Rigidity of Social Systems

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The tendency for the members of a corporation or government to be resistant to change is explored in a model that encompasses two endemic features of such systems. First, the social system is modeled as a hierarchy, and implicit within it is a selection process that determines who advances to higher levels. Second, an agent's behavior is partially determined by imitating those who have risen in the ranks. A behavioral norm of being rigid is found to be more prevalent and robust than one of being flexible. A more volatile environment may also induce agents to be more resistant to change.

> *admirandi sed non imitandi* (to be admired but not imitated) [St. Augustine]

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I. Introduction

Why do some corporations remain rigid in their practices as market conditions change? Why do some governments fail to respond to large economic and social changes and ultimately lose power? Such ossification may reflect the embodiment of a norm of being resistant to change, of acting in the same manner regardless of the state of the environment. But what are the processes that would generate such a norm of behavior? Do certain features of the external environment lead people to be unresponsive to a change in their circumstances? What about characteristics of the internal structure of the social system?

For any mode of behavior to become a norm, it would seem to require at least some redeeming features. Flexibility possesses some obvious advantages in that it allows an individual to properly condition his or her behavior on prevailing circumstances. Though rigidity may have pejorative connotations, there are actually some well-recognized advantages from being rigid. When rigidity involves restricting one's self to a small set of actions, learning by doing suggests that proficiency may come from being rigid. Relatedly, Heiner (1983) argues as to the difficulty in effectively administering a large repertoire of actions. If rigidity is shown by the messages one sends to others (e.g., political positions), espousing consistent views over time lends credibility. Consistency can be virtuous in that it may reflect an underlying set of strongly held principles. If rigidity is shown by ideas (e.g., persevering with a narrowly conceived vision), familiarity with thinking about the world in the same way may be more productive in generating ideas that work in that conception of the world. The general hypothesis that there are individual advantages associated with consistently doing the same thing seems quite compelling.

Though there may be some advantages to being rigid, there still remains the question of what types of social systems and meta-environments are conducive to promoting a rigid norm. To understand how certain behavioral patterns emerge from a social system, it is useful to think about how they are structured. A distinctive feature of most if not all social systems is that they are hierarchical, with notable examples being corporations and governments. The behavioral patterns of those at the top of social systems may then be understood by exploring the process by which people are selected for advancement in a hierarchy. Within a government, are ideologues (who are rigid in the sense of being relatively unresponsive to voters) or office seekers more likely to occupy high-level offices such as governor, senator, and president? Are apparatchiks (who are relatively responsive to their superior's wishes) or mavericks more proficient at climbing the corporate ladder and becoming senior vice-presidents and chief executive officers?

Such a selection process is explored in Harrington (1998). Selection is assumed to operate on a heterogeneous population of agents who are exogenously endowed with various degrees of rigidity. It is shown that if a hierarchical social system has sufficiently many levels, then its highest levels will be dominated by agents whose behavior is relatively unresponsive to the environment. However, by assuming that agents are endowed with behavioral rules, that analysis has little to say about behavior at the highly populated low levels of a social system, where selection has had minimal opportunity to operate. To understand how a mode of behavior can become a social norm—that is, ubiquitous throughout society—one must take account of how rules get passed along from old agents to new agents. Integral to that process are those old agents with status since they tend to be noticed, admired, studied, and imitated. Since status is determined by rank in a hierarchy, those agents who rise to high levels may then have a pervasive and lasting influence through what the next generation infers about ''what it takes to move up.'' In this manner, the behavioral characteristics of those at the top may result in a rule that causes those characteristics to become a social norm.

To investigate norms regarding how people respond to change, I develop and explore a dynamical process that encompasses both of these forces: *selection* and *social learning*. These dual dynamics are found to interact in subtle ways. A norm of being unresponsive to one's environment is shown to be more prevalent and robust than one of being adaptive. The reason is that, among those agents who get to the top, it is easier for new agents to infer their mode of behavior if they used a rigid rule than if they used a flexible rule. In the terminology of Boyd and Richerson (1985), a rigid rule is revealed to have ''higher fidelity'' than a flexible rule, and this makes it more imitable. The source of this higher fidelity is that selection tends to promote those flexible agents whose history is consistent with their using a rigid rule whereas it does not tend to promote those rigid agents whose history is consistent with their using a flexible rule. Hence, the imitation of rigid agents proves to be easier than that of flexible agents.

It would be particularly natural for a more volatile environment to enhance the chances that a flexible norm will be adopted. While this is often the case, it is not always true. There is a wide class of circumstances for which a more volatile environment promotes the adoption of a rigid norm. While an increase in the volatility of the environment always makes an agent who uses a flexible rule more likely to advance to higher levels, this need not imply that more new agents adopt a flexible rule. The reason is that a more volatile environment also makes it easier for agents who use a rigid rule to differentiate themselves from those who use a flexible rule, and this enhances the fidelity of a rigid rule. I then find that increased volatility of the environment can be conducive to the prevalence of a rigid norm.

While, to my knowledge, this paper is unique in asking how a norm of being resistant to change can develop in a social system, research on cultural transmission is similar in its interest in how behavioral norms develop. This work includes Cavalli-Sforza and Feldman (1981), Boyd and Richerson (1985), Harrison and Carroll (1991), Epstein and Axtell (1996), and Bisin and Verdier (1997).[1] Relatedly, there has been considerable work in economics on social learning. My modeling approach differs both in the space of traits over which learning occurs and in the transmission process. Previous work on social learning is concerned with learning about actions. Agents may learn from the actions and associated payoffs of others—as in Ellison and Fudenberg (1993, 1995), Bala and Goyal (1994), and Rhode and Stegeman (1995)—or agents may learn only from the population distribution of actions—as in Banerjee (1992, 1993), Bikhchandani, Hirshleifer, and Welch (1992), Bergstrom and Stark (1993), Kirman (1993), Vega-Redondo (1993), Banerjee and Fudenberg (1995), and Smith and Sørensen (1996). In contrast, I focus on learning about rules, learning about how to respond to one's environment. This is a substantive difference in that rules are not directly observable; at best one observes realizations of a rule as it interacts with the environment. In terms of modeling the transmission process, previous research has modeled *horizontal* transmission in that agents are learning from their peers. My transmission process is *vertical* in that it is predicated on a hierarchical society in which agents learn from those above them. I feel that this is a critical and largely unexplored feature of such social systems as organizations and, more generally, ones in which status is important. In terms of the process by which traits are transferred between agents, it is standard in previous work to assume that imitation is perfect. A central assumption in the model of this paper is that an agent's behavioral rule is private information so that imitation is problematic. Novel within the social learning literature, the imitability of an agent's trait is endogenized.

[1] Other related work includes Ben-Porath, Dekel, and Rustichini (1993) and Basu (1995), who discusses how social norms can limit the behavioral repertoire of societal members.

II. A Dynamical Model of a Social System

My formulation of the process determining behavioral norms in a social setting comprises four elements: a description of an agent's meta-environment and how agents interact, the selection process by which agents compete and social status is determined, the space of behavioral rules over which the population is evolving, and, finally, the social learning process by which traits are transmitted across generations.

A. Structure of Society

The most crucial element of my conception of a society is that it is hierarchical. This means that it comprises a set of k (≥ 2) ordered levels that run from a "lowest" level, level 1, to a "highest" level, level k. At each level there is a large (countably infinite) population of agents. A key presumption is that agents strive to advance to higher levels. Whether it is a politician trying to advance from the state legislature to the House of Representatives or a regional manager striving to become a vice-president in a corporation, advancement typically requires performing relatively better than a subset of one's peers who faced comparable circumstances. This process is modeled by assuming that, at each level, agents are randomly matched into pairs. Each of these matchings is faced with a stochastic environment. Once the environment is revealed to the agents, they choose actions. The agent with greater relative performance is promoted to the next level, and the other agent is assumed to exit the system. Though this "up or out" structure is extreme, casual observation suggests that most candidates who lose do not run again, and those corporate employees who are "passed over" when their time has come may no longer be on the "fast track," which makes them less likely to be considered for promotion.[2] Eventually, each agent "expires" in that I constrain agents to be in the system for at most k periods (a period equals the length of time spent at a level).

At each level, agents face two random events: the agent with whom they compete for advancement and the characteristics of the external environment. The latter is assumed to be of two possible types, $\{0, 1\}$, where the probability of environment 1 is denoted b. Without loss of generality, environment 1 is more common: $b \in (\frac{1}{2}, 1)$. An

[2] Schlesinger (1991) documents the progressive paths taken to higher office, and Rosenbaum (1984) documents the fast-track feature of corporations. The tournament-style structure of organizations is also examined in Rosen (1986), and Sah and Stiglitz (1991), Athey, Avery, and Zemsky (1994), and Prendergast and Topel (1996) explore the determinants of upper-level management.

agent's environment is assumed to be independently and identically distributed across levels so that the probability that an agent faces environment 1 is independent of the environments he faced in the past. Though there is individual uncertainty as to the environment, there is no aggregate uncertainty in that, at every level, a proportion b of all matchings have environment 1. This lack of aggregate uncertainty greatly simplifies the analysis. In responding to their environment, agents have two feasible actions at their disposal, {0, 1}. In a manner to be described below, action 0 (1) is the best (myopic) response to environment 0 (1). Since $b > 1/2$, action 1 is then more frequently the appropriate response to the environment.

B. *Selection*

The process by which people advance in this social system and thereby gain social status is specified as follows. If the two matched agents choose distinct actions, then the agent whose action matches the environment survives and advances to the next level. If both agents select the action that matches the environment, the agent who has chosen that particular action more frequently in the past advances. If they have chosen that action equally frequently, then an agent is randomly selected to survive. Who advances if both agents choose the less appropriate action need not be specified since the set of equations that describe the population dynamics is independent of it.

There are several notable features of this selection process. First, competition for advancement is local in that an agent competes with only one other agent (as opposed to competing with the population at large). Second, advancement depends only on an agent's current performance, which is implicitly determined by the current environment, his current action, and his proficiency with the action used. Third, proficiency comes from experience, from having done the same thing over and over.[3] Note that survival depends lexicographically on one's current action and one's experience with that action so that the incremental effect from choosing a better action exceeds the incremental effect from more experience.

C. *Space of Behavioral Rules*

Associated with each agent is a behavioral rule. For simplicity, attention is limited to behavioral rules that condition only on the current

[3] The model has also been generalized to allow the probability that the more experienced agent will advance to be p when both agents choose the appropriate action. While it is assumed that $p = 1$, I have also considered $p \in \{.7, .8, .9\}$ and found the results to be qualitatively robust.

environment. It is then the set of functions that map the set of environments, {0, 1}, into the set of actions, {0, 1}, with the exception that I exclude the pathological case of always choosing an action inappropriate for the current environment. I believe that this simplifies the analysis without any loss of generality. A flexible agent is defined to be one who always selects the action best suited for the environment: he chooses action 0 (1) when the environment is 0 (1). A rigid agent chooses the same action irrespective of the environment. There are two types: those who always use action 0 and those who always use action 1.

D. Social Learning

The state of the social system is represented by k populations, one at each of the system's k levels. At the end of each period, those who were at the highest level are assumed to exit the system (there is ''mandatory retirement'' after k periods in the system). For the population at level $h \in \{1, \ldots, k - 1\}$, half of them advance to level $h + 1$ according to the selection process described above and the other half exit the system. A fresh cohort of new agents is assumed to enter level 1.

The behavioral rule that a new agent adopts is determined by a confluence of two forces: imitation of those who were successful and natural predisposition. There are two aspects to imitation: identifying who is worth emulating and inferring his code of conduct. The former is relatively easy since it requires only identifying people with high rank. The latter is problematic. An agent does not wear his behavioral rule on his chest, and one cannot look into the heart of another. What an agent is presumed capable of doing is observing the past behavior of an agent and the context in which he had to act.[4] The following imitation process is specified. Each new agent randomly chooses one agent from the current level k population (those with the highest social status) to act as his role model or mentor.[5] I do not have them observe the entire population because limited information seems more natural. An incoming agent observes

[4] I suppose that a new agent cannot ask a role model what rule he used or, if he can, that such remarks are apt to be self-serving rather than truthful. How many politicians will admit that they spent their career pandering to voters as opposed to pursuing a principled course?

[5] As noted by Scott Page and Larry Samuelson, it may be more reasonable to suppose that new agents learn from those who are closer in rank. My results can accommodate this point by interpreting level k as the level that is imitated. Furthermore, it can be shown that if, at a stable point, the social system leads most agents at level k to use a particular rule, then, for reasonable parameter values, most agents above that level will use that rule as well.

his mentor's history in terms of the actions he selected and the environments he faced. If a new agent's mentor always chose the same action and, furthermore, chose it when it was inappropriate for the environment, this is unequivocal evidence that the mentor is rigid in that action. In that case, the new agent adopts that rigid rule. If a new agent's mentor chose both actions during his lifetime, then this is unequivocal evidence that he is flexible. A new agent then adopts the flexible rule. The problematic case occurs when a new agent's mentor always chose the same action but always faced the environment for which that action was appropriate. Such behavior is consistent with both being flexible and being rigid. I assume that new agents have natural predispositions to being flexible or rigid, and this predisposition breaks the indeterminacy. A proportion $w \in [0, 1]$ of new agents are predisposed to being rigid, which means that they adopt a rigid rule in that case. A proportion $1 - w$ are predisposed to being flexible, which means that they adopt a flexible rule in that case. A new agent then adopts the rule that he is predisposed to unless the behavior of his mentor is evidence to the contrary. One could imagine w being determined by what types of norms are prevailing outside of this particular social system. Once a new agent adopts a rule, it persists with him throughout his time in the system.[6]

E. Dynamical System

The initial population resides at the lowest level of the system and comprises three types: rigid agents who use action 1, rigid agents who use action 0, and flexible agents. Agents accumulate a personal history as they advance through society. Though there are then many types after the population has a chance to interact with the environment, it is sufficient for my purposes to partition the population into the following five types. A hierarchy comprises levels, whereas a generation equals the length of a single lifetime (which is k periods): $r_i^{h,g}$ is the proportion of the level h population for generation g that are rigid agents endowed with action i (Ri), $i \in \{0, 1\}$; $f_i^{h,g}$ is the proportion of the level h population for generation g that are flexible agents who have always chosen action i (Fi), $i \in \{0, 1\}$; and $x^{h,g}$ is the proportion of the level h population for generation g that are flexible agents who have chosen both action 0 and action 1 (FN).

[6] As suggested by Matt Rabin, an alternative specification is to think of an agent deciding to be rigid and then being "imprinted"; the first environment that he faces determines the action to which he is committed.

The level h–generation g state of the system is then $(r_1^{h,g}, f_1^{h,g}, r_0^{h,g}, f_0^{h,g}, x^{h,g})$. The initial conditions of the system are $r_1^{1,1} > 0$, $r_0^{1,1} > 0$, and $1 - r_1^{1,1} - r_0^{1,1} > 0$.

Since agents do not have a history at level 1, the characterization of the dynamical process is different between level 2 and higher levels. The level 2 population is determined by the following system of equations:[7]

$$r_1^{2,g} = (r_1^{1,g})^2 + 2r_1^{1,g}r_0^{1,g}b + r_1^{1,g}(1 - r_1^{1,g} - r_0^{1,g})b, \tag{1}$$

$$\begin{aligned} f_1^{2,g} = b[&(1 - r_1^{1,g} - r_0^{1,g})r_1^{1,g} + 2(1 - r_1^{1,g} - r_0^{1,g})r_0^{1,g} \\ &+ (1 - r_1^{1,g} - r_0^{1,g})^2], \end{aligned} \tag{2}$$

$$r_0^{2,g} = 2r_1^{1,g}r_0^{1,g}(1-b) + (r_0^{1,g})^2 + r_0^{1,g}(1 - r_1^{1,g} - r_0^{1,g})(1-b), \tag{3}$$

$$\begin{aligned} f_0^{2,g} = (1-b)[&2(1 - r_1^{1,g} - r_0^{1,g})r_1^{1,g} + (1 - r_1^{1,g} - r_0^{1,g})r_0^{1,g} \\ &+ (1 - r_1^{1,g} - r_0^{1,g})^2], \end{aligned} \tag{4}$$

and

$$x^{2,g} = 0. \tag{5}$$

The level $h + 1$ population, for $h \in \{2, \ldots, k - 1\}$, is determined by

$$r_1^{h+1,g} = (r_1^{h,g})^2 + 2r_1^{h,g}r_0^{h,g}b + r_1^{h,g}f_1^{h,g}b + 2r_1^{h,g}f_0^{h,g}b + 2r_1^{h,g}x^{h,g}b, \tag{6}$$

$$f_1^{h+1,g} = r_1^{h,g}f_1^{h,g}b + 2r_0^{h,g}f_1^{h,g}b + (f_1^{h,g})^2b + 2f_1^{h,g}f_0^{h,g}b + 2f_1^{h,g}x^{h,g}b, \tag{7}$$

$$\begin{aligned} r_0^{h+1,g} = {} & 2r_1^{h,g}r_0^{h,g}(1-b) + (r_0^{h,g})^2 + 2r_0^{h,g}f_1^{h,g}(1-b) \\ &+ r_0^{h,g}f_0^{h,g}(1-b) + 2r_0^{h,g}x^{h,g}(1-b), \end{aligned} \tag{8}$$

$$\begin{aligned} f_0^{h+1,g} = {} & 2r_1^{h,g}f_0^{h,g}(1-b) + r_0^{h,g}f_0^{h,g}(1-b) + 2f_1^{h,g}f_0^{h,g}(1-b) \\ &+ (f_0^{h,g})^2(1-b) + 2f_1^{h,g}f_0^{h,g}(1-b), \end{aligned} \tag{9}$$

and

$$\begin{aligned} x^{h+1,g} = {} & 2r_1^{h,g}f_1^{h,g}(1-b) + (f_1^{h,g})^2(1-b) + 2r_0^{h,g}f_0^{h,g}b \\ &+ (f_0^{h,g})^2b + 2r_1^{h,g}x^{h,g}(1-b) + 2r_0^{h,g}x^{h,g}b \\ &+ 2f_1^{h,g}x^{h,g}(1-b) + 2f_0^{h,g}x^{h,g}b + (x^{h,g})^2. \end{aligned} \tag{10}$$

Let $d_i^{h,g}$ denote the proportion of the level h population for generation g that have always chosen action i and have faced at least one type j ($\neq i$) environment. The following two equations determine the behavioral rules of the level 1 population of generation $g + 1$:

[7] A discussion of the derivation of this system is provided in Harrington (1998).

$$r_1^{1,g+1} = w(r_1^{k,g} + f_1^{k,g}) + (1 - w)\, d_1^{k,g} \qquad (11)$$

and

$$r_0^{1,g+1} = w(r_0^{k,g} + f_0^{k,g}) + (1 - w)\, d_0^{k,g}. \qquad (12)$$

The complete dynamical system then involves the embedding of (1)–(10) in (11)–(12). Because of the complexity of the system, numerical analysis is used.

III. Selection in a Hierarchical Social System

The purpose of this section is to briefly review some properties of the selection process that operates within the *k*-level system and that was examined in Harrington (1998). In Section IV, this selection process is embodied in a model of social learning to derive the main results of the paper.

To begin, the proportion of agents who are maximally proficient in action 0 (which means that either they are rigid in action 0 or they are flexible and have always faced environment 0) steadily and rather rapidly goes to zero after level 2. Since environment 0 occurs relatively infrequently, such agents are ill suited for this meta-environment. All the meaningful dynamics then take place with respect to $F1$s (flexible agents who are maximally proficient in action 1 because they have always faced environment 1), FNs (flexible agents who are not maximally proficient in either action because they have faced both environments), and $R1$s (agents who are rigid in action 1). At low levels, with agents having faced only a few environments, there will be a reasonable number of flexible agents who have faced only environment 1. Next note that when an $F1$ and an $R1$ meet to compete for advancement, an $F1$ advances with probability $(b/2) + (1 - b) > 1/2$ because, when the environment is 1, he is equally proficient in action 1 as an $R1$, and when the environment is 0, he adapts and chooses action 0. This differential advantage provides a force by which the proportion of flexible agents can rise. However, as flexible agents rise through the hierarchy and face more environments, an increasing proportion of them will have faced environment 0 and thus be less proficient in the better action than $R1$s. This lack of proficiency puts them at a disadvantage compared to those surviving agents who are rigid in action 1. Though $R1$s may initially be driven down, their differential proficiency in action 1 becomes increasingly scarce among flexible agents so that rigid agents eventually come to dominate.[8]

[8] It is shown in Harrington (1998) that if $r_1^{1,g} > 0$, then $\lim_{k\to\infty} r_1^{k,g} = 1$.

Using a phase diagram analysis, one can derive several possible paths for a population. Along one path, the proportion of flexible agents steadily rises as a cohort moves from the bottom to the top of the hierarchy. This requires that k be sufficiently small. On a second path, the proportion of flexible agents rises as one goes from low to moderate levels but falls as one goes from moderate to high levels. This can occur when k is sufficiently large. On a third path, the proportion of rigid agents (who use action 1) steadily rises as one moves up the hierarchy. This is dependent not so much on k but rather on the initial population mix. While there are other possible paths, simulations show that these are, by far, the most common.

IV. The Transmission of Behavioral Rules

An agent's rank within society is determined by the selection process characterized in the preceding section. With rank as a measure of success, we now shall explore to what extent those behavioral rules—which when followed lead to superior social status—are adopted by the next generation. To address this question, we shall characterize and examine the set of attractors of the dynamical system in which imitation operates to transfer status-producing behavioral rules to the next generation.

A. *The Set of Attractors*

In order to conduct numerical analysis, values must be specified for the system's five variables: the three parameters defining the meta-environment (b, k, w) and the two initial conditions $(r_1^{1,1}, r_0^{1,1})$, which, for shorthand, I denote (r_1, r_0).[9] Numerical analysis was conducted for a sizable subset of $(b, k, w, r_1, r_0) \in \{.5, .51, \ldots, 1\} \times \{3, \ldots, 30\} \times \{0, .1, \ldots, 1\} \times \{r_1' + r_0' \leq 1 \mid (r_1', r_0') \in \{0, .1, \ldots, 1\}^2\}$. After specifying values for (b, k, w, r_1, r_0), I ran the system until convergence was achieved; the criterion is that the absolute difference in the state variables is less than 10^{-5} in consecutive generations. To gauge the societal presence of a particular rule, the proportion of

[9] Actually, there are $k - 1$ initial populations, for we start with an empty hierarchy. An exogenous population enters level 1 in period 1 with population mix (r_1, r_0). In period 2, this cohort moves up to level 2 and a new population enters level 1. However, if $k \geq 3$, then there is no level k population for them to imitate, so we can assume that this new population is also exogenous with mix (r_1, r_0) (though all results are robust to the mix's not being too different from (r_1, r_0)). In period k, the population that entered level 1 in period 1 will have reached level k so that the new population entering level 1 will have a level k population to imitate. From period k onward, the entering level 1 population will be endogenous since it is determined by the level k population and w through (11)–(12).

agents using that rule at each level was averaged across all levels. In other words, if, after the system has converged, $\rho(Q; h)$ is the proportion of agents using rule $Q \in \{R1, R0, \text{flexible}\}$ at level h, then the presence of rule Q is measured by $\phi(Q) \equiv (1/k) \sum_{h=1}^{k} \rho(Q; h)$. I refer to $\phi(Q)$ as the average proportion of agents using rule Q.[10]

In every run, the system converged. It generally took 10–20 generations, though vastly longer in some cases. Depending on the meta-environment, there is either a global attractor or two local attractors. For $(b, k, w) \in \{.5, .52, \ldots, .9\} \times \{5, 6, \ldots, 25\} \times \{0, .1, \ldots, 1\}$, figure 1 reports whether there is a global attractor in which the average proportion of agents using a rigid rule is at least as great as ½ (white area),[11] a global attractor in which the average proportion of agents using a flexible rule exceeds ½ (black area), or two local attractors (gray area). For all attractors, the set of rigid agents is typically dominated by those who use action 1 because of the greater frequency with which environment 1 occurs.[12]

B. Properties of Attractors

1. Prevalence of Rigid and Flexible Norms

A behavioral rule is said to be a *locally stable norm* if there is a local attractor in which a large fraction of agents use that rule. In operationalizing this definition, figure 2 reports when the system has (i) a local attractor in which the average proportion of agents using a rigid rule in action 1 exceeds 95 percent (white and light gray areas) and (ii) a local attractor in which the average proportion of agents using a flexible rule exceeds 95 percent (light gray and dark gray areas). It also reports the absence of a local attractor in which the presence of a rule exceeds 95 percent (black area) so that there is no locally stable norm.

When enough new agents are predisposed to a particular mode of behavior, figure 2 reveals it is generally the case that that mode of behavior can dominate. In other words, for a wide range of values

[10] Of course, $\phi(Q)$ is not the proportion of agents in the system using rule Q since there are more agents at lower levels than at higher levels. This would argue toward having a measure that gives more weight to lower levels. On the other hand, agents at higher levels have more power, so each high-level agent is equivalent to several low-level agents. Given these two countervailing forces, I chose to give all levels equal weight. However, I do not believe that qualitative results are sensitive to the measure used.

[11] In other words, $\phi(R1) + \phi(R0) \geq ½$.

[12] The exception occurs when b is close to .5, k is low, and w is close to one. These are cases in which the selection dynamic is relatively weak because there are relatively few levels to the hierarchy and both environments are nearly equally likely. As a result, there is a substantive presence of all three rules.

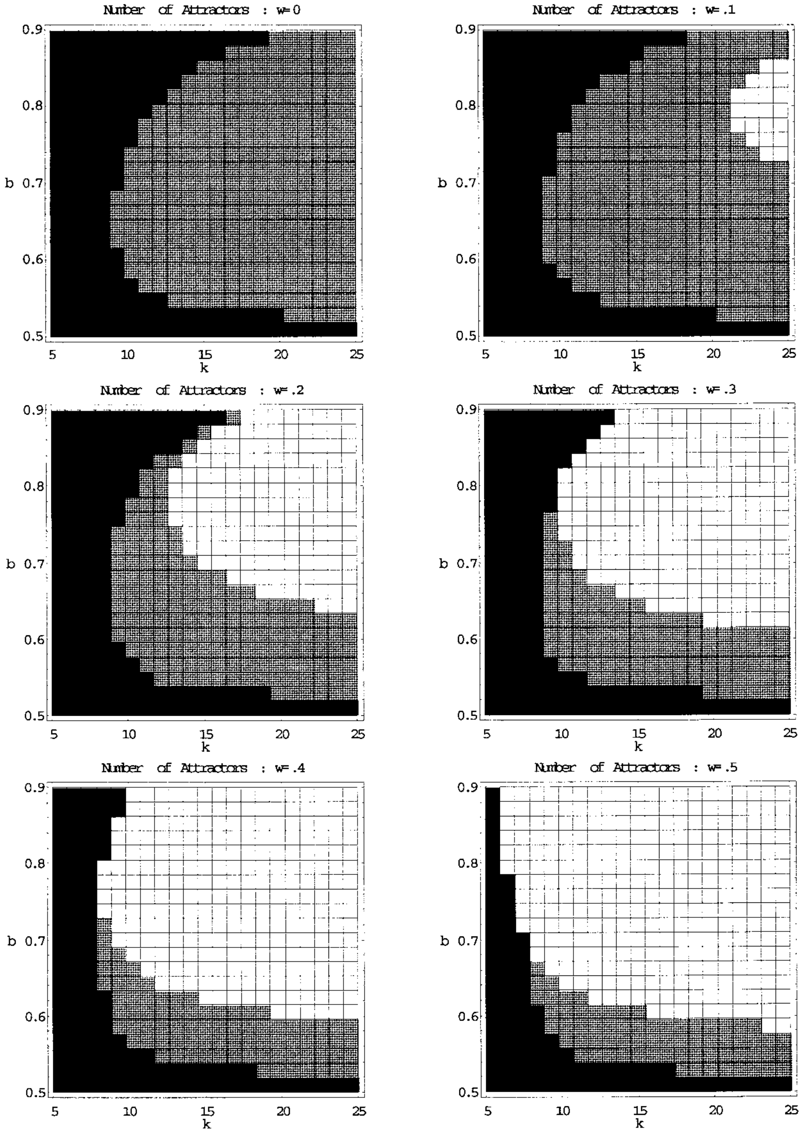

FIG. 1.—Set of attractors. White: Global attractor with average proportion of rigid agents at least as great as .5. Black: Global attractor with average proportion of flexible agents exceeding .5. Gray: Two local attractors.

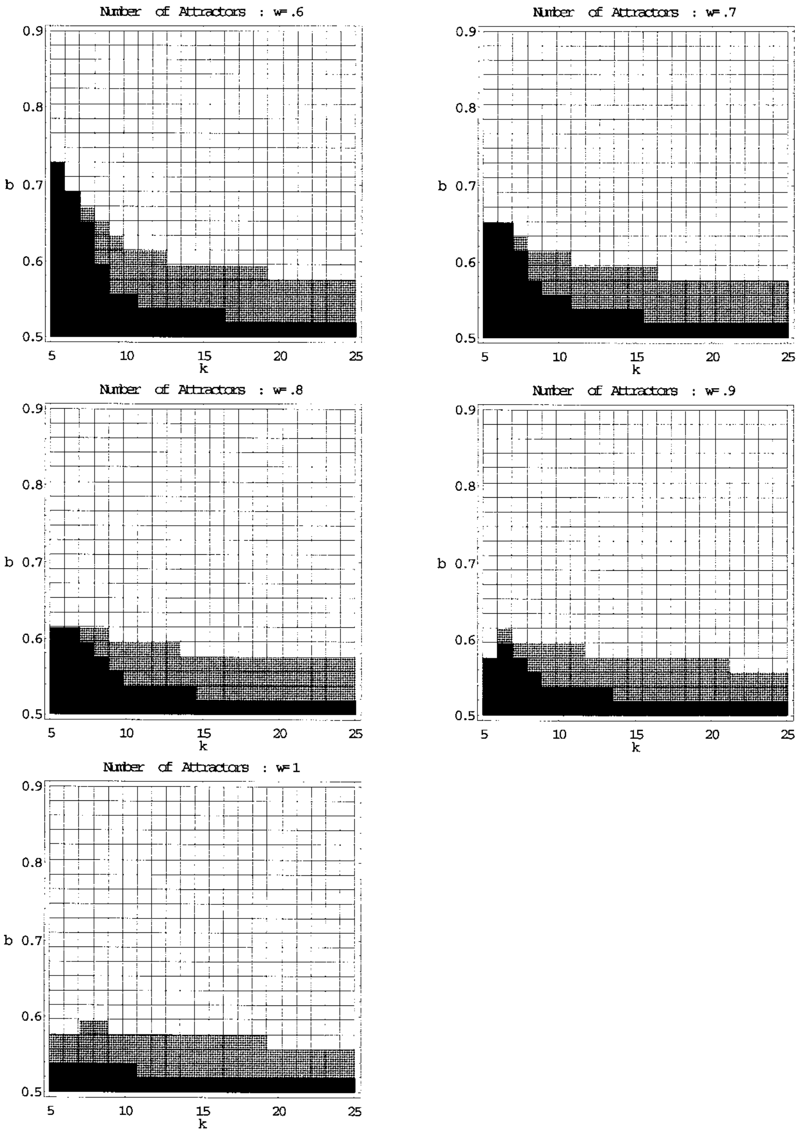

FIG. 1.—Continued

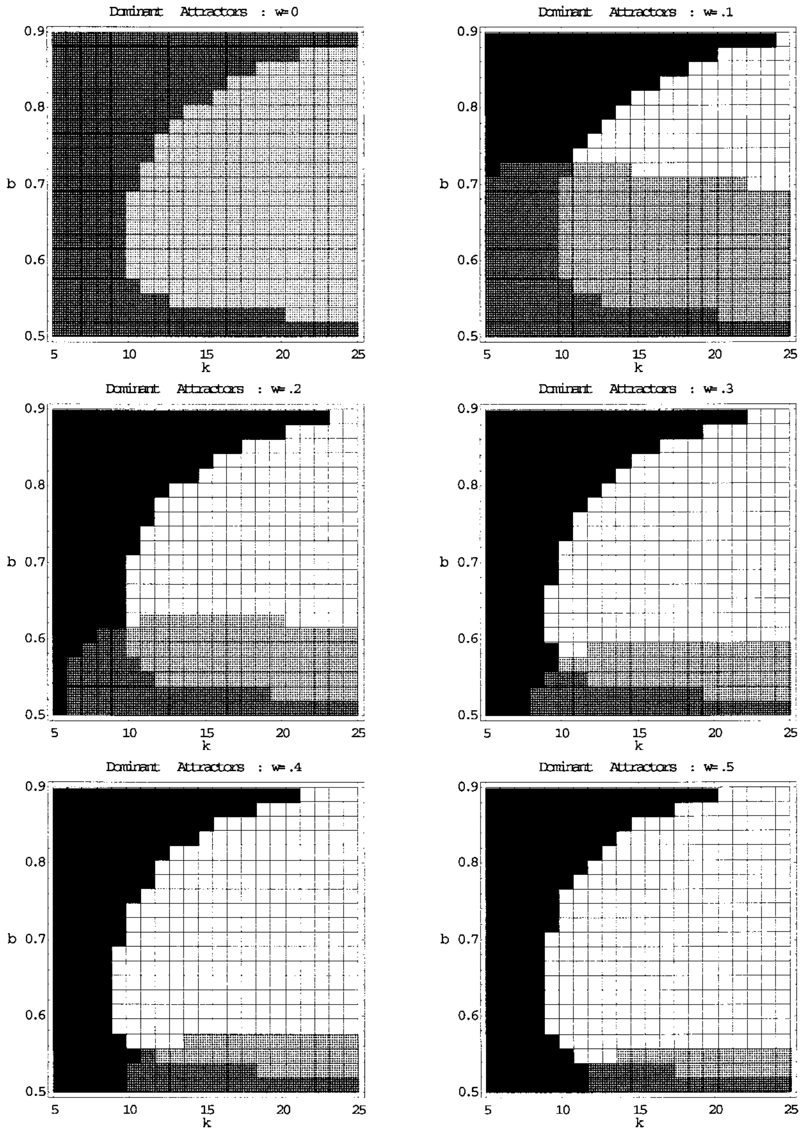

FIG. 2.—Attractors with a locally stable norm. White and light gray: Local attractor exists, with average proportion of *R*1s exceeding .95. Light gray and dark gray: Local attractor exists, with average proportion of flexible agents exceeding .95. Black: No local attractor exists, with average proportion of *R*1s, average proportion of *R*0s, or average proportion of flexible agents exceeding .95.

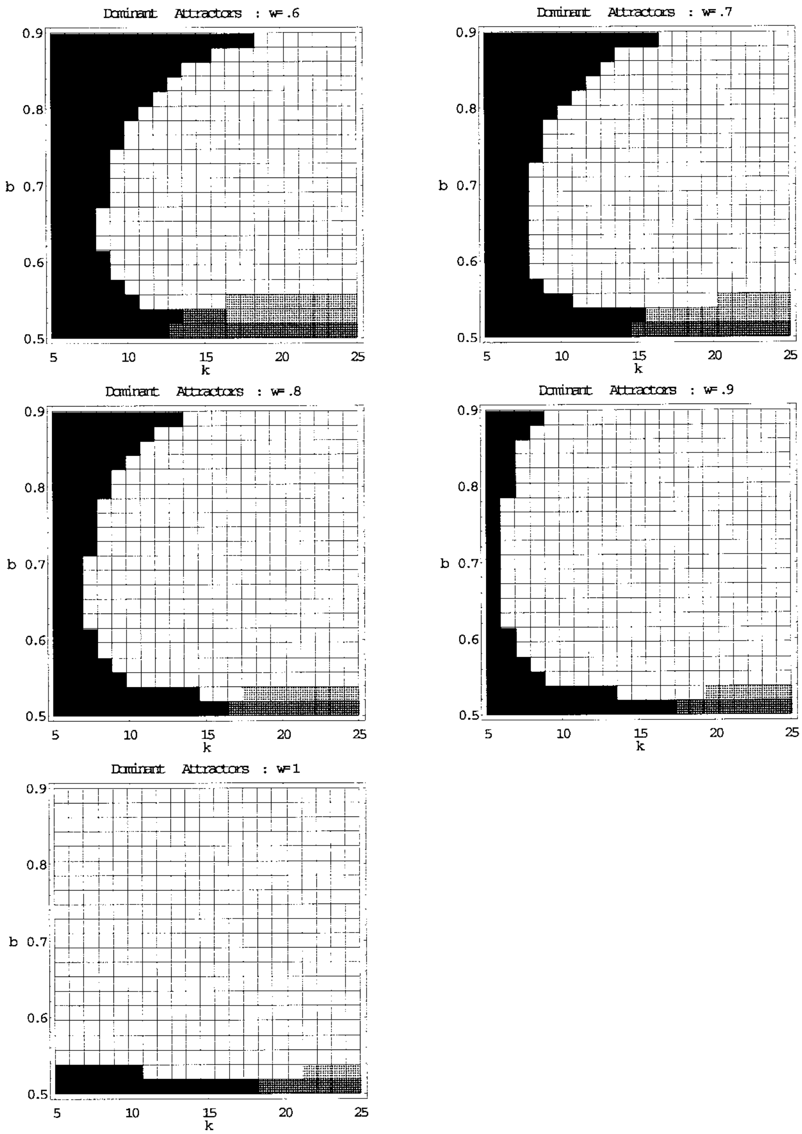

Fig. 2.—Continued

for (b, k), there exist initial conditions such that a behavioral rule—whether rigid or flexible—can dominate when enough incoming agents are predisposed to it. For example, when all new agents are predisposed to being flexible ($w = 0$), all values of (b, k) considered have a local attractor dominated by flexible behavior. When instead all new agents are biased toward being rigid ($w = 1$), there is a local attractor dominated by rigid behavior except when the environment is very volatile (b is close to .5).

It is more problematic and interesting when new agents are not predisposed to a rule. How likely is it that such a rule can dominate? Here I found a notable asymmetry: a rigid rule fares much better than a flexible rule when faced with an incoming population that is biased against it. For example, when $w \geq .8$, flexible behavior is not dominant except when the environment is very volatile ($b \leq .52$). In contrast, even when all incoming agents are predisposed to being flexible ($w = 0$), rigid behavior dominates for many values for (b, k) (over half of the parameter configurations considered).

PROPERTY 1. Regardless of the predispositions of new agents, a rigid rule is a locally stable norm for a wide range of meta-environments. When enough new agents are predisposed to being flexible, a flexible rule is a locally stable norm for a wide range of meta-environments. When enough new agents are predisposed to being rigid, a flexible rule is generally not a locally stable norm.

Of course, it is possible that the set of initial conditions whereby a rigid rule is a locally stable norm could be quite small when most agents are biased against being rigid. To explore this issue, consider figure 3. The height of the surface measures the percentage of the initial state space such that the system converges to having a rigid rule as a norm for the case in which all incoming agents are biased toward being flexible. The basin size is typically not small and is often well above 50 percent.

One interpretation of this result is as follows. Since w measures the innate tendencies of new agents, w could be determined by the prevailing norms in society at large (of which this social system is a component). What we have then been examining is the ability of a rule to be established as a norm within a system when it is contrary to behavior exhibited in the larger system from which it draws its members. My analysis showed that it is distinctly easier for a system to be rigid when society at large is flexible than it is for a system to be flexible when society at large is rigid. Furthermore, if one imagines that w is stochastic, then this analysis suggests that a rigid rule is a more robust norm. A flexible norm will tend to unravel when, over several generations, incoming agents are not heavily predisposed to being flexible (w is not low). In contrast, a rigid rule, once

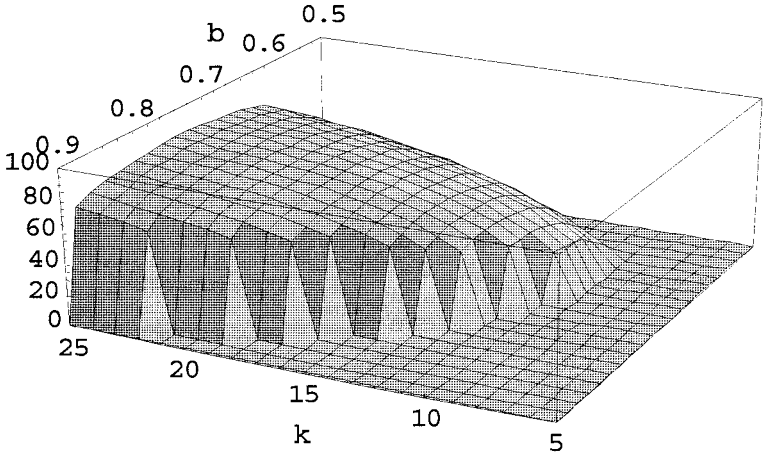

FIG. 3.—Size of the basin of attraction (as a percentage of the state space) for a local attractor, with the average proportion of $R1$s exceeding .95 ($w = 0$).

it becomes a norm, can persist regardless of the endowed tendencies of new agents.

To see why this is true, let us begin by considering $w \cong 1$ and have the level 1 population be all or almost all agents who are flexible. The next generation will not be dominated by flexible agents because as a result of social learning, a substantial number of new agents adopt a rigid rule even though their mentors used a flexible rule. This occurs as follows. Some flexible agents will work their way up to the top while having always faced the same environment and thus always having chosen the same action. A new agent who is inclined to being rigid and has such a flexible agent as his mentor will adopt a rigid rule (in the action chosen by his mentor). Of course, if few of the flexible agents at level k faced the same environment over their history, then few of the rigid-inclined new agents will adopt a rigid rule. This would allow the system to maintain a predominance of flexible agents. Though, for reasonable values of (b, k), it would seem that very few flexible agents would rise to the top while having faced the same environment, in fact, it proves to be quite common because *selection favors flexible agents who have always faced the same environment*. Consider a flexible agent who has risen to some level while having always faced environment 1. He has a higher chance of advancing to the next level than a flexible agent who has faced both environments because, by having always faced environment 1, he is more proficient in the action that is more frequently the best response to the environment. Selection then favors flexible agents who have always faced environment 1, and it is they who induce a rigid-inclined incoming agent to adopt a rigid behavioral rule. To see the order of magnitude of this effect, suppose that $(b, k) = (.6, 15)$ and that there are all flexible agents at the lowest level. At level 15, 35 percent of those flexible agents will have always faced environment 1, which means that a proportion $.35w$ of the next generation's level 1 population will adopt a rigid rule in action 1. This 35 percent is to be compared with the ex ante probability of facing 14 consecutive type 1 environments, which is $.6^{14} \cong .001$. The difference between 35 percent and 0.1 percent is the discriminating power of selection.

Having established that a flexible rule is typically not a locally stable norm when enough new agents are inclined to be rigid, let us now argue that almost all agents practicing rigid behavior (with respect to action 1) are stable even when many new agents are inclined to be flexible. Suppose that $w = 0$ and there are almost all $R1$s. New flexible-inclined agents adopt a flexible rule even when their mentor is an $R1$ if their mentor always faced environment 1. In this manner, $R1$s are transformed into flexible agents. However, in contrast to the previous case, selection does not tend to make those $R1$s who get to the top indistinguishable from an agent who uses a flexible rule because an $R1$'s chances of advancing are independent of his history of environments. As advancement depends only on an agent's behavioral rule and his past actions and given that a rigid agent's past actions are independent of the environments he has faced, rigid agents who have faced the same environment do not have a higher chance of advancing than rigid agents who have faced both environments. Returning to our example of $(b, k) = (.6, 15)$, now suppose that all level 1 agents are $R1$s. Since selection is then random, the proportion of those at level 15 that have always faced environment 1 is .001. Thus 99.9 percent of those $R1$s at the top level will have differentiated themselves from flexible agents by having faced environment 0 and chosen action 1. This means that at least 99.9 percent of new agents will adopt a rigid rule even if all are predisposed to being flexible.

In sum, selection favors those agents who have always chosen action 1, for then they are maximally proficient in the action that is most frequently the best response to the environment. For agents who use a flexible rule, this implies that selection favors those who have always faced environment 1. Hence, many of those agents who use a flexible rule and rise to the top are indistinguishable from agents who use a rigid rule. As a result of this inability to differentiate themselves, many new agents adopt a rigid rule and, in essence, "hard-wire" their mentor's history of having always chosen action

1. In contrast, since rigid agents (in action 1) are proficient in action 1 regardless of the history of their environments, selection does not favor those rigid agents who have exclusively faced environment 1. This allows them to differentiate themselves from agents who use a flexible rule, and this is why a rigid rule is a locally stable norm even when all new agents are predisposed to being flexible.

For a behavioral rule to thrive, it need not be sufficient for those agents deploying that rule to rise to the top. They may also be required to have differentiated themselves from those who use other rules. What I have found is that a rigid rule does this more effectively than a flexible rule. In the terminology of Boyd and Richerson (1985), a rigid rule has "higher fidelity" than a flexible rule. I suspect that this result is rather general because it seems to be generated by two basic assumptions: (i) proficiency with an action is increasing in experience, and (ii) the behavior of those agents who use a flexible rule is more strongly correlated with their environment (which is true almost by definition).

2. Comparative Statics

To explore how the meta-environment influences the presence of flexible behavior, let us set initial conditions and allow (b, k, w) to vary. Figure 4 reports results for $(r_1, r_0) = (.25, .25)$, $w \in \{0, .2, \ldots, 1\}$, and $(b, k) \in \{.5, .51, \ldots, 1\} \times \{5, 6, \ldots, 25\}$. The height of the surface measures the average proportion of agents who use a flexible rule. All ensuing qualitative results have been confirmed for $(r_1, r_0) = (.33, .33)$. Note that the local attractor can be very sensitive to the meta-environment. Small changes in b or k can cause the system to switch from a predominance of flexible behavior to a predominance of rigid behavior (or vice versa) because of the presence of two attractors. In that case, a small change in a parameter value can shift the basins of attraction so that $(r_1, r_0) = (.25, .25)$ moves from the basin of one attractor into the basin of the other.

Since the objective of this project is to explore the development of norms related to how agents respond to change, of utmost interest is the role of the volatility of the environment. It would be natural for a more volatile environment to be conducive to the prevalence of a flexible norm. Within my model, the volatility of the environment is regulated by b, the frequency with which environment 1 occurs. The anticipated effect is that a fall in b is conducive to the prevalence of a flexible norm. Inspecting figure 4 when $w = 1$ and holding k fixed, we do find that the presence of flexible behavior is decreasing in b; consequently, a flexible norm prevails when b is sufficiently close to .5 and a rigid norm is present when b is suffi-

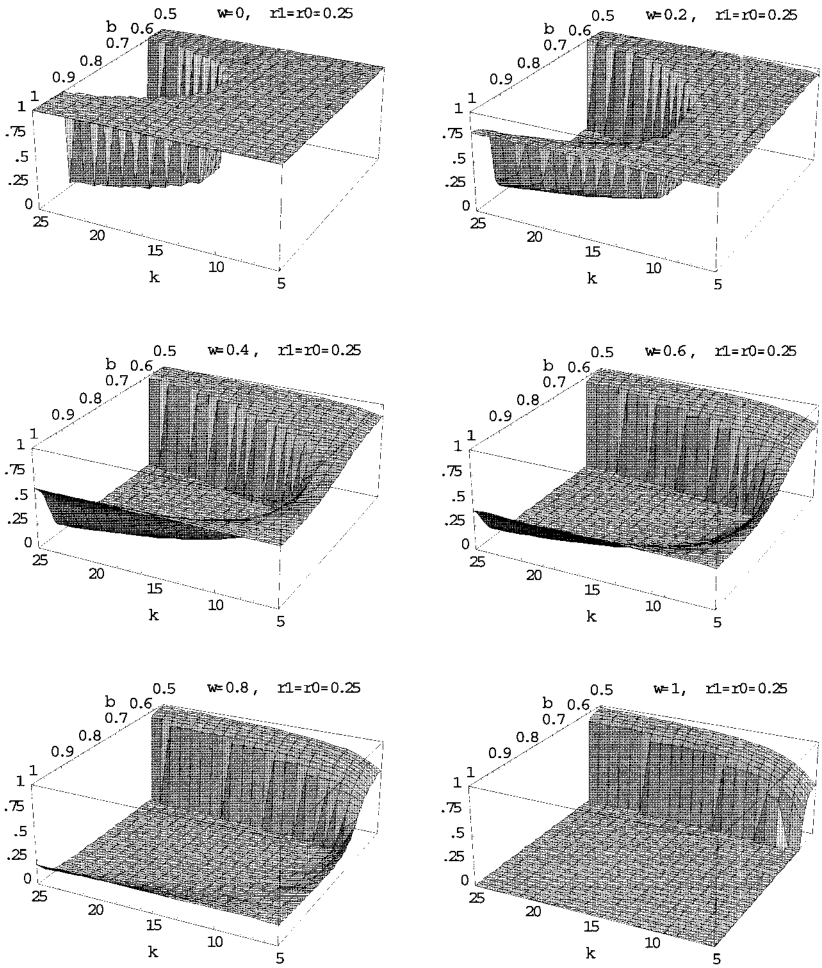

FIG. 4.—Average proportion of agents using a flexible rule ($r_1 = r_0 = .25$)

ciently close to one. However, when w is sufficiently low, the proportion of agents using a flexible rule is instead increasing in b when b is sufficiently close to one. As a result, increasing the volatility of the environment can be conducive to the prevalence of a rigid norm when the environment is very stable (see, in particular, $w = 0$).

PROPERTY 2. A rise in volatility conduces the flexible rule to be a locally stable norm when (i) most new agents are predisposed to being rigid or (ii) the environment is relatively volatile. A rise in volatility conduces the rigid rule to be a locally stable norm when most new agents are predisposed to being flexible and the environment is relatively stable.

The source of this anomaly—a more volatile environment is conducive to the prevalence of a rigid norm—is the way in which the volatility of the environment affects the imitability of behavioral rules. For any behavioral rule to thrive, those who use it must be successful in rising to the top of the hierarchy, and when that is accomplished, the rule must be sufficiently transparent so as to be inferred and then adopted by the next generation. With respect to the first task, higher b makes it tougher for a flexible agent to become a role model since the environment is less volatile. More $R1$s advance up through the ranks. However, higher values of b are not conducive to the easy observability of an $R1$'s behavioral rule by the next generation. Any incoming agent, regardless of his innate bias, will adopt a behavioral rule of being rigid in action 1 if his mentor always chose action 1 and faced environment 0 at least once. The observability of an $R1$'s rule is complete in that case. However, as b increases, it becomes increasingly common for an $R1$ to have risen to the top after having faced only environment 1. In such a case, his observed behavior is consistent with both a rigid and a flexible rule. Given such indeterminacy, a new agent who is inclined to be flexible will adopt a flexible rule. Thus, when most new agents are inclined to be flexible (w is small), a rise in b may cause a higher proportion of the next generation of agents to adopt a flexible rule because fewer agents at the top have unequivocally revealed themselves to be rigid. Even if there are many role models who use a rigid rule, there must be sufficient volatility in the environment to ensure that they differentiate themselves from agents who use a flexible rule. Once taking into account the observability of behavioral rules, we find that a change in the meta-environment that results in the better performance of a behavioral rule (in terms of achieving high rank) can result in its being less widely adopted by the next generation. In fact, it can be so extreme that as a result, that behavioral rule will go from a position of being the predominant mode of behavior to being negligibly represented.[13]

[13] Suppose that we enriched the space of rules to allow some agents to use the rigid/flexible rule of being rigid in action 1 for levels $1, \ldots, m$ and being flexible for levels $m + 1, \ldots, k$. Let us argue that properties 1 and 2 are robust. All rigid/flexible agents who survive to level m will, of course, look just like rigid agents. Among those agents, consider those who get to level $m + 2$. Those who happened to face environment 1 at levels $m + 1$ and $m + 2$ have a higher chance of surviving to level $m + 3$ than those who did not because they are more proficient in action 1. Thus the force underlying property 1 remains operative in that rigid/flexible agents who survive over levels $m + 1, \ldots, k$ will disproportionately have always faced environ-

If one examines how the height of the surface varies with k, it is clear that flatter societies (lower values of k) are conducive to the prevalence of a flexible norm. This property is more a result of selection than social learning. Since it is increasingly rare for surviving flexible agents to be as proficient as rigid agents at higher levels, if the system is sufficiently hierarchical, then rigid agents have a proficiency advantage at high levels so that they tend to dominate the set of role models. This causes the rigid rule to become the norm.

PROPERTY 3. A flatter social system conduces a flexible rule to be a locally stable norm.

Finally, lowering w—the proportion of incoming agents predisposed to being rigid—"lifts" the surface in figure 4 so that a flexible rule is more widely used.

PROPERTY 4. A higher proportion of new agents who are predisposed to being flexible conduces a flexible rule to be a locally stable norm.

A QuickTime movie of figure 4, as w is reduced from one to zero, is available at http://www.econ.jhu.edu/People/Harrington/Rigidity.htm.

V. Concluding Remarks

My central findings appear to depend on some rather general relationships. The prevalence of a rigid norm is due to its higher fidelity, which comes from (i) selection favoring those agents who are more experienced and (ii) a stronger correlation between an agent's past environments and actions for more flexible agents. As a result, those agents who deploy a flexible rule and advance to higher levels tend to have histories consistent with the deployment of a rigid rule. A more volatile environment can promote the adoption of a rigid norm in spite of its enhancing the relative efficacy of a flexible rule because it allows a rigid rule to more effectively differentiate itself from a flexible rule.

The issues motivating this paper are central to understanding organizational behavior. This analysis is the first, to my knowledge, to explore the process by which a norm of being resistant to change might develop. There are numerous directions for future research, of which I shall mention two. There are two factors determining an organization's response to change in its environment: how its members respond to change and how these members are connected

ment 1 and thus look like rigid agents. Similarly, the logic behind property 2 would also appear robust. All that changes is that the relevant forces are operative over levels $m + 1, \ldots, k$ rather than levels $1, \ldots, k$.

to produce an organizational response. This paper has focused on the former factor, and work is needed to encompass the second one. A second extension is to allow for heterogeneous competing organizations. While a rigid norm might prevail in an organization, there is the larger issue of whether such an organization will survive if there are competing organizations that are flexible. It is unclear what to expect if one allows for both internal dynamics—as I have modeled here—and external dynamics through the growth and decline of organizations by virtue of competition. What is clear is the need for further research.

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