Abstract
Does superior knowledge today engender enhanced learning and superior performance in the future? While popular managerial wisdom might typically answer in the affirmative, the strategy literature is circumspect, pointing to the benefits of knowledge for future performance, but also to costs such as competency traps and cognitive rigidities. We argue that opposing views on the implications of prior knowledge derive from the fact that knowledge has not one, but two mechanisms by which it alters future firm performance: an endowment effect because it enhances the efficacy with which new knowledge is accumulated, and a behavioral effect because it alters the search strategy a firm employs in seeking to build upon and supplement its prior knowledge. Consider, as an example, an entrant imitating the market leader?it is thus endowed with partial prior knowledge. ?good? answers to a subset of problems within a larger multi-dimensional problem. The entrant naturally focuses its search on the dimensions of the problem for which it does not have solutions. Using a computational model, we examine the efficacy of this focus heuristic and implications of prior knowledge for future performance. By considering the dual consequences of knowledge, our theory is able to reconcile opposing accounts of the benefits of prior knowledge. Specifically, we identify conditions under which prior knowledge is negatively or positively correlated with future performance.
Rubik's Dilemma:
Partial Knowledge and the Efficacy of Learning

Hart E. Posen
School of Business
University of Wisconsin-Madison
hposen@bus.wisc.edu

Dirk Martignoni
Department of Business Administration
University of Zurich
dirk.martignoni@business.uzh.ch

Markus Lang
Department of Business Administration
University of Zurich
markus.lang@business.uzh.ch

April 9, 2013

The authors would like to thank seminar participants at the Academy of Management Conference 2012, École Polytechnique Fédérale de Lausanne, ETH Zurich, Freie Universitat Berlin, George Mason University, Strategic Management Society Conference 2012, TOM Society Meeting 2012, the University of Arizona, and the University of Minnesota. We wish to thank Jerker Denrell, Marc Gruber, Thorbjørn Knudsen, and Chris Tucci for helpful comments. Special credit is due to Eric Lucas for his assistance in developing the code for this model.
Rubik's Dilemma: Partial Knowledge and the Efficacy of Learning

Abstract

Does superior knowledge today engender enhanced learning and superior performance in the future? While popular managerial wisdom might typically answer in the affirmative, the strategy literature is circumspect, pointing to the benefits of knowledge for future performance, but also to costs such as competency traps and cognitive rigidities. We argue that opposing views on the implications of prior knowledge derive from the fact that knowledge has not one, but two mechanisms by which it alters future firm performance: an endowment effect because it enhances the efficacy with which new knowledge is accumulated, and a behavioral effect because it alters the search strategy a firm employs in seeking to build upon and supplement its prior knowledge. Consider, as an example, an entrant imitating the market leader — it is thus endowed with partial prior knowledge, “good” answers to a subset of problems within a larger multi-dimensional problem. The entrant naturally focuses its search on the dimensions of the problem for which it does not have solutions. Using a computational model, we examine the efficacy of this focus heuristic and implications of prior knowledge for future performance. By considering the dual consequences of knowledge, our theory is able to reconcile opposing accounts of the benefits of prior knowledge. Specifically, we identify conditions under which prior knowledge is negatively or positively correlated with future performance.
1. Introduction

A core assumption in the strategy literature is the positive cross-sectional relationship between a firm’s knowledge and its performance (Nelson and Winter 1982, Kogut and Zander 1992, Grant 1996). Does this also imply that superior prior knowledge will engender enhanced learning and superior future performance? While popular managerial wisdom might typically answer in the affirmative, the strategy literature is more circumspect. Based on the assumption that boundedly rational firms engage in search and learning to find better solutions to the challenges they face (Cyert and March 1963), the strategy literature highlights the benefits of prior knowledge (Gavetti and Levinthal 2000, Rivkin 2000, 2001, Agarwal, Echambadi, Franco, and Sarkar 2004, Ethiraj and Zhu 2008, Dencker, Gruber, and Shah 2009, Csaszar and Siggelkow 2010, Gruber 2010), but also costs such as competency traps and cognitive rigidities (e.g., Levitt and March 1988, Levinthal 1997, Tripsas and Gavetti 2000). We argue that these opposing views on the implications of knowledge derive from the fact that knowledge has not one, but two mechanisms by which it alters future firm performance.

First, prior knowledge has an endowment effect. It provides a better starting position from which to engage in learning (e.g., head-start on the learning curve) and enhances the efficacy of new knowledge accumulation (Dierickx and Cool 1989, Cohen and Levinthal 1990). This is the basis of much popular managerial wisdom. Second, prior knowledge also has a behavioral effect because it alters the search strategy (heuristic) a firm employs in seeking to build upon and supplement its prior knowledge. By examining the interplay between the endowment and behavioral effects of knowledge, we seek to identify the conditions under which prior knowledge negatively (or positively) influences subsequent learning and future performance.

Consider imitative entry (e.g., Csaszar and Siggelkow 2010, Ethiraj and Zhu 2008, Posen, Lee, and Yi 2013, Rivkin 2000, 2001) as an important instantiation of prior knowledge and its behavioral implications. A boundedly rational firm seeks to enter a market that it has not served in the past. The entrant carefully analyzes the current market leader’s policy choices. This analysis yields the market
leader’s choices for some but not all of its policy dimensions (because of tacitness or causal ambiguity). For example, the entrant may successfully identify the leader’s marketing strategy and pricing policy while other aspects of the market leader’s approach remain unobservable to the entrant (e.g., R&D and production strategy). Thus, the entrant possesses pre-entry knowledge (Agarwal, Franco, Echambadi, and Sarkar 2004, Dencker, Gruber, and Shaw 2009) — a partial understanding of a good configuration of policy choices (Rivkin 2001) derived from its imitation of the observable attributes of a leading incumbent. We refer to this as prior knowledge, which follows a continuum from fully incomplete (no prior knowledge) to complete (full prior knowledge). We refer to intermediate levels of prior knowledge as partial knowledge.

The entrant’s partial prior knowledge of the market leader’s policy choice configuration is the basis from which it engages in subsequent search and learning (Gavetti and Levinthal 2000, Winter 2000, Rivkin 2001). How might an entrant’s search behavior change given its prior knowledge endowment? The answer hinges on the observation that, having imitated a subset of the market leader’s policy choices that are believed to be good, the entrant knows that it has partial prior knowledge. As such the entrant is likely to focus its search, restricting effort to the sub-problems for which it does not have solutions (e.g., R&D and production strategy in the example above).

On the surface, focus, as a response to partial knowledge, seems to be a reasonable heuristic. Focus is intuitively appealing because focusing economizes on search effort, allowing more exhaustive search in the domain of the remaining sub-problems. More importantly, focus is consistent with theoretical arguments for sequential attention to problems (Cyert and March 1963, Greve 2008, Baumann and Siggelkow 2013) and organizational structure and process as a means to direct attention (Ocasio 1997, Rivkin and Siggelkow 2003). Recent empirical work finds explicit support for the idea that prior knowledge engenders focus. For example, in a study of technology entrepreneurs, Gruber, MacMillan, and Thompson (2012) show that pre-entry knowledge leads entrepreneurs to focus their
subsequent search behavior, constraining the linkages between technologies and market opportunities that the entrepreneurs identify.

While, in the example above, we depict prior knowledge as deriving from imitative entry, our theory is more general. Imitation is one instantiation of prior knowledge. A broad body of research assumes, implicitly or explicitly, that prior knowledge enhances future performance. In these literatures, prior knowledge may accrue from acquisitions and alliances (Puranam, Singh, and Zollo 2006, Puranam, Singh, and Chaudhuri 2009), prior efforts at learning or pre-entry knowledge (Agarwal, Franco, Echambadi, and Sarkar 2004, Dencker, Gruber, and Shaw 2009, Ganco and Agarwal 2009, Gruber 2010), employee mobility (Corredoira and Rosenkopf 2010), or analogical reasoning (Gavetti, Levinthal, and Rivkin 2005). Our theory is independent of the source of prior knowledge, requiring only that the prior knowledge is acquired, and the firm so endowed recognizes that it possesses such knowledge (so that it can focus).

We are not the first to study the future performance implications of knowledge. Existing research points to three mechanisms, all related to change, by which current knowledge may diminish future performance. First, knowledge may be applied inappropriately to new competitive contexts, such as industries, technological domains, or geographic locations (e.g., Williams 2007). Second, knowledge may be applied inappropriately to existing contexts after an environmental change, when pre-shock knowledge is ineffective in the post-shock world (e.g., Posen and Levinthal 2012). Third, knowledge may inhibit organizational adaptation and exploration (Levinthal and March 1993) through: structural inertia (Hannan and Freeman 1984), cognitive rigidities (Levitt and March 1988, Tripsas and Gavetti 2000), and competency traps (Levinthal and March 1993, Levinthal 1997, Siggelkow and Levinthal 2003). While the evidence in the literature is fairly strong for each of these mechanisms, our research points to a complementary but substantially different mechanism. In our model, we rule out issues of inappropriate application of knowledge and inertia-inhibiting adaptation,
and highlight the implications for subsequent learning of a firm’s focus on unknown dimensions of a problem when the firm has partial knowledge and it knows-that-it-knows.

Of these mechanisms, our theory is most closely related to the idea of competency traps (Levitt and March 1988, Levinthal and March 1993, March 2010). Firms may end up in a competency trap if exploitation of a particular alternative improves their competence in it (which improves the firm’s performance), and other alternatives, even those with greater potential, appear increasingly unattractive. Thus, the theory of competency traps embodies two key features. First, a firm becomes highly competent in its pursuit of a suboptimal alternative. Second, improvement in competence with the current (suboptimal) alternative tends to suppress exploration. Our theory of focused search as a response to prior knowledge affects future performance even when the knowledge is about the optimal (very best) alternative, and the behavioral effect of focus is independent of the level of exploratory effort.

To assess the implications of partial prior knowledge for subsequent performance, we construct a NK model of learning under complexity and add two features to the standard formulation (e.g., Levinthal 1997, Rivkin 2001). (a) We endow firms with prior knowledge in the sense that a subset of policy choices correctly matches the optimal configuration (Rivkin 2001). (b) We “inform” firms about the subset of correct policy choices such that “they know what they know” and we examine the implications of focused search on the remaining subset of policy choices. In doing so, we hold fixed issues of knowledge and change (inappropriate application of knowledge, inertia) and examine the implications of a focus heuristic.

Given our simple model, we draw two sets of conclusions. First, we demonstrate that when partial prior knowledge engenders a focus search heuristic, it can generate long-run performance inferior to no knowledge at all. We decompose the performance implications of prior knowledge into the knowledge-endowment effect and the knowledge-focus effect. In the absence of focus,
performance is increasing in the completeness of prior knowledge, which is consistent with expectations of the role of knowledge endowments. The effect of focus is more complicated because focus interacts with knowledge endowments in non-obvious ways. Focus generates enhanced performance only when prior knowledge is relatively complete because focus ensures that the firm is not led astray — staying within the region of the best solution — and enhances the likelihood of finding the best solution. When prior knowledge is less complete, focus may lead to what we term a “behavioral impasse.” By excluding certain policy configurations in one period, other policy configurations are necessarily inaccessible in future periods. As a result, prior knowledge may be detrimental to long-run performance.

Second, we examine when focus might be a reasonable heuristic — generating an unambiguous positive relationship between prior knowledge and future performance. While our primary notion of knowledge reflects knowledge of the optimal configuration of policy choices (know-what), we also examine the implications of know-how (Dosi, Nelson, and Winter 2000) in the search process (Levinthal and Warglien 1999, Rivkin and Siggelkow 2003). For instance, superior know-how may imply the ability to efficiently search a broader breadth of alternatives (March 1991, Katila and Ahuja 2002, Eggers 2012). We find, surprisingly, that given any level of prior knowledge (in)completeness and enhanced search breadth, focus is unambiguously performance enhancing.

Why do we call this “Rubik’s dilemma”? Consider a Rubik’s Cube on which one face has six (out of nine) yellow tiles. These yellow tiles represent “correct” choices if that face is to be yellow - we call this the prior knowledge endowment. How does one proceed to complete the other faces of the cube and solve the puzzle? One strategy reflects a decision to hold fixed the six yellow tiles in all subsequent moves, only trying the range of alternatives that do not disturb this partial knowledge. Employing this focus strategy, finding a complete solution is (often) impossible. There are only two ways to proceed to solve the puzzle. The first is to abandon focus, and allow changes in the yellow face that reduce the number of yellow tiles temporarily, before reintroducing those correct tiles at a
later point. Rubik’s dilemma is embodied in the need to (at least temporarily) abandon what is currently known to be correct in order to solve the cube. The alternative strategy, available to firms but unavailable in a Rubik’s Cube, is to increase search breadth by making multiple changes simultaneously. The central observation of this paper is that Rubik’s dilemma is a common challenge of learning in complex task environments.

The remainder of this paper is structured as follows. Section 2 introduces our extensions of the standard NK landscape model. In Section 3, we analyze the conditions under which partial prior knowledge has positive and negative performance implications. Finally, in Section 4 we conclude by discussing our results and implications.

2. Model

To examine the implications of (partial) prior knowledge, we implement a standard NK model (e.g., Kauffman 1993, Levinthal 1997, Rivkin 2001, Ethiraj and Levinthal 2004a, Siggelkow and Rivkin 2005, Levinthal and Posen 2007, Knudsen and Levinthal 2007, Ganco and Hoetker 2009, Csaszar and Siggelkow 2010). It has three basic features: (1) a complex performance landscape, (2) a firm that is represented by a position on this performance landscape, and (3) a strategy that guides the search process a firm uses to learn and improve its position on the performance landscape.

The performance landscape maps firm policy choices to performance (fitness) where a firm is associated with a specific policy-choice vector in a given period. Firms seek to improve their positions on the landscape through a process of local search. In the standard NK model, initially firms have no information about the shape of the performance landscape; they start their search process from a random position on the landscape. In contrast, in our study firms are equipped with more- or less-complete prior knowledge about the policy-choice vector associated with the best solution (global peak). This knowledge affects both the starting position of the firm (“endowment effect”) and its
subsequent search behavior (“focus effect”). In the following subsections, we provide detailed descriptions of the elements and processes of our model.

### 2.1 Complex Performance Landscapes

The starting point of our model is an $N$-dimensional vector $a=(a_1, a_2, \ldots, a_N)$ of binary policy choices $a_i \in \{0, 1\}$ with $i \in I=\{1, \ldots, N\}$, yielding a total of $2^N$ possible combinations of choices. We interpret the vector $a$ as representing a firm’s configuration of policy choices.

The degree of interdependence among a firm’s policy choices is determined by the parameter $K \in \{0, \ldots, N-1\}$, which describes the number of choices $a_j$ that (co-)determine the performance effect of policy choice $a_i$. This effect is characterized by the contribution function $c_i = c_i(a_i, a_{i_1}, a_{i_2}, \ldots, a_{i_K})$ where $i_1, i_2, \ldots, i_K$ are $K$ distinct policy choices other than $i$. The realizations of the contribution function are drawn from a uniform distribution over the unit interval, i.e., $c_i \sim U[0;1]$. The performance of a given policy-choice vector $a$ is calculated as the arithmetic mean of the $N$ contributions $c_i$ according to the performance function $\phi(a) = \frac{1}{N} \sum_{i=1}^{N} c_i(a)$. The parameter $K$ is interpreted as a measure of complexity. The lowest value, $K=0$, implies the policy choices do not depend on each other, yielding a smooth performance landscape with a single (global) peak; the highest value $K=N-1$ implies that each policy choice depends on all other choices, yielding a rugged landscape.

A “landscape” represents a mapping from all $2^N$ possible outcomes of the policy-choice vector onto performance values. We normalize each landscape to the unit interval such that the mean value of the normalized landscape equals 0.5 and the global maximum equals 1.0. The “local peaks” on the performance landscape represent policy-choice vectors for which a firm cannot improve its performance through a given type of local search (Levinthal 1997). The “global peak” is the highest peak in the landscape. For ease of exposition, we describe the global peak on the landscape as the “best solution” and an average local peak as an “average solution.” In later analysis, we identify other
sticking points on the landscape that are neither global nor local peaks (Rivkin and Siggelkow 2003). We will refer to such solutions as “poor solutions.”

2.2 The Effect of Prior Knowledge on a Firm’s Starting Position

A standard assumption in models of search and learning in the NK tradition is that firms initially possess no information about the shape of the performance landscape. Consequently, firms start their search process from a random position on the landscape. There are two ways to model prior knowledge. In one, firms may be endowed with a high-performance starting position (Baumann and Siggelkow 2013) or placed in high-performance regions on the landscape (Gavetti and Levinthal 2000). In the other, firms may be endowed with knowledge about a subset of correct policy choices, i.e., policy choices that match the global peak (Rivkin 2001). We do not pursue the first approach because it confounds knowledge and performance. In the presence of complexity, the correlation between knowledge and performance (fitness) can be rather low. As a consequence, a firm may know its initial performance, but may not have partial knowledge at the policy choice level. In the second approach, more-complete prior knowledge reflects a starting position with a larger number of correct policy choices. We follow this approach because it allows us to model a firm that “knows what it knows,” and thus is able to pursue a search strategy that is endogenous to this knowledge of specific policy choices. Thus, our definition of knowledge reflects “know-what” (e.g., Garud 1997) in the sense of “justified true beliefs” (Polanyi 1966) about the merits of alternative policy configurations.

As mentioned in the introduction, one important instantiation of prior knowledge is imitative entry. In particular, we model a firm’s initial position as a policy-choice vector \((x_1^*, \ldots, x_\gamma^*, x_{\gamma+1}, \ldots, x_N)\), where \(\gamma\) choices \((\gamma \leq N)\) are correct in that they correspond to the policy setting of the global peak, and \(N-\gamma\) choices are incorrect (we label these as \(x_i^*\) and \(x_j\) respectively). Thus, if \(\gamma=N\), the firm starts its search process at the global peak. The assumption, that firms have partial knowledge of the global
peak, is for analytical convenience alone. In the sensitivity analysis, we examine firms with partial knowledge of a local peak and find that the qualitative pattern of results is unchanged.

An alternative conceptualization of knowledge reflects “know-how” (Garud 1997, Dosi, Nelson, and Winter 2000). Know-how is the economic notion of the efficiency of transforming inputs into outputs in production function sense. In strategy, know-how is manifest in capabilities that reflect organizationally embedded knowledge. Thus, knowledge is synonymous with both efficiency and capability. We examine the implications of know-how in Experiment 2.

2.3 The Effect of Prior Knowledge on a Firm’s Search Process

In order to improve its performance, the firm engages in a process of local search (Levinthal 1997). Following standard procedure, local search involves randomly selecting a single policy choice and inverting its value. If the modified policy-choice vector yields higher performance, it is adopted and the search continues from this new vector in period \( t+1 \). Otherwise, this modification is discarded and the next search step starts from the unchanged vector defined in period \( t \). This process may be interpreted as off-line search for better positions on a high-dimensional performance landscape (“hill climbing”). Pursuing local search, the firm will eventually converge to a policy-choice vector from which performance cannot be improved by changing one of the \( N \) policy choices. When this occurs, the firm is at either an average solution (local peak) or the best solution (global peak).

We examine focus, one instantiation of a behavioral effect of knowledge. In doing so, we add one modification to the above search process. We assume that the firm is endowed with prior knowledge about the correct answer to a subset, \( \gamma \), of policy choices in the choice vector, and also that the firm knows that these policy choices are correct. We implement focus such that the firm, knowing which \( \gamma \) policy choices are correct, searches only on the remaining \( N - \gamma \) choices.
3. Analysis

In the following sections, we report results for the case of a landscape with $N=15$ and $K=7$. Each experiment involves 10,000 firm replications. We observe firms for 200 periods, which is sufficient to ensure that the model reaches steady state. We engage in three sets of analyses. First, we unpack the long-run performance implications of prior knowledge when it engenders focus. Second, we examine alternative conditions under which a focus heuristic is performance enhancing (reducing). Finally, we examine the sensitivity of our results to alternative model specifications.

3.1 Experiment 1: The Effect of Prior Knowledge on Performance

In the first experiment, we seek to understand the baseline properties of the model. Figure 1 displays long-run performance (y-axis) over the full range of prior knowledge (x-axis), i.e., from no knowledge (zero policy choices correct), through partial prior knowledge, to complete prior knowledge (15 policy choices correct). The solid line reflects average long-run performance less than that achieved by firms with no prior knowledge.

We find that performance is reduced rather than enhanced at low to moderate levels of prior knowledge; firms endowed with no prior knowledge outperform firms with partial prior knowledge. Positive effects of prior knowledge materialize only when prior knowledge is relatively complete (i.e., $\gamma > 9$). Thus, we observe a U-shaped relationship between the completeness of prior knowledge and long-run performance, with a minimum observed in the case of partial prior knowledge ($\gamma = 7$).

Consider this result in the context of imitative entry (example from the introduction). The results of this experiment suggest that if the entrant cannot substantially imitate the market leader’s policy choices, it may be better off not imitating at all. That is, attempts to learn, starting with relatively incomplete prior knowledge may lead to outcomes inferior to entry without the benefit of prior
knowledge. In the remainder of this section, we examine the mechanisms underlying the performance implications of prior knowledge.

A central behavioral assumption in this research is that a firm endowed with prior knowledge will focus its search efforts. We decompose (Posen and Levinthal 2012) the impact of prior knowledge (in Figure 1) into two components: (1) an endowment effect driven by the prior knowledge endowment alone, and (2) a focus effect driven by the assumption that a firm will restrict its subsequent search if it knows what it knows.

The results of this decomposition are shown in Figure 2. The dashed line reflects the long-run performance implications of the endowment effect, while the dotted line reflects the long-run performance implications of the focus effect. The net effect of these two components of prior knowledge is plotted as the solid line, fully reconstructing the main result in Figure 1.

Consistent with Rivkin (2001), we find that a more-complete knowledge endowment has an unambiguous positive effect on long-run performance. The impact of focus is less straightforward (and more interesting). The behavioral implication of knowing what you know, focused search, decreases performance if the prior knowledge endowment is less-complete, but increases performance if the prior knowledge endowment is more-complete.

In the following subsections, we seek to uncover the mechanisms underlying the endowment and focus effects.

*Decomposing the Endowment Effect*

In the analysis above, we find that in the absence of focus, more-complete prior knowledge endowments unambiguously increase performance (dashed line in Figure 2). This positive endowment effect is driven by two mechanisms. First, knowledge endowments (prior knowledge about the
position of the best solution) might increase the probability that a firm discovers the best solution. Second, because better solutions (higher local peaks) tend to be co-located on the landscape (Kauffman 1993, Rivkin and Siggelkow 2007), knowledge endowments might help a firm discover better solutions.

< Insert Figure 3 about here >

In Figure 3, we decompose these two effects. We isolate the impact of knowledge endowments for discovery of the best solution by computing the increase in the probability of discovering the best solution (relative to no prior knowledge) and multiply it by the average performance improvement associated with moving from an average solution to the best solution.

The set of average solutions is not homogeneous. Some local peaks reflect superior configurations of policy choices, even though they do not reflect the best solution. We isolate the impact of knowledge endowments for discovery of better local peaks by determining the average improvement in the performance of those firms remaining in local peaks (compared to the average performance of firms endowed with no prior knowledge), multiplied by the probability that a firm converges to a local peak (despite knowledge endowments).

Results suggest the total endowment effect (dashed line) is driven primarily by a higher probability of discovering the best solutions (solid line). Only when prior knowledge is relatively complete does it enhance a firm’s ability to discover better local peaks (dotted line).

Decomposing the Focus Effect

In the previous subsection, we analyzed the performance implications of the knowledge-endowment effect. Now we seek to understand the focus effect. In Figure 2, we demonstrate that the focus effect is positive only when prior knowledge is relatively complete, otherwise it has negative performance implications. This U-shaped relationship is the result of two opposing mechanisms.
On the positive side, focus ensures that the firm is not led astray — it stays within the region of the best solution — and enhances the likelihood of finding the best solution. Even if the prior knowledge endowment is relatively complete (e.g., 12 out of 15 policy choices correct), local search in the absence of focus does not ensure that the firm finds the best solution. Unfocused search may (permanently) overturn correct policy choices and lead the firm to the basin of attraction of an average solution (which by definition is inferior to the best solution). When prior knowledge is relatively complete, focus reduces this risk. For example, at a prior knowledge of 12 correct policy choices, focus increases the probability of finding the best solution by over 60 percent.

On the negative side, focusing search effort on the sub-problems for which the firm does not yet have solutions may prevent a firm from converging to a local or global peak, because it comes to a “behavioral impasse.” Focusing excludes certain policy configurations in one period, and by implication, other policy configurations are necessarily inaccessible in future periods. As a consequence, a firm at a behavioral impasse tends to find a solution that is inferior to the local (global) peak associated with its current basin of attraction.\(^1\) A firm at a behavioral impasse finds a “poor solution,” with performance approximately 11 percent lower than that of a firm with an “average solution” (local peak).

Consider Microsoft and Dell’s failed efforts to replicate Apple’s successful iPod/iTunes business model. They obtain partial prior knowledge by imitating the observable features of Apple’s policy choices. One interpretation of why Microsoft and Dell failed is that they did not fully imitate Apple’s complete set of policy choices (Porter 1996). Given interdependence, incomplete imitation may result in dramatically lower performance. Our model suggests an alternative explanation because we assume that the initial imitation attempt is not the final solution employed by the imitator. Rather, Microsoft and Dell’s partial prior knowledge obtained via imitation is the starting point for their subsequent

\(^1\) The basin of attraction of local peak is the set of locations on the landscape for which local search leads to this local peak (Kauffman 1993).
effort at search and learning by which they attempt to reconstruct the remainder of Apple’s policy choices.

It is commonly understood that Apple’s close integration of hardware (iPod) and software (iTunes) was one of the key elements of their success. Microsoft and Dell engaged in search, but were reluctant to abandon this integrated business model, even temporarily (e.g., Dell’s Digital Jukebox and Microsoft’s Zune). Both Microsoft and Dell get stuck at behavioral impasses, unable to replicate the remainder of Apple’s policy choices via local search. Moreover, because of their focus response to partial knowledge, Microsoft and Dell failed to identify other policy configurations, such as Spotify’s software-based product, which may have provided a better solution to the one they identified.

Thus, our model suggests that Microsoft and Dell did not fail in digital music because they persisted with outdated or incorrect knowledge, or imperfectly imitated a successful template. Rather, our model suggests that the opposite may be true – Microsoft and Dell performed poorly in digital music because they failed to (at least temporarily) abandon “correct” beliefs. This observation is the heart of “Rubik’s dilemma” – sometimes one must forgo partial solutions that are known to be correct, in order to find a path to a more complete and better solution.

Technically, focus implies search on a constrained landscape consisting of only the set of sub-problems for which the firm has no prior knowledge endowment. A behavioral impasse is a local peak on this constrained landscape. An impasse occurs because a peak on the constrained landscape may not be a peak on the unconstrained landscape; these constrained landscape peaks are then behavioral impasses that foreclose future advancement along a particular search path. For example, by measuring the change in the probability of converging to the best solution, an average solution, and a poor solution (between search with and without focus), we find that when prior knowledge is set to eight policy choices, these negative consequences of focus are maximized, with nearly 60 percent of firms finding only a poor solution. To reach an average solution or even the best solution, a firm may need
to (temporarily) forgo a policy choice that correctly matches the best solution. The emergence of behavioral impasses is consistent with empirical research that shows entrepreneurs’ pre-entry knowledge focuses their subsequent search behavior in the sense that “the visible area of the landscape is a more, or less, constrained subset of the total landscape” (Gruber, MacMillan, and Thompson 2012 p.16).

In Figure 4, we assess the performance contribution of these mechanisms underlying focus. To compute the costs of a behavioral impasse (poor solution), we identify those firms that do not converge to a local or global peak. We then determine the average performance effect by multiplying the performance difference between the average peak height and those below-peak positions with the probability of a failure to converge to a local or global peak. We normalize it by subtracting the average performance of firms without a prior knowledge endowment, to obtain the performance implications of a behavioral impasse.²

To compute the benefit associated with an increased probability of finding the best solution, we measure the relative increase in the probability of converging to the global peak (compared to a search process without focus) and multiply it by the performance improvement of moving from an average local peak to the global peak.

< Insert Figure 4 about here >

The solid line in Figure 4 reflects the (negative) performance implications of a behavioral impasse. The dashed line reflects the (positive) performance implications of ensuring that the firm stays within the basin of attraction of the global peak. When prior knowledge is relatively incomplete, the negative effects of an impasse dominate. When prior knowledge is more complete, the positive

---

² There is a relatively small effect associated with the different probabilities of converging to an average solution between search with and without focus. For brevity, we subsume this effect under the impasse result.
effects of getting pulled to the global peak dominate. The focus effect (dotted line) is the net result of these two opposing mechanisms.

In sum, in this experiment, we find a U-shaped relationship between the level of prior knowledge and long-run performance. This effect is driven by two interacting mechanisms, the positive effect of knowledge endowments, and the effect of focus, which is negative when knowledge is less complete, and positive when knowledge is more complete.

3.2. Experiment 2: Focus as a Sensible Heuristic

In Experiment 1, we find that when partial prior knowledge engenders focused search, it may reduce performance. These results suggest that focus is a reasonable heuristic only when prior knowledge is relatively complete. In Experiment 2, our starting assumption is that we observe heuristics (such as focus) in practice not only because they economize on firms' scarce cognitive resources (Simon 1955), but also because these heuristics might be on average good (Gigerenzer 2008). Thus, we seek to understand when focus is a reasonable heuristic — enhancing rather than reducing the positive implications of more complete prior knowledge endowments.

To more fully understand the implications of prior knowledge, we observe that knowledge may take the form of know-what (our analysis in Experiment 1), as well as know-how (e.g., Garud 1997, Dosi, Nelson, and Winter 2000). We pursue two approaches. In one approach, we examine know-how that embodies procedural knowledge, which may reflect more versus less intelligent search in our model. We examine firms that are able to search more broadly or more deeply for a given unit of search effort (Katila and Ahuja 2002, Eggers 2012). In the other approach, we examine know-how that embodies an understanding of the interdependencies between policy choices (Garud 1997). In particular, we examine how a firm’s beliefs about the complexity of the task environment (interdependences among policy choices) alters the extent focus is a reasonable heuristic.
Extended Search Breadth and Depth

We examine the implications of know-how that takes the form of extended search breadth or search depth, in addition to the focus heuristic and prior knowledge (know-what). The results are presented in Figure 5, where the dotted line represents the baseline focus effect result from Experiment 1 and the solid line reports the implications of extended search breadth. The dashed line reports the implications of increased search depth, to which we return later.

< Insert Figure 5 about here >

We model search breadth as follows. In Experiment 1, firms employed standard local search (e.g., Levinthal 1997). Standard local search has a radius of one; in each period, the firm considers a randomly chosen alternative that differs from its current policy configuration by only a single policy choice. To reflect broader search, we extend the search radius to five. In each period, a firm can identify and evaluate an alternative that simultaneously differs in up to five policy choices from its current policy configuration (Rivkin and Siggelkow 2007).  

In Figure 5 we plot the focus effect, which reflects the performance contribution of focus net of the direct effect of knowledge endowments. We find, surprisingly, that the focus heuristic is always performance enhancing when combined with extended search breadth. That is, focus and breadth are complements: for any level of prior knowledge, focused search with extended breadth outperforms search with that level of breadth alone. Thus, given any endowment of prior knowledge and extended search breadth, focus is always a good heuristic.

To identify the mechanism underlying this result, from Experiment 1 we recall that the positive effect of focus is driven by the enhanced probability that a firm reaches the best solution (global peak), while the negative effect is driven by an increased probability of a behavioral impasse. The balance

---

3 To ensure that the model reaches steady state in the case of increased search breadth, we observe firms for 2000 periods.
between these two mechanisms determines the net effect of focus. We plot the probabilities of these two outcomes in Figure 6, Panel A (poor solution due to a behavioral impasse) and Panel B (best solution). Once again, the dotted line reflects the result from Experiment 1 (search radius of one) and the solid line reflects the implications of broader search. The dashed line reports the implications of extended search depth, to which we return later.

< Insert Figure 6 about here >

The probability of an impasse decreases substantially because increasing the search breadth serves to overcome the negative implications of focus (Figure 6, Panel A). Focus leads firms to a behavioral impasse because, by excluding certain policy configurations in one period, other policy configurations are necessarily inaccessible in future periods. Increasing search breadth allows firms to overcome this obstacle. At the same time, increasing breadth strongly increases the probability that a firm finds the best solution (Panel B). Thus, breadth both mitigates the deleterious effects of focus and enhances its beneficial effects.

Next, we consider increased search depth, which we model as follows. In Experiment 1, firms employ standard local search in which only one policy alternative is examined per period (e.g., Levinthal 1997). In Experiment 2, we allow firms to pursue the steepest gradient by exhaustively examining all fifteen local alternatives in each period, selecting the best (Rivkin 2001, Rivkin and Siggelkow 2003, Csaszar and Siggelkow 2010). This accelerates local search (Ganco and Hoetker 2009). The result of deeper search, presented in the dashed line in Figure 5, is a significant decrease in the performance contribution of focus, which is now negative at all levels of prior knowledge.

To examine the mechanisms, we once again turn to Figure 6 looking now at the dashed lines. We observe a significant increase in the probability of a behavioral impasse across all levels of prior knowledge (Panel A). The deleterious effects of depth and focus stem from the fact that in deep search, a firm follows the steepest gradient to the local peak (average solution). This, in turn, implies
there is only one acceptable pathway to the peak. Any obstacle (local peak on the constrained landscape) that blocks this path will trap a firm at a non-local peak location. Because focus generates such obstacles, deep search compounds the negative implications of partial prior knowledge. We also observe a strong decrease in the likelihood of finding the best solution (Panel B). As such, focus and depth are substitutes because focus reduces the returns to greater search depth.

*Beliefs about the Extent of Complexity*

In the experiment above, we examine the possibility that firms are also endowed with know-how that enables search that is broader or deeper. We find that while breadth is a complement, depth is a substitute for focus. We now seek to examine the implications of know-how that embodies an understanding of the interdependencies between policy choices (Garud 1997). In particular, we examine how a firm’s beliefs about the complexity of the task environment (interdependence between policy choices) alters the extent focus is a reasonable heuristic.

In Figure 7, we plot the performance effect of focus for three different beliefs about complexity: (1) the firm believes that all levels of complexity are equally likely, implemented with \( K \) distributed uniformly (dashed line), (2) the firm believes that complexity is likely to be low, implemented using a Beta(2,6) distribution for \( K \) (solid line), and (3) the firm believes that complexity is likely to be high, implemented using a Beta(6,2) distribution for \( K \) (dotted line).

< Insert Figure 7 about here >

The key result is that the level of prior knowledge necessary for focus to be a reasonable heuristic is increasing in the extent to which complexity is believed to be high. While the focus heuristic cutoff point (the point above which focus is no longer a reasonable heuristic) is a prior knowledge of seven given beliefs that complexity is low, the cutoff increases to ten when complexity is assumed to be uniformly distributed, and further increases to eleven given beliefs that complexity is high.
In more abstract terms, a firm’s beliefs about the complexity it is facing may affect its decision to adopt a focus strategy, particularly if it holds only partial prior knowledge. If the firm holds complete or almost complete prior knowledge, its beliefs about the extent of complexity do not affect its decision to focus — it should always adopt a focus heuristic. Similarly, if the firm is endowed with very incomplete prior knowledge, it should avoid a focus heuristic independent of its beliefs about complexity. Only at partial levels of prior knowledge is a firm’s belief about the level of complexity relevant to its decision to employ a focus heuristic.

Underlying the previous analysis is the mechanism by which complexity alters the returns to focus. Clearly, in the absence of complexity \((K=0)\), focus is always positive, because on a single-peak landscape, even those firms with no prior knowledge eventually converge to the best solution. Firms with focus converge faster to the best solution because they avoid changes to those policy-choice dimensions that are already correct. Thus, a firm that believes there are no interdependencies in its policy-choices should adopt a focus heuristic. As complexity increases, it tends to magnify the effects of focus. That is, it increases the malign effects of focus (coming to a behavioral impasse) over a low to moderate range of prior knowledge, and also increases benign effects of focus (finding the best solution) at high levels of prior knowledge.

3.3 Sensitivity Analysis

In this section, we examine the sensitivity of our results to alternative model initializations and specifications.

First, we examine the sensitivity of our key findings with respect to initial firm performance. We examine the performance of firms in \(t=1\) that have identical prior knowledge, but heterogeneous initial performance. Results indicate that firms with low initial performance suffer slightly less and benefit slightly more from more-complete prior knowledge, but the qualitative results are robust.
Second, we consider the possibility that the short run results are different from the long-run results (used in the main experiments). We find that the qualitative pattern of results is consistent between the short and long runs. We do observe that in the short run (first five periods), the benign effects of focus tend to be magnified, while the malign effects are diminished. Thus, one might conclude that in contexts where there is very early intermediate selection (Posen and Levinthal 2007), a focus heuristic may be beneficial.

Third, we consider the possibility that firms are endowed with partial prior knowledge of an average solution (local peak), but not the best solution (global peak). We repeat the analysis from Experiment 1. We find that, as expected, the endowment effect is somewhat diminished, and the negative implications of the focus effect are somewhat strengthened. Nonetheless, the qualitative pattern of results remains unchanged. We also examined the situation in which the prior knowledge endowment, which is the subject of focus, is more or less correct vis-à-vis the best solution (i.e., the firm's prior knowledge is faulty). This may reflect prior knowledge that has degraded due to environmental turbulence, or degraded because it represents knowledge transfer across industries or geographies. In both situations, as the extent of (faulty) prior knowledge increases, we observe magnified negative effects of focus and diminished positive effects. If the prior knowledge has become random with respect to the world (perhaps because of an extreme turbulence event), we observe an unambiguously negative effect of focus — with the negative effect increasing as a function of the extent a firm focuses given its faulty prior knowledge.

Fourth, we examine a task environment that is modular. We implement a block-diagonal interaction matrix (Marengo, Dosi, Legrenzi, and Pasquali 2000, Rivkin and Siggelkow 2003, Siggelkow and Levinthal 2003, Ethiraj and Levinthal 2004b, Ethiraj, Levinthal, and Roy 2008). Our results are robust to this alternative specification of the interaction matrix.
Fifth, we examine a task environment that consists of more (and fewer) policy choices. In particular, we varied the parameter \( N \) and analyzed \( N = \{8, 10, 12, 20\} \). The observed pattern of results is qualitatively the same across the number of policy choices.

Finally, we analyze how prior knowledge endowments affect the speed of convergence to steady state. As expected, more complete prior knowledge and focused search increase the speed of learning. However, differences in the speed of learning are significant only when the task environment is low complexity (low \( K \)) or the completeness of prior knowledge is relatively high.

4. Conclusions and Discussion

We formally consider how the completeness of a firm’s initial endowment of knowledge affects its learning process and subsequent performance. While popular managerial wisdom might typically conclude that superior prior knowledge will engender enhanced learning and superior future performance, the strategy literature is more circumspect, pointing to the benefits of knowledge for future performance, but also to costs such as competency traps and cognitive rigidities. We argue that these opposing views on the implications of knowledge arise from the fact that knowledge has not one, but two mechanisms by which it alters future firm performance. First, prior knowledge has an endowment effect that enhances the efficacy of new knowledge accumulation (Dierickx and Cool 1989, Cohen and Levinthal 1990). Second, knowledge also has a behavioral effect because it alters the search strategy a firm employs in seeking to build upon and supplement its prior knowledge. By considering the dual consequences of knowledge, our theory is able to reconcile opposing accounts on the benefits of prior knowledge.

At the core of our analysis rests a simple proposition: A firm’s prior knowledge endowment alters its subsequent search strategy and ultimately its prospects for additional learning. We examine one instantiation of a behavioral effect of knowledge, focus. Implicit is the assumption that a firm “knows what it knows,” and as such, naturally focuses its search effort on the remaining unknown
dimensions of the problem. This focus heuristic is not only intuitively appealing but also consistent with theoretical arguments for sequential attention to problems (Cyert and March 1963, Greve 2008, Baumann and Siggelkow 2013), and organizational structure as a means to direct attention (Ocasio 1997, Rivkin and Siggelkow 2003).

In a strategic setting, prior knowledge may have many sources. One obvious example is imitation (Ethiraj and Zhu 2008, Rivkin 2000, 2001). In entering a new market, a firm might seek to imitate the current market leader. In most instances, the entrant can only observe select aspects of the market leader’s approach. It seems natural that a firm will focus its subsequent search efforts on those aspects that were not easily imitable. Yet sources of prior knowledge extend well beyond imitation to include: acquisitions and alliances (Puranam, Singh, and Zollo 2006, Puranam, Singh, and Chaudhuri 2009), prior efforts at learning or pre-entry knowledge (Agarwal, Franco, Echambadi, and Sarkar 2004, Dencker, Gruber, and Shaw 2009, Ganco and Agarwal 2009, Gruber 2010), employee mobility (Corredoira and Rosenkopf 2010), or analogical reasoning (Gavetti, Levinthal, and Rivkin 2005). Our theory is independent of the source of prior knowledge, requiring only that the prior knowledge is acquired, and the firm so endowed recognizes that it possesses such knowledge (so that it can focus its subsequent search efforts).

We find that there are conditions under which prior knowledge can generate long-run performance inferior to no knowledge at all. Our result hinges on the implications of focus, when a firm has partial knowledge. In the absence of focus the benefit of prior knowledge unambiguously increases with the extent of knowledge completeness. This result is the basis of the endowment effect of prior knowledge. While this result conforms to popular managerial wisdom, it is only part of the story. When prior knowledge engenders a focus heuristic, the future performance implications of prior knowledge are less straightforward. The focus heuristic positively contributes to future performance of prior knowledge when knowledge is relatively more complete, but negatively when prior knowledge is less complete.
Why does the focus heuristic have such a large impact on the future performance implications of prior knowledge? Our study suggests that focus is a double-edged sword. On the positive side, focus ensures that the firm is not led astray — it stays within the region of the best solution — and enhances the likelihood of finding the best solution. On the negative side, focus forecloses pathways for search and learning. This foreclosure occurs because of the path dependent nature of search (Arthur 1994). Focus excludes certain policy configurations in one period, and as a consequence, this implies that other policy configurations are necessarily inaccessible in future periods. This may prevent a firm from converging to a local or global peak, because it comes to a “behavioral impasse.” The former effect dominates at high levels of prior knowledge, while the latter effect dominates at low levels of prior knowledge.

The behavioral theory of the firm (Simon 1955, Cyert and March 1963, March and Olsen 1975) holds that in the face of bounded rationality, firms will employ simple heuristics to guide search and learning. We examine one such heuristic — focus in the presence of partial knowledge. A central contribution of our paper is to illuminate the conditions under which focus is a reasonable heuristic in the sense that it is, on average, performance enhancing.

While our main results examine a firm engaging in simple local search, we also examine the implications of assuming that firms are somewhat “smarter” than simple local search suggests. First, firms able to engage in more intelligent search processes (Levinthal and Warglien 1999, Rivkin and Siggelkow 2003), i.e., search processes that employ increased search breadth (March 1991, Katila and Ahuja 2002, Eggers 2012), can reap the benefits of focus without incurring its costs. Indeed, our results suggest that in the presence of prior knowledge, focus and breadth are complements. In our model, for any level of prior knowledge, focused search with increased breadth outperforms search with the same level of breadth alone. Given prior knowledge and increased search breadth, focus is always a reasonable heuristic. We also examine increased search depth, but find that focus and depth
are substitutes. Thus, given prior knowledge, a decision to increase search depth should rule out the pursuit of a focused search strategy.

Second, firms may have some limited understanding of the extent of complexity in the task environment (Siggelkow 2002). We find these beliefs about complexity strongly influence the reasonableness of focus. If a firm believes complexity is relatively low, then focus is a reasonable heuristic even when prior knowledge is relatively incomplete. If, however, the firm believes that complexity is relatively high, then focus is only a reasonable heuristic if knowledge is relatively more complete.

These results point to the need to enhance our understanding of the implications of current knowledge for future performance. If knowledge is behaviorally neutral, not affecting a firm’s subsequent search strategy, then more-complete prior knowledge is certainly better than less-complete prior knowledge (e.g., Nickerson and Zenger 2004, Miller 2007). Yet the assumption of behavioral neutrality in the face of more-complete knowledge seems unlikely given strong evidence that strategies depend on current knowledge states (Kahneman and Tversky 1979, Audia and Greve 2006). Under such circumstances, partial knowledge may reflect what is popularly called “dangerous half truths,” suggesting that we need to take a more critical look at the behavioral and performance implications of knowledge.

The behavior that we refer to as a focus heuristic can be interpreted in alternative ways. While we suggest that focus is a heuristic firms may employ when endowed with prior knowledge, our model is more general. Focus-like behavior may result from, for example, inertia, organizational decision-making structure, high search cost, or external institutional or competitive constraints. When focus is driven by one of these alternative mechanisms, there need not be any direct link between knowledge and behavior. If inert policy choices are incorrect, focus-like behavior may serve to magnify the negative effects of those policy choices. But if these inert policies are correct, focus-like behavior may
still be performance reducing (or, under alternative conditions, performance enhancing). Thus, our theory suggests conditions under which alternative drivers of focus-like behavior will negatively or positively impact future performance.

Our research is also complementary to work that holds search behavior is endogenous to performance. In this work, search strategies may respond to performance aspirations, whereby firms employ different search heuristics depending on whether performance is above or below some comparison baseline (Greve 1998, 2002, Baum and Dahlin 2007). In contrast to this earlier research, we focus on the observation that knowledge, independent of performance, may have direct implications for the nature of subsequent search behavior. The distinction between knowledge and performance is important because, while they are positively correlated in the cross-section, the correlation diminishes with increasing complexity (Kauffman 1993, Levinthal 1997). As such, knowledge may diverge from performance, and aspiration-like behavior may be based on knowledge rather than performance.

We often tend to think that “not knowing what you know” is a problem. For example, Lew Platt, CEO of Hewlett-Packard, contended, “if HP knew what HP knows, we would be three times as profitable” (Davenport and Prusak 1998: p. xxi). Similarly, research on causal ambiguity (Lippman and Rumelt 1982) argues that the inability to identify the factors that are responsible for superior (and inferior) performance might create barriers to successful imitation. It seems obvious that there should be a value in being able to identify these factors. In our study, in contrast, we demonstrate the flip side of “knowing what you know” — if it engenders a focus heuristic, there are conditions under which you might be better off “not knowing what you know.”

At the heart of Rubik’s dilemma is the observation that sometimes one must forgo partial solutions that are known to be correct, in order to find a path to a more complete solution. In attempting to solve Rubik’s Cube, one must not pursue focus in the face of partial knowledge, instead
one must allow for temporary abandonment. In organizational life, another possibility exists — continue to focus on the unknown parameters, but increase the search breadth.

In sum, knowledge plays a central role in the strategy literature. We have sought to enhance our understanding of the consequences of knowledge endowments for the efficacy of subsequent learning, and in turn, future performance. Knowledge does not affect performance alone. Knowledge has behavioral implications, because a firm’s search strategy tends to change when the firm knows what it knows. We study focus as one instantiation of a behavioral effect of knowledge. However, there is a large set of heuristics that might be triggered by prior knowledge, which may be the subject of future research. The issues surrounding the implications of knowledge for learning remain a fertile and important line of inquiry for strategy scholars.
References


Gruber, M., MacMillan, I. C., & Thompson, J. D. (2012). Escaping the prior knowledge corridor: What shapes the number and variety of market opportunities identified before market entry of technology start-ups? Forthcoming in Organization Science.


Figures

Figure 1

The Downside of Partial Knowledge

Average Long-Run Performance Effect
(in t=200, normalized by no knowledge)

Prior Knowledge
(Policy choices matching the best solution in t=1)
Figure 2

Decomposing the Effect of Prior Knowledge

Average Long-Run Performance Effect
(normalized by no knowledge)

Prior Knowledge
(Policy choices matching the best solution in t=1)
Figure 3

Decomposing the Endowment Effect

Average Long-Run Performance Effect
(in $t=200$, normalized by no knowledge)

Prior Knowledge
(Policy choices matching the best solution in $t=1$)
Figure 4

Decomposing the Focus Effect

Average Long-Run Performance Effect

(Policy choices matching the best solution in t=1)
Figure 5

Extended Search Breadth and Depth

Average Long-Run Focus Effect (in t=200, normalized by no knowledge)

Prior Knowledge
(Policy choices matching the best solution in t=1)
Figure 6

Panel A

Probability of Coming to a Behavioral Impasse (Poor Solution)

Panel B

Probability of Finding the Best Solution
Figure 7

Beliefs about the Extent of Complexity

Average Long-Run Focus Effect
(in $t=200$, normalized by no knowledge)

Prior Knowledge
(Policy choices matching the best solution in $t=1$)

Uniform Beliefs

Complexity Believed Low

Complexity Believed High

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15