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**Exploration and Exploitation Revisited:
Extending March's Model of Mutual Learning**

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Abstract

A system of actors, appropriately organized, is able to learn even in situations where individuals in isolation cannot. This was one of the most important, though seldom emphasized, insights of March's paper, "Exploration and Exploitation in Organizational Learning" (1991). The present paper builds on March's original simulation and incorporates a number of different real-world organizational features. The results suggest that unconstrained experimentation is of great benefit to organizational learning, although it should not be carried to excess. Low levels of turnover in personnel are beneficial and mitigate the problem of high socialization March noted in 1991. Inclusion in the policy-making elite should be predicated on performance rather than seniority and on shorter rather than longer individual performance histories, particularly when environments are changing rapidly. Finally, erring on the side of stringency in selecting members of the organization for the policy-making elite is better than erring towards laxity.

Introduction

An important albeit seldom emphasized aspect of March's paper, "Exploration and Exploitation in Organizational Learning" (1991), is that individuals are able to learn when participating in an appropriately organized system when they could not do so in isolation. The present paper takes as its starting-point the general principles of March's conceptualization of a collective learning system and links them with work from the domains of human resources and strategic management, to ask the question: How do certain organizational policies effect organizations conceptualized as mutual learning systems? Since the learning system March described in 1991 is in essence evolutionary, the organizational policies selected for investigation here were those likely to impact learning through their role in variation (exploration), and in selection and retention (exploitation).

I define learning here, rather simply, as 'the acquisition of useful knowledge' and vicarious learning as the acquisition of useful knowledge from others rather than through direct experience. Organizations provide a context in which vicarious learning is facilitated and encouraged. Indeed, it has been suggested that it is their knowledge-sharing properties that accounts for their existence (e.g., Conner & Prahalad, 1996; Grant, 1996). One way in which organizations disseminate knowledge among their members is through routines and standard operating procedures (March & Simon, 1958; Cyert & March, 1963; Levitt & March, 1988). As Levitt and March note: "The experiential lessons of history are captured by routines in a way that makes the lessons, but not the history, available to organizational members who have not themselves experienced the history" (1988, p 320). There is a relatively long tradition of considering organizations as learning systems, and as repositories and conduits of knowledge.

While Barnard (1938) notes the organization's utility in achieving ends that require cooperation, he also suggests, as Galbraith (1974) and Egeloff (1982) did later, that organizational structure arises from the need to pass information efficiently. Operations management has a rich literature dealing with learning in organizations (e.g., Epple, Argote & Devadas, 1991; Argote, 1999; Argote & Darr, 2000; Argote, Ingram, Levine & Moreland, 2000; Argote, McEvily & Reagans, 2003). The role of routines as a means of holding and disseminating knowledge throughout the organization has been examined by March & Simon (1958) and Cyert & March (1963). Many studies have followed in this vein, dealing specifically with organizational routines (e.g. March & Simon, 1958; Cyert & March, 1963; Nelson & Winter, 1973; Levinthal & March, 1981; Lounamaa & March, 1987; Nelson, 1987; Winter, 1987; Levitt & March, 1988; March, 1988; Levinthal & March, 1993; Miner, 1994; March, Schulz & Zhao, 2000). During the 1990s, knowledge and its role in the firm was the focus of much activity (Kogut & Zander, 1992; Kogut & Zander, 1993; Nonaka & Takeuchi, 1995; Grant, 1996; Grant, 1996; Galunic & Rodan, 1998), and there was renewed interest in the topic of organizations as learning systems (Cohen & Levinthal, 1990; Cohen, 1991; Levinthal, 1991; March, 1991; March, Sproull & Tamuz, 1991; Simon, 1991; Lant & Mezias, 1992; Levinthal & March, 1993; Bruderer & Singh, 1996).

Individual experiential learning relies on the temporal or spatial proximity of stimuli that are potentially causally related (Bullock, Gelman & Baillargeon, 1982; Fiske & Taylor, 1991).

Experiential learning involves considering the outcomes of many trials over time and selecting the action that yields an outcome closest to a desired goal (March & Simon, 1958). However, in many situations, clear correlations between cause and effect are hard to detect. When environments are complex and much is changing simultaneously, the links between actions and outcomes are often ambiguous (Lounamaa & March, 1987; Levitt & March, 1988; Levinthal,

1991; Levinthal & March, 1993). Yet March (1991) showed that learning is possible, even where considerable causal ambiguity exists, if individuals are part of an organized system. Although March (1991) has been criticized for presenting an overly narrow and stylized view of organizations, the strength of his original conception lies in its general insight about collective learning in ambiguous settings, regardless of the specifics of its implementation.

March's model is a useful starting-point for further theorizing about organizational learning because it presents a mechanism whereby collectives can learn in situations where individuals on their own cannot. Building on this model, the present paper speculates about a variety of individual- and organizational-level processes that affect variation (exploration) and selection (exploitation) of beliefs – processes that may therefore have an impact on organizational learning. Two classes of variance-inducing mechanisms are considered. The first centers on the propensity of individuals to experiment and the influence of two different forms of restraint on experimenting, one organizational and the other individual. The second is turnover in organizational membership. Alternative selection mechanisms considered here include the use of tenure rather than performance as the criterion for promotion to the organization's policy-making elite, the stringency of the entry requirements to that group, and the extent to which a person's cumulative performance or 'track record' rather than their most recent performance is used as the yardstick for promotion decisions. The paper is organized as follows: the next section presents the theory and sets out some propositions. The methods section then explains how the simulation was implemented. After a presentation of the results, there follows a discussion and some conclusions.

Theory

The basic mechanism of the model of mutual learning created by March in 1991 is evolutionary, depending on variation in beliefs about the environment across actors and time (exploration), and selecting and retaining the most accurate knowledge (exploitation). Drawing on the experiences of others throughout the organization means that individuals have a larger set of trials on which to draw and need to rely less on their own personal experience. To illustrate this, March constructed a model in which individuals learned only from others and never directly from their own experience (1991). The organizational processes considered below are some that are likely to influence either variation (exploration) or selection/retention (exploitation).

Exploitation is about making best use of what we already know. If we can avoid the mistakes others have made in the past, we can achieve our ends faster and at less cost. Exploitation of current knowledge includes best-practice transfer and vicarious learning from those who seem to have more knowledge than we do. Exploitation of an organization's knowledge leads to a convergence in beliefs: excessive exploitation can result in premature consensus (Levitt & March, 1988). Exploration mitigates this by reintroducing variation into the system. Variation is essential to any evolutionary process, but the key—as March noted—is striking a balance between exploitation and exploration.

Variation-producing processes

Experimentation

Experimentation typically involves making choices when outcomes are unpredictable. This implies that choices, however well intentioned and considered, are ultimately indistinguishable

from a random selection. Random choices constitute a source of variation. Such choices may be thought of as representing stochastic alterations in individuals' underlying beliefs. If collective learning involves exploiting the knowledge of the most knowledgeable members of the organization, beliefs will converge on those of the organization's single most knowledgeable member. Since this individual has no one whose knowledge he or she can exploit, absent any random alterations in his or her beliefs, the final level of knowledge attainable across the organization can be no higher than that of its most knowledgeable individual at inception. To learn more, there must be some means for members to 'leapfrog' the current most knowledgeable individual. Experimentation provides a way in which this can happen.

Experimentation captures such things as risk-taking (March, 1991), guessing and foolishness (March, 1988). It allows the most knowledgeable person at a particular moment to be displaced by someone who, perhaps by chance or trial and error, has happened on a more accurate set of beliefs about the environment. While exploitation increases efficiency, it makes organizations vulnerable to environmental change by driving out variation which might serve as the basis for successful adaptation (Hannan & Freeman, 1977). Experimentation ensures that an organization's learning is not limited to the knowledge of the best-informed individual at its inception. Constant experimentation, on the other hand, may be as bad as no experimentation, since it makes no use of prior knowledge. Thus, questions that emerge are: How much experimentation should organizations undertake? Should experimentation be controlled and if so, how can this best be done?

Some organizations discourage experimentation by inadequately rewarding successful attempts at innovation and routinely punishing failures. In contrast, others—Microsoft being one example—actively encourage experimentation (Theilen, 1999, p 52). Moreover, not all people

are alike in their willingness to experiment. Some people feel comfortable making decisions with relatively little information while others may prefer to proceed more cautiously, waiting for the organization to which they belong to offer some guidance. Altering both individuals' predisposition to experiment and the constraints imposed on their experimental endeavors will influence the rate at which variation is introduced to the system, and will thus have an effect on organizational learning.

In the next three subsections I consider three different aspects of experimentation. I look first at the effect of varying the rate of experimentation. Next, I consider how organizational policy might influence experimentation by indicating the domains in which it is sanctioned. Lastly, I explore an approach to limiting excessive experimentation that depends on individual judgment.

Unconstrained experimentation or 'Foolishness'

March has described experimentation as action that is “‘irrational,’ ‘out of character’ or ‘foolish’” (March 1994, p 263). Weick notes that “An ambivalent stance towards past wisdom makes adaptive sense”; without testing our surroundings, we become prisoners to our assumptions (1979, p 7). Absent experimentation, there is insufficient variation and inadequate testing of the environment. The only variation in beliefs will be that present at the beginning of the organization's life, before socialization causes members' views to converge. In a static environment this may not matter, as the organization will learn by selecting from the early trials of the initially heterogeneous population. However, in a changing world, insufficient experimentation will have severe consequences. As views converge and heterogeneity disappears the organization will soon find itself with an insufficient variety of beliefs from which to generate useful adjustments to its store of knowledge. Raising the rate of experimentation will

increase the variation in beliefs among individuals in the system. The more diverse the beliefs in the organization, the higher the likelihood that, in a given period, a few individuals will have beliefs that more accurately reflect the state of environment than do the beliefs of organization as a whole. Their knowledge is exploited as it is passed on to the rest of the organization through the organization's rules and standard operating procedures. However, in excess, unconstrained experimentation will have a negative effect on learning; the more frequently individuals experiment, the more often they will discard accurate beliefs. One should therefore expect an inverted U-shaped relationship between experimentation and learning, and an optimal level of experimentation that provides sufficient variation without discarding existing knowledge.

Proposition 1: Organizational learning will exhibit an 'inverted U-shaped' relationship with the amount of unconstrained individual experimentation.

Organizationally constrained experimentation

Experimentation is often directed and constrained by the organization. It may be steered in particular directions by means of rules, incentives and organizational values. For example, Bower (1970) describes how firms create a strategic context through resource allocation decisions that serve as a guide to behavior, encouraging individuals' efforts in certain directions and prodding them away from others. The organization imposes a 'global rationality' on experimentation—it being 'rational' to experiment only in domains where knowledge may not be regarded as reliable and mature. This maximizes the exploitation of existing organizational knowledge. In contrast to unconstrained experimentation, given the influence of the organization's strategic context, individual experimentation will not be so excessive as to prevent the organization from learning by discarding knowledge that it has already acquired.

If experimentation is only sanctioned in areas where the organization has not reached a collective consensus, most experimentation will likely occur at an early stage in the organization's life. As the organization develops a set of recommendations in its routines and standard operating procedures that enable its growing body of knowledge to be exploited, the scope for experimentation will decline and may ultimately disappear altogether. Moreover, even if some experimentation does occur, because it will be limited to organizationally sanctioned domains, all members will be exploring the same aspects of the environment and neglecting the same issues—those where a consensus has been reached—leaving certain parts of the environment untested. Such constraint limits the usefulness of experimental activity and there may never be a complete testing of the environment.

Proposition 2: Constrained experimentation will exhibit a monotonically increasing relationship with organizational learning but at no level will it be as effective as the best level of unconstrained experimentation.

Rational self-restrained experimentation

In contrast to Bower's view of organizational activity, Burgelman (1988) described how individuals often step outside the bounds of the strategic context; 'autonomous strategic behavior' results in many small deviations from the firm's strategic direction. Some of these may prove fruitless. Others, such as Intel's initially un-strategic foray into microprocessors, turn out to be so important as to cause a sea-change in the company's strategy.

Self-restrained experimentation lies somewhere in between foolishness and organizationally constrained experimentation. Individuals exhibit self-control in their choice of domains in which to experiment while ignoring the guidance of the organization. Individuals with such 'local rationality' experiment only on issues about which they, rather than the organization, consider

their knowledge to be lacking. This mode of experimentation allows the organization to maximize the exploitation of individual knowledge and avoids the discarding of information about which individuals feel secure. However since gaps in their knowledge will not appear systematically in the same domains, experimentation in the organization as a whole will take place across a broader range of domains than when it is organizationally constrained to particular issues. This should increase the extent of testing of the environment in any given period, yielding a wider distribution of scores. This will augment the pool of candidates for the policy-making elite¹, leading to improved learning, relative to the organizationally constrained case. Rationality (i.e., not experimenting when you think you know the answer) will maximize the exploitation of individual knowledge and prevent the discarding of knowledge in which individuals have confidence.

Proposition 3: Self-restrained experimentation will be positively associated with organizational learning and at its best, generate greater learning than organizationally constrained experimentation.

Turnover in Organizational Membership

A second source of variation comes from turnover in organizational membership. Prior work in the domain of learning and organizational turnover has considered the mitigating effect of organizational structure (Carley, 1992) and the implications of turnover for breaking out of an institutionalized consensus among the top management team (Virany, Tushman & Romanelli, 1992). Kesner and Dalton (1982) list the replacement of poor performers, the infusion of new knowledge, and the stimulus to change current policies and practices among the benefits of turnover. While turnover has the benefit of disrupting a suboptimal consensus, the departure of

¹ I use the term 'policy-making elite' to refer to the institutional artifact March termed the 'superior group'.

knowledgeable people represents a loss of knowledge for the organization as a whole. The direct costs associated with training new people can be considerable (Hall, 1981), even when the job requires only basic skills; the cost is greater still when account is taken of the indirect costs arising from the reduction in overall organizational performance.

Turnover should influence learning in two ways. As organizational members are increasingly socialized into the organization's ways of doing things, the less variety in beliefs there will be across the organization. The departure of highly socialized members and their replacement by 'new-blood', introduces variation that should help organizational learning. However, at high rates of turnover the organization will lose many people whose level of knowledge is high, and organizational knowledge as a whole will decline as turnover rises. Thus a general prediction regarding turnover is:

Proposition 4: Turnover will exhibit an inverted U-shaped relationship with organizational learning and will have a greater impact in a dynamic than in a static environment.

Selection mechanisms

The three following sections concern selection mechanisms. In March's framework, selection works through the choice of those responsible for developing the organization's rules and standard operating procedures. Changing the way the organizational elite is constituted should change the organization's ability to learn; promote all the wrong people to the boardroom and organizational learning might stop altogether. The three questions I consider here are: 1) What is the effect of promoting people to the policy-making elite on the basis of tenure rather than performance? 2) Is it better to look at recent performance or at an entire record of

accomplishment when promoting people to the policy-making elite? and 3) How stringent should the qualification criteria be for promoting people to the policy-making elite?

Promotion Based on Tenure rather than Performance

Individuals are not always promoted on the basis of their performance or ability. Seniority is widely used as the principal criterion for promoting within many organizations (Dobson, 1988).

In a study of promotion criteria, Mills (1985) found that almost three-quarters of the managers surveyed considered length of service when making promotion decisions, while a quarter felt *obligated* to award promotion based on seniority. Of these, half reported promoting someone with greater seniority over another whom they felt had greater potential. Though Mills concedes that promotion based on seniority was less important in managerial than in non-managerial cases, ability was seldom the only criterion used, and even in managerial promotion decisions seniority often played a role.

So long as there is a link between seniority and knowledge, promoting people on the basis of tenure should not be problematic; tenure can be used as a reasonable proxy for knowledge.

However, when tenure and performance decouple, a seniority-based promotion system may have adverse consequences for organizational learning. If those promoted to the policy-making elite are the most senior but not necessarily the most knowledgeable, learning will suffer. Defenders of seniority-based promotion systems point out that experience is typically correlated with knowledge. Even when learning takes place vicariously, the longer individuals are exposed to the organization's policies and procedures, the more knowledge they will assimilate. Thus, as individuals are socialized into organizational best-practice, an association between tenure and knowledge should arise. However, if the organization's standard operating procedures do not

reflect the views of the most knowledgeable members, then socialization will not generate the necessary link between knowledge and tenure, and tenure will be a poor, even useless, proxy for knowledge. The greater the use of seniority as a criterion for promotion, the less the organization and its members are likely to learn.

Proposition 5: Learning will be negatively related to the proportion of people promoted on the basis of tenure rather than knowledge.

Increasing Emphasis on Longer Performance Histories

“Microsoft gives you virtually nothing for what you have already done. You never get to coast on previous work” (Theilen, 1999, p 76).

If basing promotion on performance is important, does the length of time over which performance is evaluated may also matter? How much should recent accomplishments be emphasized over more historically distant achievements? High discounting of the past, as exemplified in the above quotation from David Theilen, may not be particularly common; decisions to promote are very often based on an individual’s historical ‘track record.’ A weighting scheme that heavily discounts the past will favor those who have had recent successes, but may lead to frequent changes in direction. Conversely, reliance on a cumulative track record, giving equal weight to the past and the present will mean that people who have been successful in the past, but whose knowledge may no longer be relevant, will be promoted alongside those with little or no success in the past but who have achieved good results more recently. The latter group will introduce more recent, and hence more relevant, information into the policy-making elite than the former. Increasing the weight given to performance histories will reduce the usefulness of the recommendations that the policy-making elite produces for the organization. This relationship is likely to be more pronounced the more dynamic the environment since the

association between older knowledge and the current state of the environment weakens as environmental turbulence increases.

Proposition 6: Organizational learning will be positively associated with the weight given to recent performance relative to that of earlier periods. This association will be stronger the more dynamic the environment.

Stringency – raising or lowering the bar

If basing promotion decisions on performance is important for organizational learning, how stringent should the criteria for entry into the policy-making elite be? Raising the standard needed for inclusion in the policy-making elite increases its average level of knowledge, thereby improving the accuracy of the knowledge disseminated through the organization's rules, regulations, and procedures.² It is possible that increasing the stringency of the standard for admission to the policy-making elite might result in an overly rapid convergence on a single common understanding of the environment that might be relatively inaccurate. Slowing the process by including a greater variety of less accurate views in the elite might lead to a more thorough exploration of the environment, with better results in the long-run. Conversely, including everyone in the policy-making group removes any selectivity from the process, and selection is crucial for learning to take place. Thus one might expect learning to be better at mid-range values rather than at either extreme.

Proposition 7: Learning will exhibit an inverted U-shaped relationship with the stringency of the criterion for admission to the policy-making elite.

² A counter-argument might be that excessively high standards will discourage the majority, who realize that such standards are never attainable, and, hence, their motivation and effort will be dampened. However, motivation is not a feature of this model.

Methods

This stylized model of the organization has three main components, namely members, a policy-making elite and a set of standard operating procedures or organizational code. It has three knowledge transfer processes: socialization, whereby individuals are socialized into the organizationally prescribed beliefs embodied in the organizational code; learning whereby the code is updated by drawing on the beliefs of the policy-making elite; and promotion/demotion, whereby members are selected (or deselected) from this elite. The model is evolutionary; successful belief sets, like genes, are selected for propagation by temporarily including their ‘carriers’ (the individuals who hold them) into the policy-making elite that generates an ideal belief prototype, the organizational code. This code provides a template that individuals use as a model. The model contains the three elements of an evolutionary system: variation (from experimentation), selection (inclusion into or exclusion from the policy-making elite) and retention (the aggregation of the policy-making elite’s beliefs into the organizational code).

The model simulates n individuals in a single organization. The simulated organization’s goal is to maintain the best possible representation of an exogenous environment, represented by a vector of m elements, $e = e_1, e_2, \dots, e_m$, whose elements assume two possible values, -1 and +1, i.e., $e_j \in \{-1, +1\}$. Each individual, i , holds beliefs about the environment in an m -element vector $b^i = b^i_1, b^i_2, \dots, b^i_m$ with $b^i_j \in \{-1, 0, +1\}$. The organizational code, from which individuals acquire knowledge, is a vector also with m elements: $c = c_1, c_2, \dots, c_m$ $c_j \in \{-1, 0, +1\}$. Individual knowledge in the simulation is defined as the extent to which a belief structure matches the exogenous real world. An individual’s knowledge is calculated as:

$$IndKnow^i = \frac{1}{m} \sum_{j=1}^m b^i_j * e_j$$

The average level of individual knowledge, (*AvIndKnow*) is given by:

$$AvIndKnow = \frac{1}{n * m} \sum_{i=1}^n \sum_{j=1}^m b^i_j * e_j$$

This measure is bounded at +1 and -1. The upper bound, 1, indicates complete correspondence between all individuals' belief structures and the environment. An average knowledge level of zero would result if individuals' beliefs were set randomly. The measure seldom dropped below zero. All the reported simulation runs were conducted with $m=50$ and $m=30^3$. The level of knowledge embedded in the organization's routines and operating procedures, used as the baseline for choosing the members of the policy-making elite, was similarly calculated:

$$OrgKnow = \frac{1}{m} \sum_{j=1}^m c_j * e_j$$

A single simulation run was 200 periods in length. Results were averaged over 80 runs with the same parameter settings.

The simulation cycle

At the start of each run, every element of the environment vector is set randomly to +1 or -1.

Each one of the 50 people in the organization is also assigned an initial set of beliefs, each

³ Different values of n and m were tested. For the base model, in which March's 1991 results were replicated, knowledge fell with increases in m and increased with an increase in n . However, the choice of n and m had no apparent interaction effect with the results of the particular tests. All experiments were repeated for $n=30$ and 50 and for $m=30$ and 50 .

element of their belief set having a value, of +1, 0 or -1 with equal probability. Each period, individuals may adjust their beliefs by experimenting. An experiment regarding a particular belief, b^i_j , involves choosing a value (-1 or +1) for that belief at random. The probability of an individual experimenting on any given issue (belief element b^i_j) depends on an exogenously set *experimentation* parameter, and on which one of the three experimentation regimes is in use; the choice of regime is also set exogenously. All individuals whose scores exceed an endogenously determined promotion threshold are selected to be part of the policy-making elite, which determines the organizational code. The *stringency* parameter determines the height of the promotion threshold relative to the organization's level of knowledge. The size of the policy-making elite is not fixed, but varies depending on the number of individuals whose scores exceed the promotion threshold. In all but the last of the sets of trials, *stringency* was set to 0, i.e., the organization's score in a given period was used as the promotion threshold.

The code is updated by taking each element in turn and setting its value to that of the majority among those in the policy-making elite with probability that increases monotonically as a convex function of the size of the majority:

$$p[c_j \rightarrow v_j] = 1 - (1-l)^{|k_j|}, \quad k_j = \sum_{i=1}^n b^i_j, \quad v_j \in \{-1, 0, +1\} = \begin{cases} +1 & \text{if } k_j > 0 \\ 0 & \text{if } k_j = 0 \\ -1 & \text{if } k_j < 0 \end{cases}$$

where $p[c_j \rightarrow v_j]$ is the probability that c_j is set to v_j , c_j is the j th element of the code, k_j the size of the majority on issue j , v_j the majority view regarding j in the policy-making elite, and l (set exogenously) is the organizational *learning* parameter (p2 in March's original model).

The final step in the cycle is to disseminate the code knowledge to the organization. Socialization involves each member of the organization (including those in the policy-making elite) adjusting his or her beliefs towards those of the organizational code, with a probability given by the *socialization* parameter (p_1 in March's 1991 model).⁴

Environments differ in the degree to which they change over time. All experiments were therefore carried out in a static environment and in an environment that changed completely at least twice during a single simulation run. The rate of change in the environment depends on the exogenously set *turmoil* parameter which represents the probability that in any given period an element in the environment is reset to +1 or -1 with probability of 0.5. As turmoil increases, the extent of change in the environment⁵ asymptotically approaches one. In experiments performed with a dynamic environment, *turmoil* was set at 0.01; this generated a degree of environmental change of almost 1 by period 100, halfway through the run.

Experimentation

In all cases, the propensity to experiment was varied from 0 where no experimental activity takes place, to 1, where individuals attempt to alter their beliefs at every opportunity, subject to the constraints of the particular experimentation regime. To simulate the effect of constrained experimentation, a rule was applied whereby experimentation could take place only when the organizational code had no position on an issue, j , i.e., $c_j = 0$. When organizational policy on a particular issue was defined (i.e., $c_j = \pm 1$), no experimentation was allowed. Under this regime,

⁴ In all cases where not explicitly stated, the socialization and learning parameters were set at 0.5

organizational knowledge is exploited to the greatest possible extent. Self-restraint was implemented in a similar way, but here the decision to restrict experimentation depended not on the organizational code but on each individual's beliefs. Self-restrained experimentation was permitted when an individual had no position on an issue, i.e. $b^i_j = 0$.

Turnover

Turnover was simulated by replacing a proportion of the organization's members, selected at random. This proportion was an exogenously set model parameter. For example, if *turnover* was set at 10% in an organization with 50 members, five members were replaced by new 'un-schooled' members every period. If the departing percentage did not constitute a whole number, the fractional remainder was used as the probability that one more person would be replaced. For example, if turnover was 11% in an organization with 50 members (suggesting 5 ½ people should be replaced that period) five people were replaced each period and the sixth was replaced with 50% probability in any given period.

Promotion to the policy-making elite

The mechanism used in all of the preceding experiments was to promote based on performance; organizational members were promoted to the policy-making elite if their scores exceeded that of the code. The number of policy-making elite members is endogenous, depending on individuals' scores and on the level of knowledge in the organization code in any given period. For the seniority-based mechanism, the average tenure of organizational members was used as the

⁵ Change in the environment is measured as $\Delta E_t = \frac{1}{m} \sum_{j=1}^m e_{j,0} * e_{j,t}$

reference point. Individuals were included in the policy-making elite if their tenure exceeded the average tenure of the organization's members. The effect of seniority-based promotion relative to performance-based promotion was assessed by stochastically choosing the seniority-based method over the performance-based method with a probability equal to the exogenously set *seniority* parameter. No single individual was consistently promoted based on one or the other mechanism.

Varying the degree of *stringency* for promotion to the policy-making elite involved reducing (or increasing) the score required for inclusion in the policy-making elite, relative to the code's score. A *stringency* of zero, the baseline case, meant that individuals with scores greater than that of the code were designated as members of the policy-making elite. A stringency of +1 meant that only individuals whose scores exceeded the code's score plus 1 were admitted to the policy-making elite.

Results and Discussion

Figure 1 shows the results for different modes and amounts of experimentation, in static and dynamic environments, and for high and low rates of socialization. While the propensity to experiment was varied in each series of trials from about 10^{-5} to 1, the rate of realized experimentation, that is experiments that were permitted by the particular rules in use, was much lower in both the constrained and the self-restrained cases. The horizontal axis shows the amount of realized experimentation. The point furthest to the right in each series is for a propensity to experiment of 1; that is individuals experiment every time the rules permit. For unconstrained experimentation, the realized rate of experimentation is the same as the propensity to experiment, while for constrained and self-restrained experimentation the realized rate is lower than the

propensity. Taking constrained experimentation in a static environment with high socialization as an example, when propensity to experiment is 1, realized experimentation is about 0.0065; in other words only one experimental initiative in 150 attempts is permitted.

An increase in the socialization rate reduced realized experimentation for both self-restrained and organizationally constrained experimentation. The more readily individuals adopt the code's recommendations, the fewer elements of uncertainty that remain in their beliefs for which experimentation is possible. As socialization also leads to a convergence in beliefs, the number of issues for which there is a relatively even mix of views among the policy-making elite will fall as the socialization rate rises. This reduces the number of occasions on which the organizational code might change its position thus hastening convergence towards what may be a suboptimal set of beliefs. Thus, socialization reduces experimentation under both the organizationally constrained and the self-restrained regimes.

Figure 1 about here

Experimentation

Proposition 1 predicted that experimentation would have an inverted U-shaped relationship with learning. This proved to be the case only in a static environment. In a dynamic setting, the relationship is more complex, with two peaks. No theoretical explanation for this could be found, and it may simply be an artifact of the model. Propositions 2 and 3 predicted that both the constrained modes of experimentation would be associated with increases in learning. However, organizationally constrained experimentation had no noticeable effect at a high rate of socialization, although there was a very slight increase in learning in the case of self-restrained

experimentation in a dynamic environment. In a static setting, with a low socialization rate, both constrained and self-restrained modes made a slight contribution to learning, though there was little difference between the two. Even at their best, neither was as effective for learning as unfettered foolishness. Moreover, low rates of socialization, while important for both constrained modes of experimentation, are suboptimal when experimentation is unfettered.

In a dynamic environment, unconstrained experimentation emerges as the only mechanism that can sustain learning. Self-restrained learning at low rates of socialization only reaches knowledge levels of around 12%. Constrained experimentation with low socialization achieves less than 10% and neither mechanism provides any benefit at all when socialization is high.

Turnover

Figure 2 shows the effect of turnover on the level of knowledge reached by the simulation. The introduction of low levels of turnover improved learning. In a static environment the average level of knowledge attained by the organization as a whole reached a peak at a turnover rate of around 1%. At higher rates of turnover the level of knowledge attained declined, thus providing support to proposition 4. In a static environment, the relationship is not completely U-shaped because there is always an initial heterogeneity of beliefs that allows the organization to learn before convergence in beliefs prevents further exploration. Without any turnover in membership, the organization reaches relatively high levels of knowledge (0.7 to 0.82) in the static case. However, in every case some turnover is better than none, and too much is always problematic. In a dynamic environment, the prediction of a U-shaped relationship is more accurate, as learning rises from zero when turnover is zero, and falling back to zero when turnover is 100%. The increase in knowledge attained at the optimal level of turnover above that achieved without

turnover was on average 8% in static environments and 42% in dynamic settings. This lends support to the second part of proposition 4, that turnover matters more in a dynamic than in a static setting.

Turnover was tested at three levels of socialization. One interesting result is the reversal in the order of the three series. At low levels of turnover (under 0.3% in the static case, and under 0.1% in the dynamic environment), socialization is negatively related to learning, as March showed in 1991. However, as turnover is increased, the line order changes above 3% in the static case and above 10% in the dynamic one, and socialization is *positively* related to learning. The perils of socialization noted by March in 1991 arise when variety is driven out of the system. By increasing the rate at which variety is reintroduced—in this case through turnover—socialization is no longer problematic. Furthermore, a higher level of socialization allows the organization to withstand higher rates of turnover. The optimal turnover is an order of magnitude higher when socialization is high compared to the optimal level when socialization is low.

Figure 2 about here

Performance-based promotion

The *seniority* parameter was used to alter the ratio of promotion decisions made based on performance to those made based on seniority. The results are in line with expectations and proposition 5 (Figure 3).

Figure 3 about here

In a static environment, performance declines slightly the more frequently seniority is used as the criterion for promotion. This result is consistent with Carley & Herald's observation (1997) that

promotion based on performance is an important component of collective learning. The slow decline in learning as emphasis shifts from performance to seniority reflects the fact that in a static environment, tenure and knowledge are closely related. However, when seniority is the only criterion, the organization is unable to learn. When the environment is unchanging, the organizational code quickly comes to reflect a relatively accurate picture of the environment. On average, new hires will enter with zero knowledge; longer tenured members will have been more thoroughly socialized into the organization's prevailing view of the world and their knowledge will be greater. In a static setting, tenure works as a crude but serviceable proxy for knowledge.

In a changing environment, however, increasing reliance on seniority as a basis for choosing the policy-making elite leads to a steady reduction in an organization's learning capability. The more rapidly the environment changes, the weaker the link between tenure and knowledge, and the more frequently the 'wrong' people are promoted to positions from which they can influence organizational policy. The larger the fraction of the policy-making elite that such poor choices comprise, the less the organizational code reflects the views of those whose beliefs most closely match the external environment. In summary, decoupling promotion from performance, particularly in a changing environment, is likely to hinder an organization's learning capability.

Track record

As the weight given to past performance increased, learning declined (Figure 4), and the rate of the decline varied with the degree of turmoil in the environment. In static environments, increasing the attention paid to long performance histories had only a mild effect at first, although when the same weight was given to past as to present performance, no learning was achieved. As environmental turmoil increased, the decline in learning became more marked as

longer performance histories were taken into account. Both predictions of Proposition 6 are supported. In promoting people, taking into account longer track-records is increasingly problematic, the more dynamic the setting.

Figure 4 about here

Stringency

Altering the stringency of the entry requirements to the policy-making elite had the expected effect (proposition 7). Excessively high standards for inclusion in the policy-making elite proved counter productive; so too did excessively lax standards (Figure 5).

Figure 5 about here

Increasing stringency reduces the heterogeneity of the policy-making elite, thus reducing the level of learning. In a static environment, the optimal place to set the bar is just below the level of knowledge of the organization. Raising or lowering the height of the bar reduces organizational learning.

In a dynamic environment, the optimal level for the bar appears to be slightly above zero. As in the static case, increasing stringency much above the zero level lead to a drop in learning. The sharp decline when the threshold dropped below zero in a dynamic environment was unexpected. When the environment is changing, admitting anyone to the policy-making elite whose score is equal to or lower than that of the code, had a dramatic effect on learning; there is a precipitous decline as the stringency is lowered below zero. Learning occurs only when organizational policy is developed by people who have more knowledge than that already embedded in the

organization's rules and procedures. In deciding where to set the bar in a dynamic environment, it seems that erring on the side of excessive stringency is preferable to being overly lax.

Conclusion

“[Nokia] is a meritocracy, a place where you are allowed to have a bit of fun, to think unlike the norm, where you are allowed to make a mistake.” (Jorma Ollila, quoted in Fox, 2000)

Nokia's Chief Executive draws attention to two features of importance for learning organizations: meritocracy, necessary as a selection mechanism to ensure that organizational knowledge is exploited, and experimentation or exploration, necessary to ensure that an adequate source of variation is present. The simulation described here suggests that systems of mutual learning require not only the means by which variation can be generated, such as individual experimentation or turnover in membership, but also a relatively strict application of performance-based selection processes that take account of shorter performance histories, particularly in a dynamic setting. Foolishness emerges as the most effective mode of experimentation and the types of organizational constraint on experimentation modeled here were not useful at all. In practical terms one might ask individuals or teams to 'rediscover' in a systematic way knowledge that they and the organization believe that they already have. This would overcome the drawback of the constrained modes of experimentation that preclude testing the environment in domains that are thought to be well understood.

Ensuring that promotion is tied to performance is crucial to organizational learning. While this may seem self-evident, prior research suggests that merit-based promotion is by no means ubiquitous. If we are moving towards a knowledge-based economy and if knowledge, as is frequently claimed, is becoming more important to firm performance and survival, then

seniority-based promotion will pose a problem, particularly for firms in high velocity environments. Similarly, increasing the degree to which individual performance history is factored into promotion decisions also has a negative effect on learning, again particularly in a dynamic environments. This presents managers with a problem that the model does not address: how to achieve a level of confidence in making promotion decisions on apparently insufficient information. It could also lead to the emergence of a very fluid organization, one in which people are promoted, but also demoted, frequently, an environment that many might find troubling. The organizational context at Microsoft described by Thielen is one in which the level of experimentation and the rate of turnover for poor performance are both high, and promotions are based largely on people's most recent performance. Microsoft's policies could be construed as being well suited to promote organizational learning, even though this creates what Thielen describes as a "Darwinian environment" (1999, p.72).

One avenue for future work would be to simulate the same kinds of phenomena as have been investigated here using different simulation 'substrates,' that is, using other collective learning systems to which these same set of tests might be applied. An obvious candidate for such an alternative would be a simulation model that does away with the policy-making elite. The present model is in the tradition of March's earlier work with Cyert and is consistent with the work on organizational routines in the behavioral economics literature. A model in which individuals learn not through conforming to a set of rules and routines but by learning directly from one another would have much in common with learning models from the literature on social networks. In such a model, individuals would have chance encounters with other members of the organization and choose whether or not to update their beliefs after an exchange of

information with the colleague they have just met. Yet another avenue for future work would be to test these propositions empirically.

The aim here has been to build on March (1991) as a means of theorizing about the implication for organizational learning of a number of real-world organizational practices. However, much remains to be done to complete a link between the theoretical conceptualization and learning processes in real organizations. Whether researchers explore these processes using alternative simulations or whether they move into the field to test some of the simulation's predictions, March's model of mutual learning remains an important conceptual cornerstone in the understanding of organizations as learning systems.

Appendix: Structural Model Estimation

While the above results are informative, they represent only a very selective set of pictures of the model's behavior and thus may not provide a robust account of the theoretical mechanisms represented in the simulation. To assess the behavior of the model more thoroughly it is necessary to move away from single 'slices', that is from snap-shots taken with one particular set of parameters, since the results in each slice may be contingent on the choice of model parameters not being investigated in that particular experiment. To overcome this problem an econometric approach was used: a great many experiments were run in which each parameter was chosen stochastically. Using the logic articulated in the theory section above, the structural model shown in Figure 6 was estimated using these stochastically generated data.

Figure 6 about here

In addition to the model parameters, and the dependant variable of average organizational knowledge (*Av. Ind. Know.*) used as the outcome measure in the preceding sections, two additional simulation variables were also measured to capture knowledge in different parts of the system. These were the average level of knowledge of the members of the policy-making elite, (*Av. Sup. Grp. Know.*), and the level of knowledge embedded in the organizational code (*Org. Knowledge*). Two additional measures were also constructed to monitor the variation in beliefs among all individuals in the system and among those in the policy-making elite. *Individual Heterogeneity*, the variation in individual beliefs, was calculated as the average of the distances between belief structures measured between each possible pairing of individuals:

$$\text{Individual Heterogeneity} = \frac{1}{n(n-1)} \frac{1}{n} \sum_{i=1}^n \sum_{j=1}^n \sum_{k=1}^m |b_k^i - b_k^j|$$

where n is the number of people in the simulation and m is the number of dimensions in the environment (and each individual's belief vector). An identical measure, *Policy-making elite Heterogeneity*, was constructed for the heterogeneity of beliefs among members of the policy-making elite.

The five equations were estimated simultaneously using the STATA *reg3* procedure (StataCorp., 1999). The results are shown in Table 1. Because all three of the equations reference each other (*Av. Sup. Grp. Know.* depends on *Av. Ind. Know.*, *Av. Ind. Know.* depends on *Org Know.*, and *Org Know.* on *Av. Sup. Grp. Know.*), a simple system containing just these three sets of interdependent variables was estimated first as a baseline to indicate the amount of additional variance explained by the addition of the model parameters, the independent variables of interest in the estimation. In the first equation (*Av. Ind. Know.*), the addition of the parameters explains

an additional 20% of the variance, in the second (*Av. Sup. Grp. Know.*), another 9% is explained and a further 4% is explained in the third equation (*Org. Know.*).

Table 1 about here

In all cases except one, the independent variables were significant and their coefficients had the expected signs. The one instance in which a parameter did not behave exactly as expected was the organization learning parameter. Overall, the results of the estimation suggest that the simulation is behaving as expected. It also confirms the logic of the mechanisms linking each of the parameters to average individual learning as an outcome. For example, experimentation is seen as acting through two paths, one direct, and the other indirect. The direct effect of experimentation is to reduce the average level of individual knowledge. Indirectly, it increases variation (belief heterogeneity), which increases the possible states of the environment that are tested, thus increasing the number and variety of views represented in the policy-making elite. An increase in the level of individual knowledge heterogeneity also increases the belief heterogeneity in the elite, which allows policy to be more easily changed and helps the organization to adapt.

The structural model therefore lends support to the explanations provided in the theory development, as well as reducing the likelihood that the results are narrowly contingent on particular settings of the model parameters for which the earlier results were obtained.

Figure 1

Three Modes of Experimentation at Two Rates of Socialization, with and without Turmoil

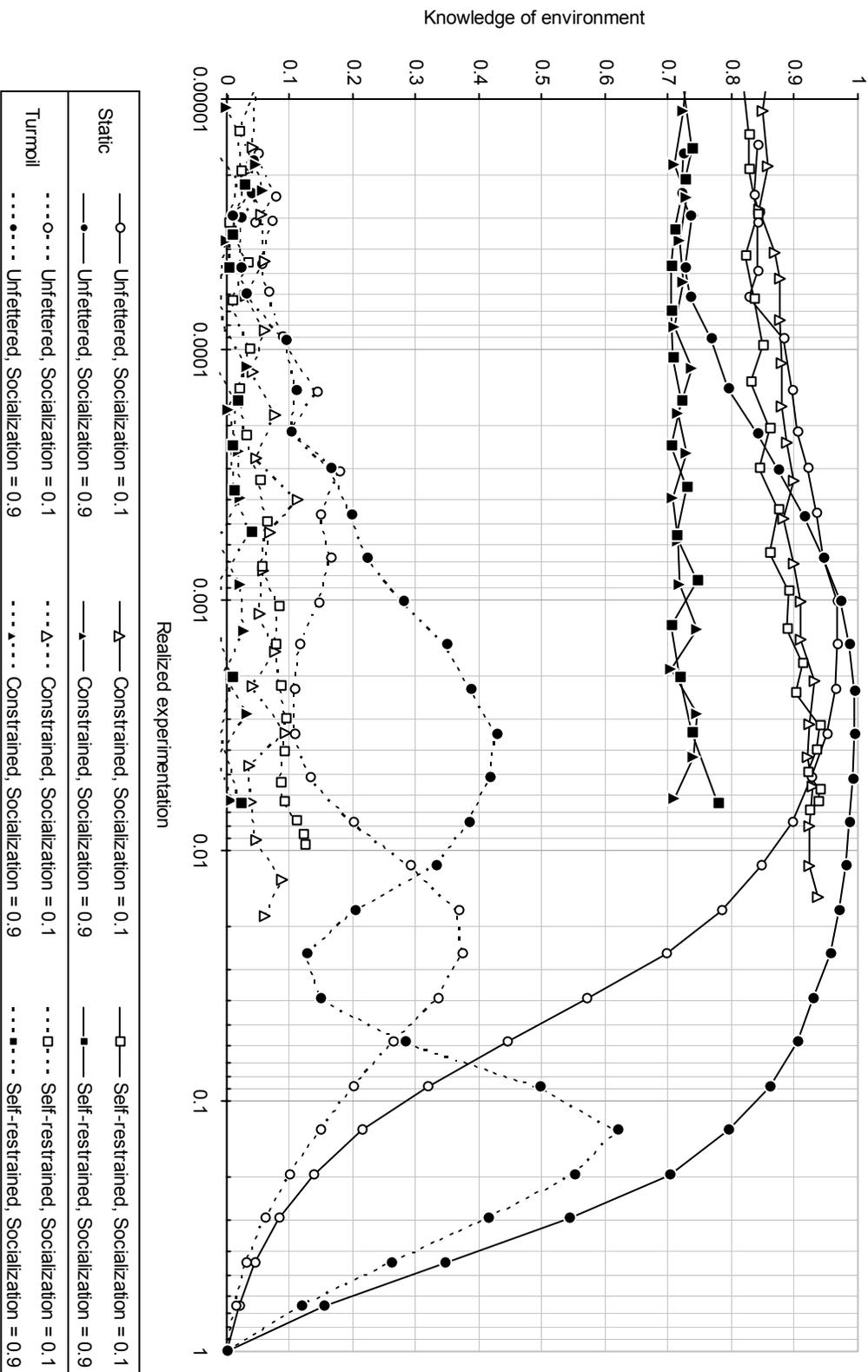


Figure 2

Effect of Different Turnover at Different Levels of Socialization

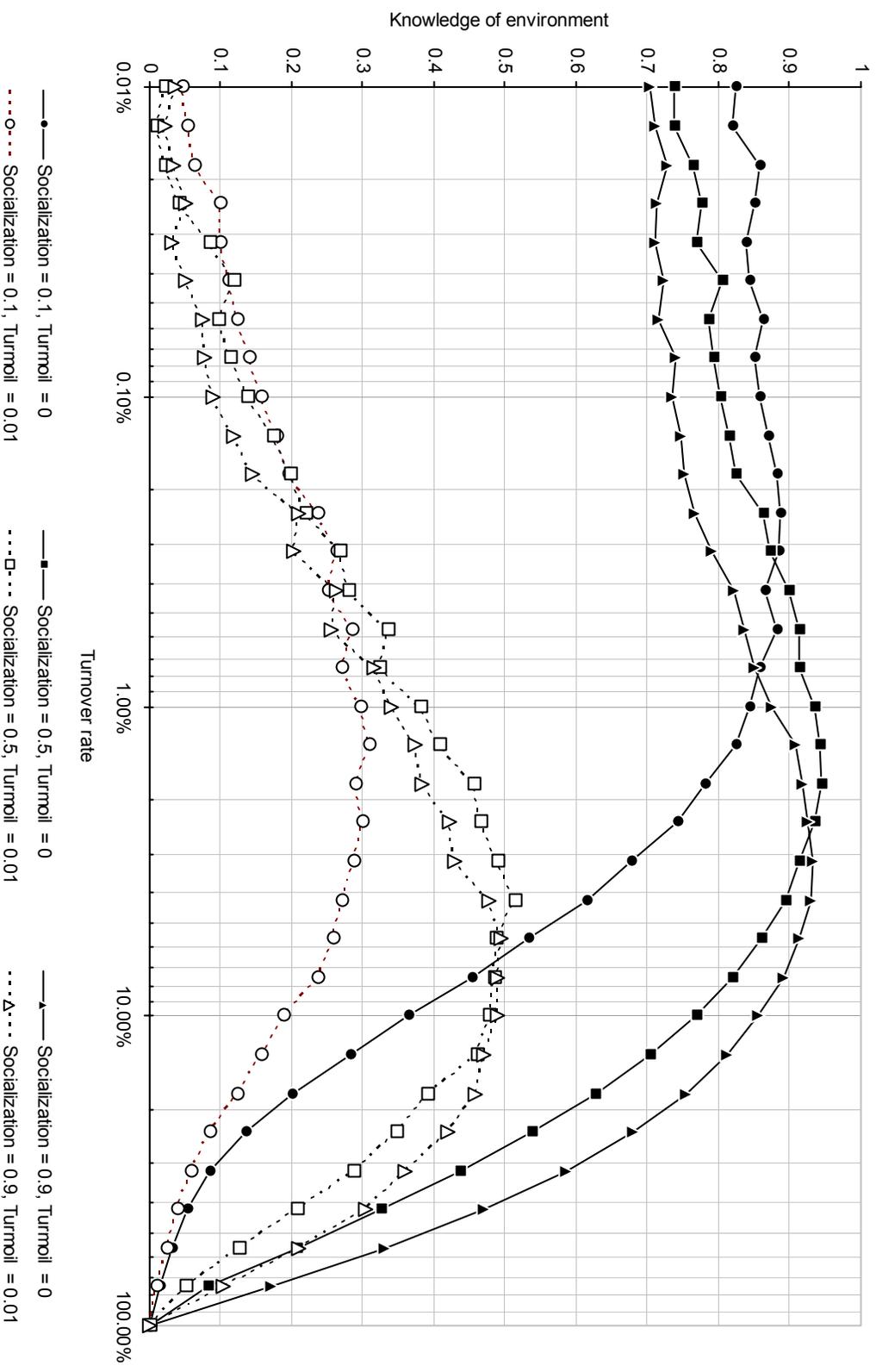


Figure 3

Effect of Frequency of Participation in Policy Setting Group Based on Seniority

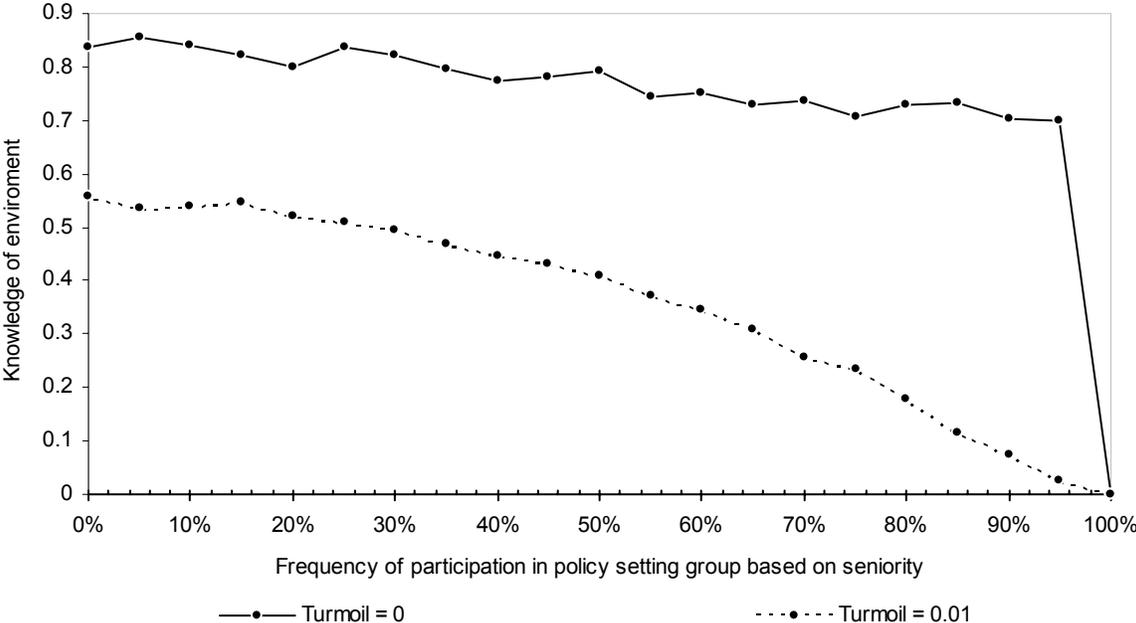


Figure 4

Effect of Increasing Attention to Performance History at Different Rates of Turmoil

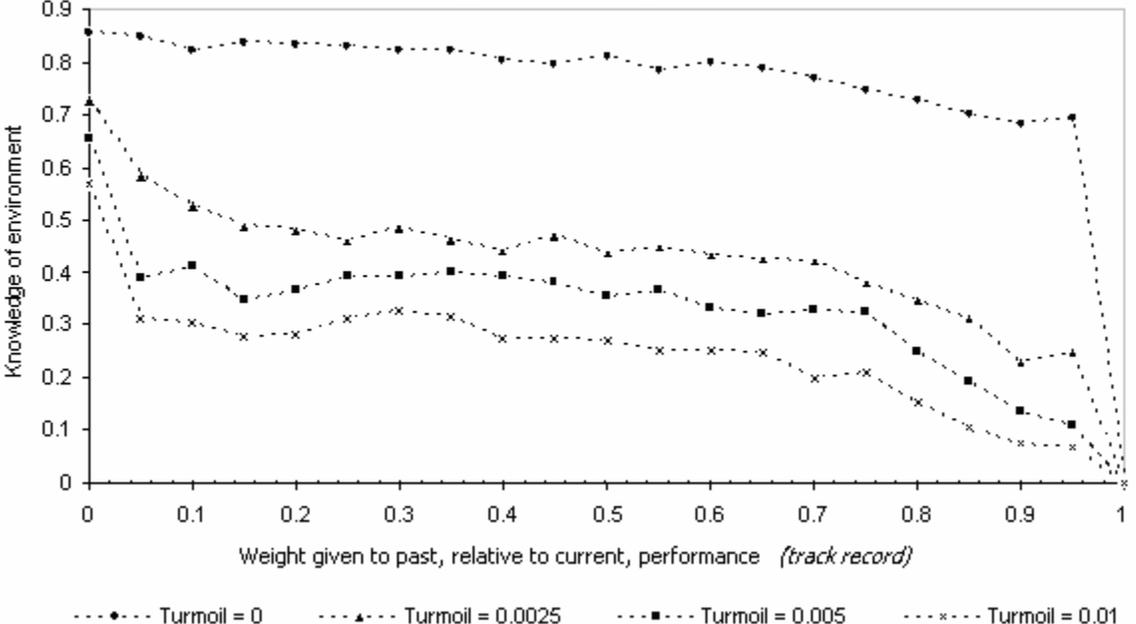


Figure 5

Effect of Stringency of Requirement for Inclusion in Policy Setting Elite



Figure 6

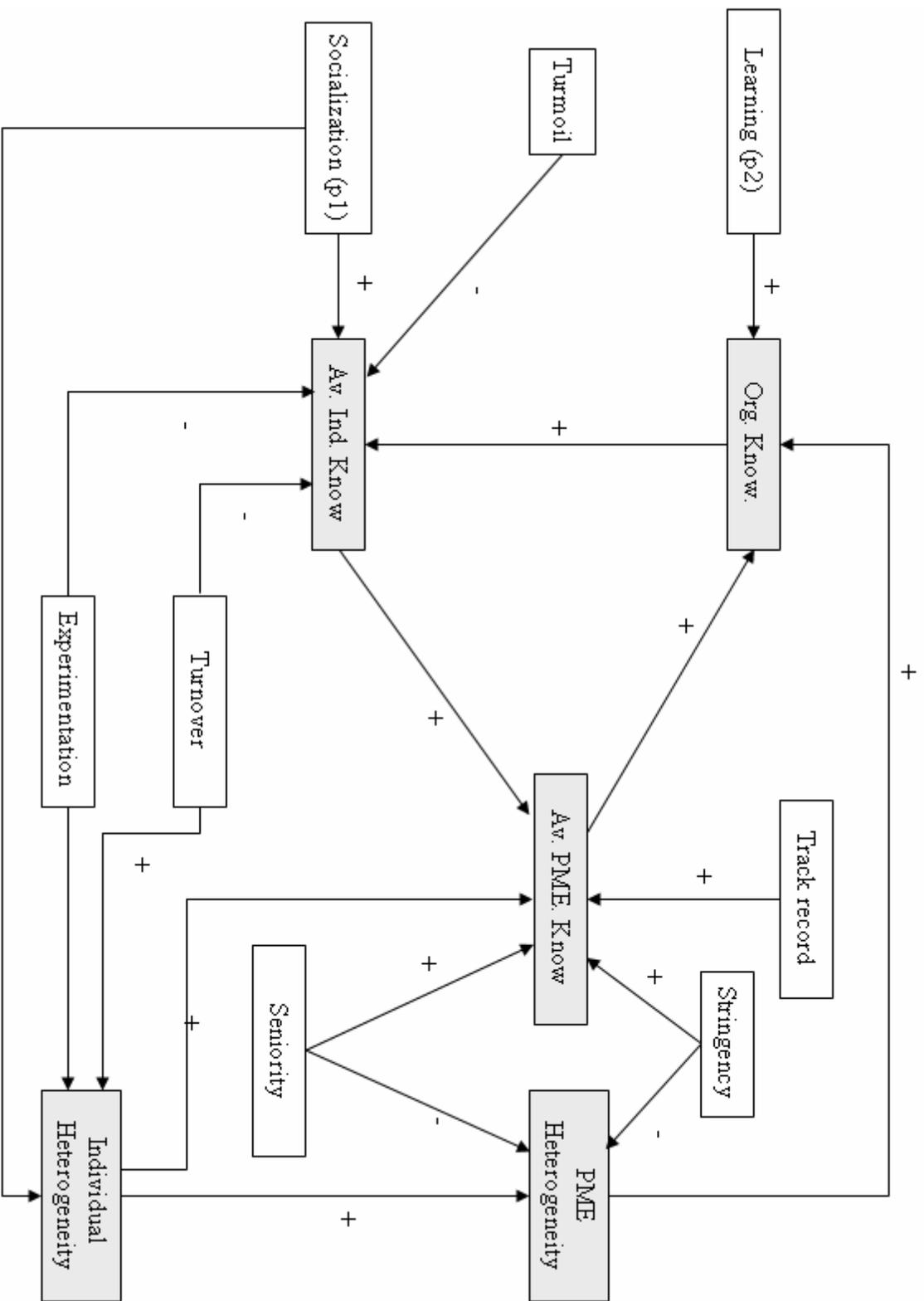


Table 1
Structural Model Estimation

		Baseline model	Full model (all variables)
	Pred. sign	Coeff.	Coeff.
Average individual knowledge (Av. Ind. Know.)		R ² 0.479 ***	R ² 0.686 ***
Constant		-0.4031 ***	0.060 ***
Av. Org. Know.	+	0.431 ***	0.254 ***
Socialization (p1)	+		0.056 ***
Experimentation (constrained)	-		-0.144 ***
Experimentation (self-restrained)	-		-0.159 ***
Experimentation (unconstrained)	-		-0.116 ***
Turnover	-		-0.077 ***
Turmoil	-		-1.027 **
Average policy-making elite knowledge (Av. PME. Know.)		R ² 0.527 ***	R ² 0.601 ***
Constant		0.028 ***	0.303 ***
Av. Ind. Know.	+	1.48 ***	1.724 ***
Track record	-		-0.013 ***
Seniority	+		0.073 ***
Individual heterogeneity	+		0.639 ***
Stringency	+		0.001 ***
Average organizational knowledge (Av. Org. Know.)		R ² 0.739 ***	R ² 0.787 ***
Constant		0.057 ***	-0.090 ***
Av. PME Know.	+	1.31 ***	1.524 ***
Learning (p2)	+		-0.012 ***
PME Heterogeneity	+		0.357 ***
Individual heterogeneity			R ² 0.656 ***
Constant			0.359 ***
Socialization (p1)	-		-0.111 ***
Experimentation (constrained)	+		0.188 ***
Experimentation (self-restrained)	+		0.362 ***
Experimentation (unconstrained)	+		0.215 ***
Turnover	+		0.095 ***
PME Heterogeneity (Policy-making elite heterogeneity)			R ² 0.499 ***
Constant			0.052 ***
Seniority	-		-0.070 ***
Stringency	-		-0.003 ***
Individual heterogeneity	+		0.761 ***

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