switching Costs:

To understand the simple implications of our formal description, consider the static case where the firm maximizes its single-period profits. The firm faces exogenously determined “quality adjusted prices”, θ. The single-period profit obtained when operating under the set of capabilities ***c*** and facing prices θ_t is denoted $\Pi(\theta_t, \boldsymbol{c})$. This simple description captures the idea that firms are heterogeneous and their profits are determined both by the price of output and their organizational capabilities.

As a first pass, the firm ignores organizational inertia and costlessly obtains any feasible capability in *C*. Then we can define a *static capability* c^* as

$$c^*(q) = \underset{c \subseteq C}{\text{argmax}} \quad [\Pi(q, c)]$$

(Argmax simply picks the capability that achieves the optimal response for a given θ.) In our simple example, ***c**** picks an element from either mass or lean families depending on the respective profit functions and the particular realization of θ. Though simple, this static definition states our central claim, namely, that the selection of a core capability depends on its market valuation.

Static Profit Maximization with Switching Costs

Consider now the case where switching between capabilities involves costs reorganization.

The critical capability set depends not only on θ and the characteristics of the various profit functions, but also on the currently employed capability set. For instance if the firm is currently using $\boldsymbol{c_m^i}$, the optimal single-period profit maximizing capability set is given by the solution to the following problem:

$$\Pi(q_t, c_m^i) = \max_{c_l^j \in C}\left[\Pi(q_t, c_l^j) - d_{ml}^{ij}\right]$$

Figure 3 illustrates this choice in the special case where mass and lean families each contain only a single technique. In a costless world, the lean technique dominates globally the mass technique. However, with switching costs, the relevant comparison is between the profit function of the currently employed mass technique and the profits of the lean technique net of switching costs. When θ falls below the intersection point θ^*, the static decision rule calls for switching families. In other words, as Tushman and O'Reilly (1997) among many others observe, the adoption of innovative change occurs when a firm is in serious crisis.

Dynamic Value Maximization

The static analysis ignores the impact of the current capability choice on future choices. When future values of θ evolve stochastically, the current decision influences all future decisions as well. The decision by a mass producer of cars to invest in flexible manufacturing using lean production runs the risk that the American market suddenly decides to buy large recreational vehicles made best by standard mass production techniques. But now they face the problem that there are invested in lean manufacturing, and cannot easily switch back. The tight coupling of organization and technology is essential to understanding why capabilities radically changes the understanding of strategy as not only the choice of entering markets, but also as the selection of competence.

The way to analyze fully the implications of inertia is to write out explicitly the problem over time. To do this, we no longer work directly with profit functions, but instead with a value function. While technically this problem is often hard to solve, its formulation is both intuitive and insightful.

At a point in time (t), this formulation treats the present value of all future benefits given optimal future behavior, as represented by the value function $V(q_t, c_m^i)$. The value function is the solution of the well-known Bellman equation:

$$V(q_t, c_m^i) = \max_{c_l^j}\left[\left(\Pi(q_t, c_l^j) - d_{ml}^{ij}\right) + rE_t\left[V(q_{t+1}, c_l^j)\right]\right]$$

where $\boldsymbol{c_m^i}$, is the current capability pair (consisting of technology i and organization m) and j and *l* are chosen from the set of feasible technologies and organizations at time t+1.

The Bellman Equation has an intuitively appealing formulation, for it directly evaluates the exploitation the choice of current capabilities (the first term in brackets) with the value of persisting or switching in the future (the second term). This equation indicates that in each period the producer contemplates switching into a new capability. If it chooses capability $\boldsymbol{c_l^j}$, it realizes benefits of $\Pi(q_t, c_l^j)$, but pays switching costs of d_{ml}^{ij}, and then arrives at the following period with value function $V(q_{t+1}, c_m^j)$. This value depends on the capability chosen, c_l^j, as well as on the value of the state variable next period, q_{t+1}. Because still θ_{t+1} unknown at time *t*, we take expectations; we also discount at rate ρ.[15]

In each period, the producer chooses the capability c_l^j that maximizes the value of the project. This choice can be interpreted as defining the *dynamic capability* as

$$c^{**} = \operatorname*{argmax}_{c_l^j}\left[\left(\Pi(q_t, c_l^j) - d_{ml}^{ij}\right) + rE_t\left[V(q_{t+1}, c_l^j)\right]\right]$$

In the absence of switching costs, the solution to this optimization problem is simple: choose in each period the capability $\boldsymbol{c_l^j}$ that maximizes $\Pi(\boldsymbol{q_t}, \boldsymbol{c_l^j})$ in that period. This is the *static critical capability* discussed earlier. However, the presence of switching costs makes a forward-looking analysis

[15] For present purposes we ignore issues of risk. See Pindyck [1991] and Kulatilaka and Marcus [1994] for a treatment of the systematic risk in θ.

necessary. In the case of costly reorganization, the probability distribution of future prices affects the *current* choice of technology and organization.

This definition of a dynamic capability defines our reinterpretation of a ‘core competence’. Core competence is the capability set (i.e. combination of organization and technology elements) that permits the firm to choose dynamically the optimal strategy for a given price realization of the strategic factor.

Hysteresis and Inertia:

With the above concepts, we can now analyze more fully the hysteresis band first given in Figure 2. If a firm is unable to choose the optimal response, these conditions lead to a competency trap that is expressed by a hysteresis band. In figure 4, the profit functions for two capability sets and the resulting hysteresis band is graphed. Since the dynamic analysis takes into account the impact of a current switching decision on all future switching decisions the hysteresis band is wider than in a static analysis.

For the costless switching case, the switch occurs exactly at where the two functions cross. The presence of switching costs has two effects: static and hysteretic. The static costs results in the switch occurring at the value of θ where profits associated with the new mode justify the costs of adopting new organizational capabilities of lean production. θ would have to decline past this point of switching in order to justify the switching costs back to mass production.

The band between the switching costs is underestimated by looking only at static costs. Because of the possibility that θ may revert back to previous values (e.g. due to a sudden drop in oil prices favoring gas-guzzling cars), the firm persists in its current mode and waits to see how prices evolve in the future. At some point, however, θ takes on values that justify not only the one-time switching costs but also the probability-weighted costs attached to switching back. The range of inaction associated between switching in and out of a capability set is what is defined as the ‘dynamic hysteresis band’ depicted in figure 4.

Competency Traps and Learning to learn

Due the benefits of learning by doing, simply exploiting current capabilities leads to cumulative and incremental improvement. In effect, the profit function can be described as shifting outward over time. By staying in its current activities, the firm becomes increasingly more competent. Techniques of mass production are expressed in well-understood routines that couple technology and people through known organizing principles of work.

The danger remains, of course, that θ will suddenly jump to a range or cross a critical threshold in which the firm's competence is no longer profitable. In a sense, its accumulated learning in the old techniques is a *'competency trap.'* (See the discussion in March, 1991.) Yet, as a consequence, by improving in mass production, it is less attractive to change organizational capabilities. Hence a firm might rationally preserve its way of doing things, because it has become so good at doing the (now) wrong thing. Dougherty (1995) has labeled this "core incompetence". Exploitation of current knowledge drives learning by doing; the pitfall is that this learning increases the rigidity of the firm.

To speed its transition to new techniques, the firm may decide proactively to allocate funding to exploration by experimenting with new techniques. This diversion of resources slows down its accumulation of learning with the current technology. At the same time, it increases the value of the option to switch to new capabilities by lowering the costs of switching. To characterize this wider menu of choices, figure 5 depicts the decision of a firm that has accumulated a particular breadth of knowledge in the current production techniques, as well as in learning derived from experiments with new methods. (We can think of these experiments as 'joint ventures', such as the Nummi venture between General Motors and Toyota).

The net effects of learning are ambiguous and depend upon the rate by which new knowledge is gained through learning by doing relative to experimentation. In figure 6, this comparison is graphed by showing the upward change in profit functions over time due to these two learning effects. By construction, we show the gains to experimentation dominating learning by doing.

There is a more important insight provided by the investments in exploration, namely, that the literature on innovation overemphasizes the difficulty posed by discontinuous change. In more contemporary parlance, the prospects of successful radical change are viewed as poor, because of the chance of jumping from one performance peak to a distant peak is considered as improbable. But exploratory investments permit the building of ridges between peaks. By exploring the current assets that can be recombined and coupled with new ones, a firm is able to reduce the risks of falsely choosing new capabilities. Through recombination, exploration reduces the organizational costs to successfully adopting radical change in its capabilities.

How Good a Heuristic?

Strategic option theory is obviously a complex heuristic to apply, though are reasonable ways to simplify the application (Bowman and Moskowitz, 1997). However, much like the BCG growth matrix does not need to measure costs, a core competence heuristic does not (always) need to value the option. Instead, through insisting on the value of the competence as derived from market price of correlated assets, strategic option theory disciplines the core competence analysis to understand valuation as sensitive to competitive forces. These forces tend to limit the potential exploitation of a competence through a consideration of the effects on price and competition.

There are, however, several important complications to a strategic option heuristic. These complications provide important insight into the use of strategic options, and they also suggest the hazards of a sub-optimal transfer of the heuristic to inappropriate settings. For illustration, we consider four problem areas.

Competitive Interactions:

The valuation of a strategic option requires an identification of a market price by which to derive the replicate the underlying asset. In financial markets, this price is easily given by stock or future prices. An important, and reasonable assumption, is that exercising the option does not influence the value of the replicating portfolio.

This assumption does not hold always for strategic options for two reasons. First, by exercising an option to enter a market, a firm often influences prices through increasing supply. Second, by entering (or exiting) a market, competitors will alter their behavior. As a result, the market price is endogenous to the decision whether to exercise the option.

This problem is partly resolved by recognizing that the value of theta reflects the assessment on entry. But this assumption hardly provides insight into the identity of possible entrants and their strategic behavior. A structural approach is explicit regarding the nature of future competition. Kulatilaka and Perotti (1998) follow this approach by evaluating the decision to launch a new technology in the context of different conjectures about market structure. This solution marries the industry structure analysis to core competence, but through the stipulation that the analysis is forward-looking rather than focused on current market structure.

Bargaining:

The hysteresis band, we have suggested above, is influenced by the extent to which a firm has locked into a tightly-coupled system. Another explanation seeks to explore a question –often under-theorized in strategy research—concerning who gains from a decision to switch. Baldwin (1982) showed, for example, that owners would maintain inefficient plants in a bargaining setting to threaten workers from seeking higher wages. Kulatilaka and Marks (1988) analyzed why owners might choose to persist in an older, non-flexible technology as a way to signal a credible commitment to workers over wages. Both of the above papers suggest that bargaining strategies increase the value of maintaining older technologies and hence widen the hysteresis band.

A related issue is the difference between innovators and imitators. In the case of innovation, the profit windfall means that the bargaining problem is dividing a larger pie; Ford could win acceptance by increasing wages to $5 a day. (See Raff, 1988.) For imitators, adoption is in the midst of declining revenues; there is less to redistribute and hence bargaining is more of a zero-sum game for some parties. The situation facing imitators is more of an endgame, where bankruptcy is a credible outcome. In this context, switching to new practices is more an issue of survival than improving fitness relative to rivals. These concerns form the central debate in the strategic thinking in Europe and elsewhere on whether firms should insist on flexible labor markets as a policy to respond to international competition.

Stock Options as Compensation:

This notion of flexibility in employment is often also extended to flexibility in compensation. There is a frequent belief that a large firm could be more flexible to seize opportunities if employees' compensation was contingent on outcomes. There are, however, two major problems to such an argument. Putting in option-like compensation clauses results in high variance of compensation for managers in comparable positions. As almost all studies on compensation show, pay and performance are not closely linked because it is demoralizing; employees do not believe that differentials reflect ability and they find the social comparison to be unfair. The implications for promoting what should be the source of gain to a firm –namely, sustained coordinated and cooperative behavior—are invidious.

Second, compensation by options does not encourage flexibility. As Lambert et al. (1991) found, managers treat options that are in the money as wealth, and they consequently do not want to take decisions that eradicate their value. Unless a compensation scheme can be designed so that every decision is linked to a contingent payment, compensation by options is a disincentive for flexibility. Excessive incorporation of options in compensation is a heuristic, while appealing in its financial language in an age of institutional investors, whose application can be detrimental.

Design of the firm:

The explicit valuation of the activity of experimentation raises an important issue of the design of the firm. It would seem, arguably, that the best design for exploration is based on modularity, whereby a firm can pick and choose the best components. Since modules might be viewed as independent experiments, a reasonable inference is that the firm, like a market, should be designed around independent teams. This argument is, in fact, congruous with Simon's (1969) argument of the social decomposition of organizations into relatively independent units.

Baldwin and Clark (Forthcoming) analyze precisely this intuition by modeling the value of modularity as options under the assumption of independence among the modules or development projects. They also explicitly propose rules of thumb to guide the investment in combinatorial experimentation. Each module has an implicit option value insofar that it contributes to the emergent product design. *Ex ante*, the value of investing in a module is given by the expectation of its contribution to the final product. In this way, they implicitly derive the value from the market, since their valuation is driven by an unknown hedonic index (such as a quality-adjusted price, as explored above) to which each module contributes a weighted component.

The implications of modularity as maintaining the option to recombine capabilities has an intuitive appeal to current trends in flat and flexible organizations. It is especially suited to an extreme Silicon Valley scenario, in which individuals float between teams to join promising projects without regard to the name of the employing firm. But such a vision faces three important obstacles. First, the picking and choosing of modules is not easily coupled with most human resource policies that guarantee a modicum of job stability and personal development, even in Silicon Valley firms. As with compensation packages, the human complement is an important constraint on the implementation of the technically-best vision of organizational design.

However, more intriguing is the distinction between modularity within a capability family and that between them. It might seem that, as the many stories of skunk works suggest, that radically new ideas should be hived off from the corporation. Modularity might seem to work best if each set of experiments were kept independent. The trouble with this design is that there is likely to be correlated learning that should not be duplicated but shared by each module. With correlation, the portfolio of options across modules decreases in value. But more importantly, correlated learning is desirable insofar that experiments that identify paths from current capabilities to new ones are more organizationally feasible. Thus, the coupling of technology and organization is of considerable importance for tempering the technical solution to incorporate explicitly the consideration of organizational dimensions.

Conclusions

Real option analysis provides the theoretical foundations to the use of heuristics for deriving core competence and capabilities. Through conditioning an understanding of competence in relation to a market test (e.g. Barney's notion of a strategic factor market), it identifies the coupling of organization and technology as the leading explanation for the irreversibility of investments in capabilities. In a narrow sense, it faults discounted cash flow analysis as the principal tool of understanding the value of a firm. But more profoundly, the recognition that the coupling of people and technology is a source of option value challenges simplistic notions of firms as "pure asset plays." In this respect, it strengthens the recent argument that a firm's most enduring advantage lies in its human resources (Pfeffer, 1994).

Ironically, then, the derivation of the option value from the embedded knowledge in organizational assets deflects a purely financial evaluation of the firm. Because organizations consist of coupled systems, the value of the firm is not reflected in the present value of its constituent parts, but in the combinative potential of deploying these capabilities for innovation in existing markets or for addressing new markets. It suggests that firms are dynamic systems consisting of the complex coupling of technology and people through organizational design. The paradoxical conclusion to the sustained application of financial modeling to firms is that in the end, the fundamental basis of the value of the firm is its organizational capability to exploit current assets and explore future opportunities.

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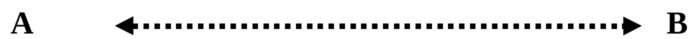
Figure 1

Correspondence of Technology and Organization

A. Element to Element:

Organizational	**Technological**
Vertical Hierarchy	**High Volume Production**



B. Set to Set:

Organizational	**Technological**
Set of Different Ways to Achieve Flexibility	**Set of Different Automated Equipment Systems**

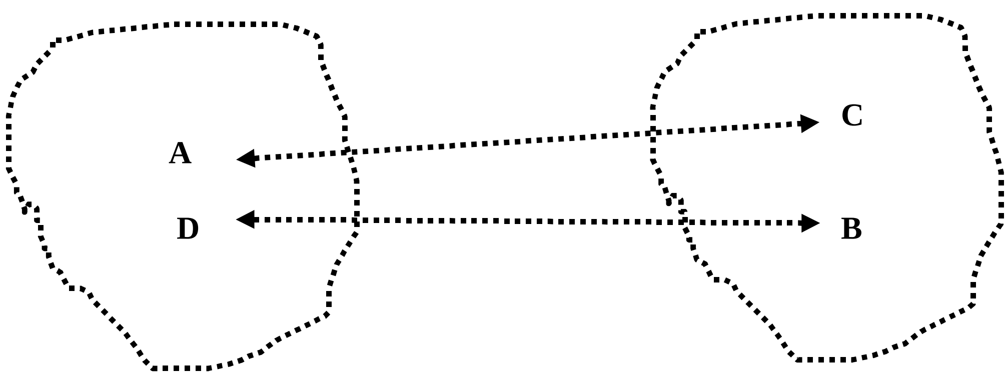
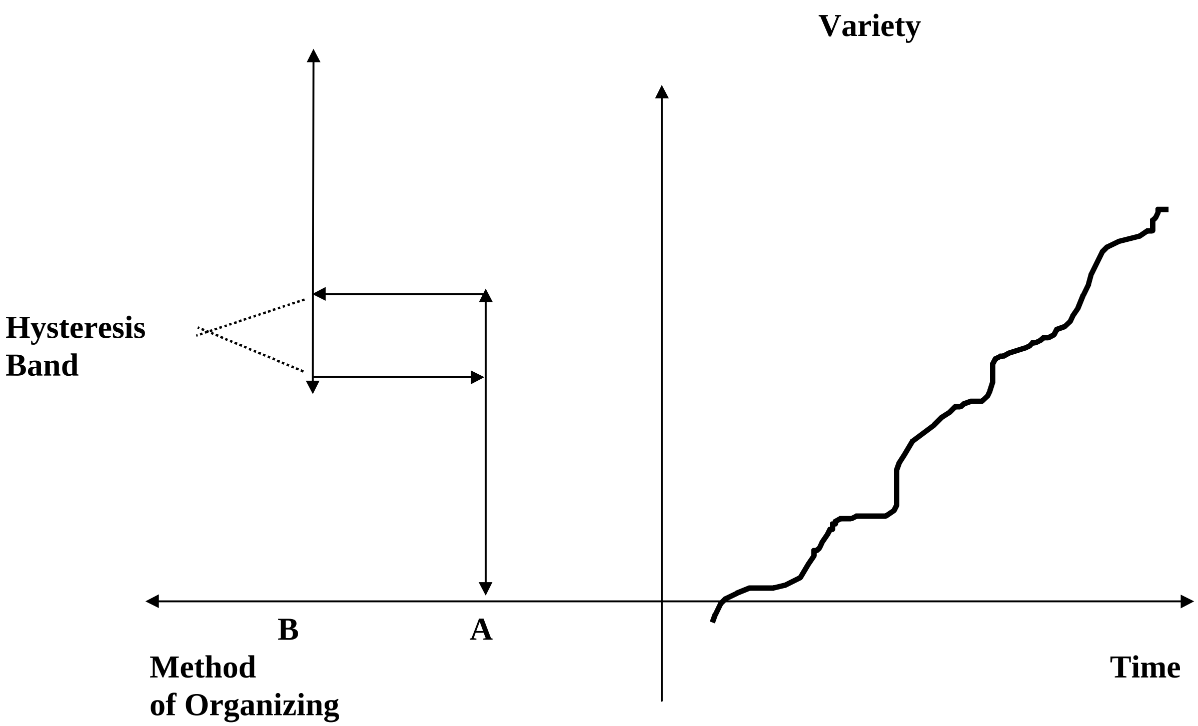


Figure 2

The Implications of Hysteresis on the Choice of New Techniques



A: Mass Production
B: Toyotaism

Figure 3

Choice of Capability Set: "Static Case"

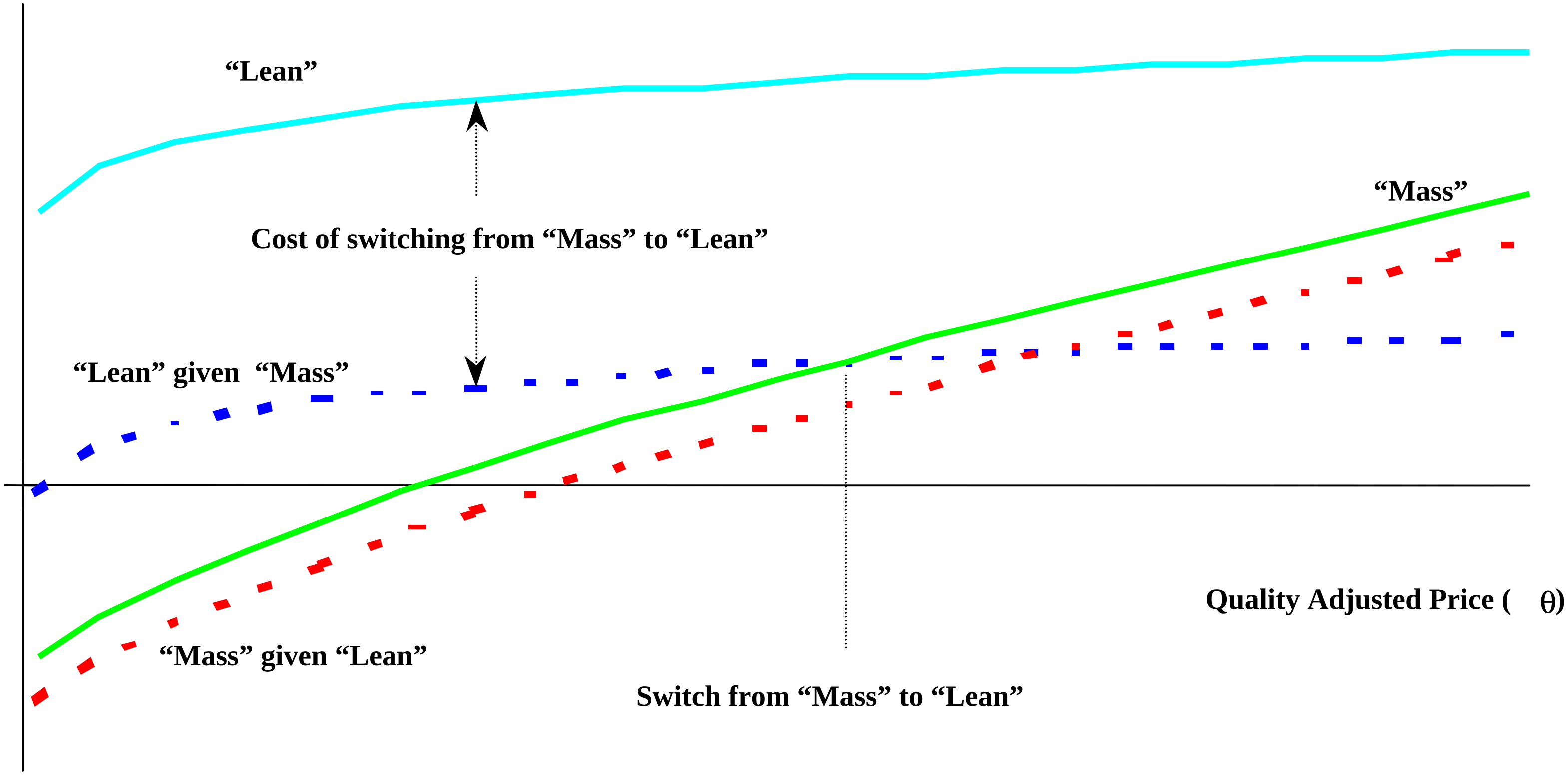
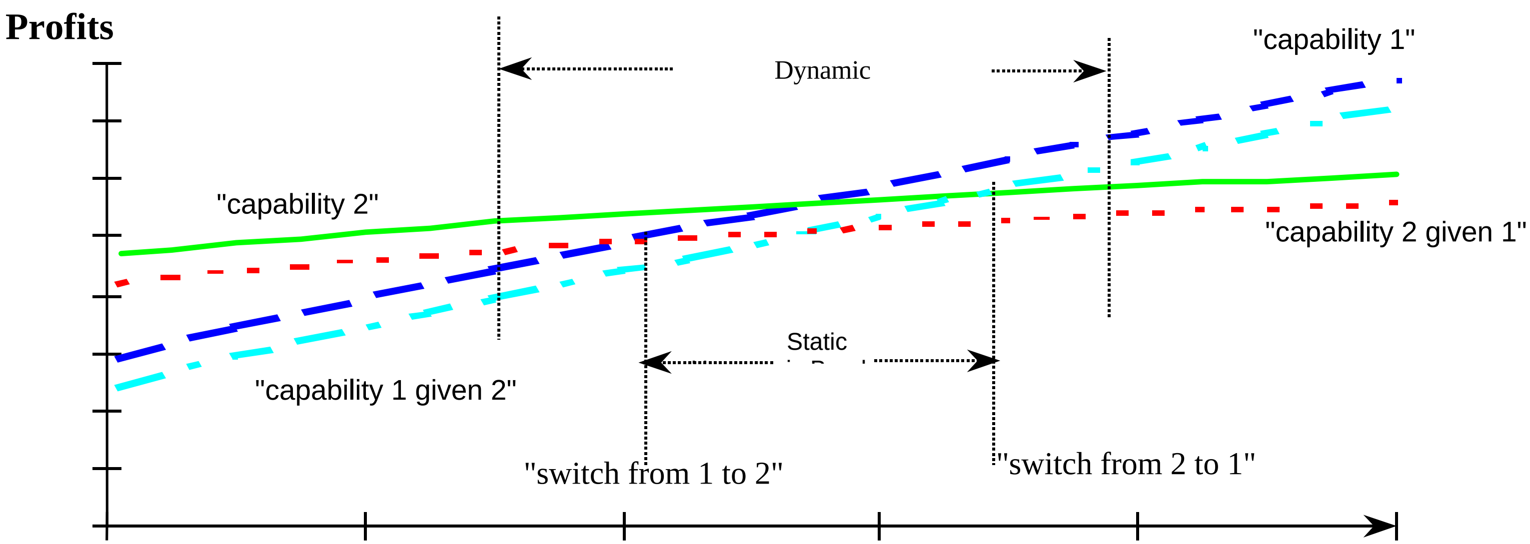


Figure 4

Static and Dynamic Hysteresis



Quality Adjusted Price (θ)

Figure 5

Expanded Capability Sets

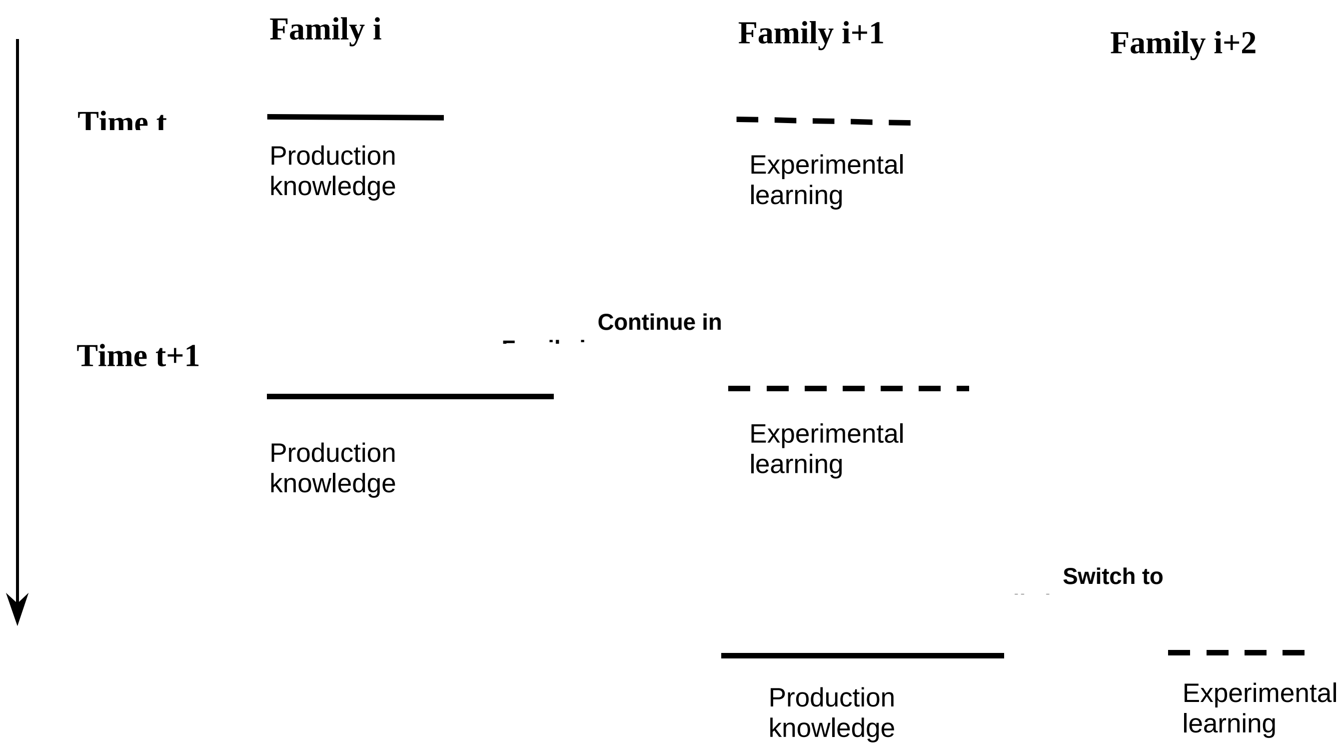


Figure 6

Effects of Learning