Excerpt from Richard N. Langlois, "Coherence and Flexibility: Social Institutions in a World of Radical Uncertainty," in Israel Kirzner, ed., Subjectivism, Intelligibility, and Economic Understanding: Essays in Honor of the Eightieth Birthday of Ludwig Lachmann. New York: New York University Press, pp. 171-191 (1986).

> In our view the central problem of the institutional order hinges on the contrast between coherence and flexibility, between the necessarily durable nature of the institutional order as a whole and the requisite flexibility of the individual institution.
>
> — L. M. Lachmann
> *The Legacy of Max Weber* (1971)

The success of any individual plan depends on the extent to which that plan is adapted to the environmental conditions the agent will face in carrying out the plan. This environment includes nature and its vagaries — the weather, for example, or the constraints of physical laws. But the environment also means the actions of other individuals: successful plans are in large measure those that dovetail with the plans of others. Indeed, as Ludwig Lachmann suggests, the uncertainties thrown up by the actions of others are in general far more worrisome for planning than are the uncertainties of nature. Human action, he points out, is more volatile than the conditions of nature, and thus far less easy to predict; this means that "we have here a source of danger to successful action, the importance of which grows as society grows more complex" (Lachmann 1971, p. 45).

It is at this point that social institutions enter the picture. A social institution is a "recurrent pattern of conduct" that helps an individual plan by reducing the volatility in the plans of others (Lachmann 1971, p. 75). "An institution provides a means of orientation to a large number of actors. It enables them to co-ordinate their actions by means of orientation to a common signpost" (Lachmann 1971, p. 49).

The distilled essence of social institutions, and of their role as aids to the coordination of plans, emerges from a consideration of what are called — appropriately enough —coordination games. The agent in such a game is confronted with the sort of situation depicted in Figure 1. He or she can choose any of the three actions represented by the rows of the matrix. The opponent faces the same choice of three actions, represented as the columns of the matrix. The payoffs are an indication of the extent to which the agent's actions are coordinated with those of others. In this case, coordination — high payoffs for both — occurs when both players choose the same action. A standard illustration is the problem of choosing the side of the road on which to drive: it is irrelevant which side, left or right, one chooses, except that it had better be the one all other drivers choose.

Suppose that the actions of Agent B are very volatile — that B is given to shifting among the three actions over time in a more-or-less unpredictable fashion. Clearly, this makes A's task of planning a difficult one. A may often be wrong in her anticipation of what B will do, and their payoffs will suffer. Yet if both happen to hit upon the same action (action 1, let us say) at the same time, and, moreover, find themselves continuing to pursue the same

		Agent B		
		Action 1	**Action 2**	**Action 3**
Agent A	**Action 1**	3 3	0 0	0 0
	Action 2	0 0	3 3	0 0
	Action 3	0 0	0 0	3 3

Figure 1

action over time, they will have solved their coordination problem. Neither will have the incentive unilaterally to deviate from the established pattern. Thus the behavior pattern “always take action 1” emerges as a social convention, becoming one of those “successful plans which have crystallized into institutions through wide spread imitation” (Lachmann 1971, p. 88).

All of this is fairly elementary. It is also a rather stark portrayal of the culturally and historically rich process by which institutions take shape. But it does provide an intuitively appealing schematic for talking about the interaction of plans. We can already see here the outlines of the "signpost" function of institutions: by reducing the volatility of other people's actions, an institution can provide an agent with useful information. To put it another way, an institution creates predictability — it brings order of out relative disorder. Indeed, our simple game-theory representation permits us to make this assertion in a slightly more formal way that connects with conceptions of order and disorder familiar from other disciplines.

Suppose that we stand back from the game in figure 1 and watch the play of the two agents. A glance at the figure confirms that there are nine possible squares in which the players might "land" on any play. If agent A takes action *i* and agent B takes action *j*, call the appropriate square s_{ij}, with i,j = 1, 2, or 3. Suppose further that, after observing for a while, we decide that f_{ij} is the frequency with which we observe s_{ij} to occur. Using the familiar formula,[1] we can talk about the *entropy* of the game, defined as

$$H = -\sum_{i,j} f_{ij}\, \ell og f_{ij} \quad .$$

It turns out that entropy is highest when all the squares are equally likely. Therefore, a high-entropy game is one in which the agents move about unpredictably from square to square. By contrast, entropy is least when the players always stick to one particular square and never land on any others. Thus a low-entropy game is one in which the agent's behavior is completely orderly — completely predictable (Schotter 1981, pp. 140-3).

A social institution, then, is a mechanism to reduce the entropy of the environment. The presence of such a mechanism means coordination — high payoffs — and, in this context at least, a rigid and predictable pattern of behavior by both agents. Moreover, a state of minimum entropy means a situation that is "fully informative": continuing to observe the play of the game can teach us nothing useful to predicting the agents' behavior, since that behavior is already perfectly predictable (Schotter 1981, p. 140-3).

In order to push these ideas a little further, let's consider a slightly different representation of the game the agent faces. Now we will let agent B play first. We may take B to represent all the other agents in the economy or "the environment" in general. Agent A's task is now to respond to what B does. Unfortunately for A, though, her competence to respond adequately may be limited in a couple of ways that I will make more precise shortly.

We discussed the entropy of a game from the point of view of an outside observer. But we can also take the point of view of the agent. As A sees it, B can take any of three actions. If she is as likely to take Action 1 as

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1 The information-theory version of the entropy formulation traces back to Shannon (1948). The notion of entropy has a much older history in thermodynamics and statistical mechanics.

to take Action 2 or Action 3, then B's actions are maximally unpredictable and A's environment is a high-entropy one. If B invariably takes the same action every time, A's environment is a predictable, low-entropy one. A's goal, of course, is to maintain coordination — to maintain a non-zero payoff. This means that A wants to make sure that, irrespective of what B does, the same outcome occurs every time. And that in turn means, in effect, that A wants to maintain the set of payoffs in a low-entropy state: she wants to make sure that the payoff she receives is predictably positive and infrequently zero. How does A accomplish this? As figure 1 suggests, A must adjust her behavior constantly to the behavior of B. If B picks Action 1, A must do likewise; if B picks Action 2, so must A; and so on. In figure 1, such adjustment is always possible. But consider figure 2. Here A is barred from ever taking Action 3. As a consequence, she no longer has complete control of the situation. If B takes Action 3, A can never match; and the entropy of her payoffs must increase, that is, she must sometimes get zeroes as well as ones if B sometimes chooses Action 3.

This suggests the outlines of a well-known principle in cybernetics: the "law of requisite variety" (Ashby 1956, chapter 11). Let's call the entropy of B's moves "environmental" entropy and the entropy of A's behavior "behavioral" entropy. In these terms, the law of requisite variety says, roughly speaking, that, in order to maintain the set of outcomes at a state of minimum entropy, A's behavioral entropy must be at least as great as the

Agent B

Agent A		**Action 1**	**Action 2**	**Action 3**
	Action 1	3	0	0
	Action 2	0	3	0

Figure 2

environmental entropy. To see this, consider first a world in which B takes Action 1 with certainty. The environmental entropy is zero. To maintain a favorable outcome, A need only follow suit with action A. Her entropy is also zero, as is that of the outcomes. Suppose now that B changes his behavior, and begins alternating randomly between Action 1 and Action 2. B's entropy increases to log2. If A continues to take only action A, her entropy remains zero, but the entropy of the outcomes increases to log2, since half the time the payoff is one and half the time zero. In order to keep the entropy of the payoffs at zero, A has to increase her own entropy to log2 by switching back and forth between actions 1 and 2 with the same frequency as B. In short, then, the only way to fight entropy is with entropy.

In the type of coordination game we have been considering here, the presence of a social institutions reduces the entropy of the agent to exactly the same degree that it reduces the entropy of the environment. A social convention to drive on the right-hand side of the road constrains other drivers and makes their behavior more predictable; but it also constrains my own behavior, since I too now always drive on the right. At the same time, though, the existence of this convention does not remove my *ability* to drive on the left. I decide to follow the convention in order to avoid the crash of metal that would attend the discoordination of my driving plans; but I can still drive on the left if I have to — to avoid an obstruction, or when I find myself in England. Thus a social institution reduces the *observed* entropy of the agent but not necessarily the *potential* variety in his actions.

We might think it reasonable to suppose that the agent is always better off with a greater variety of actions — a larger repertoire of possible plans — at his or her disposal. Ronald Heiner (1983) has suggested that this is not always the case. To the extent that the agent is unreliable in responding to the environment, he or she is sometimes better off limiting or reducing the set of actions available.

Heiner's analysis works this way. Consider again the coordination game in which agent B plays first and agent A must respond. Now ask the following sort of question about each possible response at agent A's disposal: is A well served by having this action in her repertoire or is she in fact better off debarring herself completely from ever taking this action? The answer will depend upon how "reliable" A will be in using this action — that is, the extent to which she is able to use the action when appropriate and refrain from using it when inappropriate. If π is the probability that it is the right time to use the action; r is the probability that the agent takes the action when it is the right time; w is the probability that he or she takes the action when it's the wrong time; g is the gain from taking the action at the right time; and ℓ is the loss from taking the action at the wrong time, then the agent should include the action when $\pi rg - (1-\pi)w\ell > 0$. Rearranging gives Heiner's "reliability condition," $r/w > [(1- \pi)/ \pi](\ell/g)$.

The left-hand side is the "reliability ratio," which reflects the agent's competence in responding to the actions of agent B (or of the environment). The right-hand side is the "tolerance limit," which sets a lower bound on the reliability the agent must be able to claim before allowing the action into the repertoire will do more good than harm. If, as Heiner maintains, reliability decreases as the volatility of the environment increases, then fewer and fewer actions will satisfy the reliability condition as the environment becomes more volatile. This means that high environmental entropy can lead to lower potential (and therefore lower observed) behavioral entropy.[2]

This would seem at first glance to leave us with a paradoxical result. A stable environment leads us to expect rigid and predictable behavior in our agent — but so does a highly volatile environment. There is in fact no paradox, of course, merely a spectrum. At one extreme we find predictable behavior arising as an adaptation to an unchanging environment. If the environment becomes more volatile, the agent benefits from the ability to alter his behavior in response. But once the environment becomes sufficiently volatile, its demands begin to exceed the agent's ability to respond, which causes the agent to retreat again to a more predictable pattern. At this second extreme, the agent actually benefits from self-restraint — from foreclosing options that she cannot trust herself to use reliably.

2 There is, of course, a selection argument operating behind the scenes. Those agents who have repertoires containing many actions that violate the reliability conditions will do worse *ceteris paribus* than agents who have fewer actions in their repertoires; therefore the agents with over-large repertoires will be selected out, will lose relative command over resources. and/or will recognize the need to imitate their more successful rivals. The result is a decrease in the average size of repertoires. Such an argument is subject to all the usual cautions that attend selection stories.

There are also some differences between rule-following behavior in a placid environment and predictable behavior in a volatile environment. For one thing, it remains true that the agent's performance — his or her ability successfully to coordinate plans— always deteriorates (or, at any rate, never improves) as the environment becomes more volatile. More importantly, though, we can expect a difference in the *type* of actions the agent would

Agent B

Agent A		**Action 1**	**Action 2**	**Action 3**
	Action 1	3	0	0
	Action 2	0	3	0
	Action 3	0	0	3
	Action 4	2	2	2

Figure 3

undertake at each extreme. Consider the variant of our standard game depicted in figure 3. Here the structure of the payoffs is a bit more complex. Agent A can respond to B's moves in the usual way by matching actions 1, 2, or 3. But she can also resort to a "generic" action — #4 — that achieves the same payoff no matter what B does. If A can respond reliably to B, we would expect A to keep all the actions within her repertoire; and we would expect her to rely exclusively on action 1, 2, and 3, since they provide the highest payoff. If B plays action 1 every time without fail — which is to say that the environment is entirely placid — A would follow the rule "always play 1." If B became less predictable, we would expect to see A jump around among actions 1 through 3 in response. But if B became so unpredictable that it thrust A beyond the "tolerance limit," A might eliminate some of the actions from her repertoire. More to the point, A might choose a repertoire consisting entirely of Action 4. Thus A would again display rule-following behavior — but the rule would be a quite different one.

We can perhaps see this best in light of the entropy formalism. Once again, A is trying to maintain her payoffs in a low-entropy state. She can do this — at first at least — by increasing her own entropy to match that of B. But as A's response becomes unreliable, she can turn to another strategy: A can choose an action that has inherently lower entropy. (Actions 1 through 3 have a maximum payoff-entropy of log2 because they contain two possible payoffs; action 4 has only one payoff, which gives it a maximum entropy of zero.) In a sense, then, increased flexibility is always desirable as the volatility of the environment increases — but that flexibility comes increasingly in the form of "state flexibility" rather than "action flexibility."[3]

Actions that are flexible across states are general actions; and, as Adam Smith reminds us, such actions are likely to be less productive — to have lower payoffs — than more specialized actions. Thus it seems reasonable to suppose that, *ceteris paribus,* increased volatility in the environment brings with it a decrease in the division of labor, while increased stability in the environment has the opposite effect.

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3 Bookstaber and Langsam (1985) talk about "general" actions versus "state-specific" actions.

Uncertainty, Flexibility, and the Origin of Predictable Behavior

by

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In a series of papers beginning with a 1983 piece in the *American Economic Review*, Ronald Heiner developed the thesis that uncertainty is the origin of predictable behavior. The simplest version of the argument goes something like this. Consider an agent playing a coordination game against the environment. The agent can respond to the various potential states of the world by taking actions from a repertoire. Heiner argues that, because of uncertainty and perceptual limitations, the agent may be better off with a smaller rather than a larger repertoire. The behavior of an agent thus constrained is more predictable than that of an agent wielding a larger repertoire of possible actions.

In more formal terms, the story is the following. Let π be the probability that it is the right time to take a particular action; r be the probability that the agent takes the action when it is the right time; w be the probability that he or she takes the action when it is the wrong time; g be the gain from taking the action at the right time; and l be the loss from taking the action at the wrong time. The agent is better off including the action in his or her repertoire when

$$\pi rg - (1-\pi)wl > 0.$$

To put it another way, the agent is better off keeping the action available only when doing so satisfies the "reliability condition"

(1) $$w > [(1-\pi)/\pi](l/g).$$

Heiner's argument is that, as the volatility of the environment increases, fewer and fewer actions will fulfill this condition, thus shrinking the agent's repertoire. An agent with a smaller repertoire is less flexible, in one sense at least. He or she is also more predictable, in that such a restricted repertoire must lead to behavior that appears repetitive and routine.

Part of what makes this argument so intriguing is that it reverses the common intuition that predictable behavior is the result not of a volatile environment but of precisely the opposite – an unchanging environment. It is a common thread in the work of writers like Max Weber, Schumpeter, and Veblen – to name just a few – that predictable behavior is the result of habits forged in a repetitive environment in which, in Schumpeter's words, "precedents without number have formed conduct through decades and, in fundamentals, through hundreds of thousands of years, and have eliminated unadapted behavior" (Schumpeter, 1934, p. 80).

This paper is an attempt to reconcile these competing views of the origin of predictable behavior. By making some distinctions and presenting a few simple examples, we hope to illuminate the role that uncertainty plays--and the role it doesn't play--in generating predictable behavior.[4]

Predictability, Volatility, and Flexibility

The first thing we need to do is to look more closely at the meanings of some of the key terms in this discussion. For this purpose, consider the following coordination game,

4 Bookstaber and Langsam (1985) offer a critique of Heiner that addresses some similar issues.

which we can view the agent as playing either against another agent or against the environment:

	x_1	x_2
a_1	P_{11}	0
a_2	0	P_{22}
a_3	P_3	P_3

There are two possible states of the environment: x_1 and x_2. The agent's repertoire contains three possible actions: a_1, a_2, and a_3. The payoffs depend on the action the agent takes and the state of the environment that occurs. For reasons that will become clear in a minute, let

$$P_{11} > P_3 > 0,$$

$$P_{22} > P_3 > 0,$$

and, for simplicity, let $P_{11}=P_{22}=P$. The agent in this situation has the following possible strategies:

S_i = always choose action a_i, $i= 1,2,3$, regardless of the state; or

S_c = choose action a_i conditional on observing state x_i, $i=1,2$.

Before considering the agent's behavior, we should first clarify what it would mean in these circumstances for behavior to be *predictable*. One appealing way to do this is in terms of the *entropy* of the game (Schotter, 1981, pp. 139-143). If $\{f_{ij}\}$ are the frequencies of occurrence of the six states[5] of the game above, then the entropy of the game is given by

$$-\Sigma_{i,j}\, f_{ij}\log(f_{ij}).$$

Entropy is a measure of predictability in the following sense. High entropy means that we observe the states of the game to fluctuate in a random--and hence "unpredictable"--way, whereas low entropy indicates that the states of the game are less random and more "predictable." For example, if we observe the game always to result in one particular outcome and never in any of the other possible outcomes, then the entropy is zero and the game is perfectly predictable. By contrast, if we observe each of the possible outcomes with the same frequency, then entropy is at its highest, and we are least able to predict which outcomes will occur next.

For our purposes, it may be more useful to measure not the entropy of the game but the separate entropies of the environment and of the agent's behavior, since it is the predictability of the latter in the face of the former that interests us. We can define *environmental entropy* as

$$E = -[\pi\log\pi + (1-\pi)\log(1-\pi)],$$

5 Actually, there are only four distinguishable states of this game, since an observer could not distinguish (a2,x1) from (a1,x2), which both have a payoff of zero, or (a3,x1) from (a3,x2), which

where, by analogy with equation (1), π is the probability that state x_1 will occur and $1-\pi$ is the probability that state x_2 will occur. Entropy is zero when the environment always remains in one or the other state, and it is at a maximum when $\pi = \frac{1}{2}$. Similarly, we can define *behavioral entropy* as

$$B = -\Sigma_i \gamma_i \log(\gamma_i),$$

where γ_i is the probability that the agent will take action a_i ($i=1,2,3$). This measure is zero when the agent is most predictable--sticks completely to one action--and increases as the agent switches from action to action.

The γ_i will depend on which of the strategies the agent chooses to play, which will in turn depend on the expected returns from those strategies. The expected return will depend on the payoffs; on the volatility of the environment (π); and, as Heiner points out, on the agent's probability of detecting which state, x_1 or x_2, has occurred. As in equation (1), let

$$r = \Pr(\text{agent chooses } a_i \mid x_i \text{ has occurred}),$$

which implies that

$$1-r = \Pr(\text{agent chooses } a_j \mid x_i \text{ has occurred}),$$

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both have a payoff of P3.

for $i,j = 1,2$ and $i \neq j$. The expected returns from each strategy are:

$$V_1 = \pi P,$$

$$V_2 = (1-\pi)P,$$

$$V_3 = P_3,$$

$$V_c = \pi r P + (1-\pi) r P = rP.$$

When will each strategy dominate? It depends on π and r, given P and P_3.

We can compare the strategies pairwise as follows:

$$V_1 > V_3 \Rightarrow \pi P > P_3, \text{ or}$$

(2) $$\pi > P_3/P \equiv \pi,$$

and

$$V_2 > V_3 \Rightarrow (1-\pi)P > P_3, \text{ or}$$

(3) $$\pi < (P-P_3)/P \equiv \underline{\pi}.$$

In order for the agent to choose S_3 for some π, it must be the case that

$$\pi > \underline{\pi}, \text{ or}$$

(4) $$P_3/P > \tfrac{1}{2}.$$

Assume that this holds (otherwise, alternating between a_1 and a_2 dominates a_3). Further,

$$V_1 > V_c \Rightarrow \pi P > rP, \text{ or}$$

(5) $$\pi > r,$$

$$V_2 > V_c \Rightarrow (1-\pi)P > rP, \text{ or}$$

(6) $$1-\pi > r,$$

and

$$V_c > V_3 \Rightarrow rP > P_3, \text{ or}$$

(7) $$r > P_3/P.$$

Figure 1 summarizes conditions (2) - (7).

When an agent's ability to detect the correct state of the world is high – that is, when $1>r>P_3/P$ – the agent is better off fine-tuning performance by choosing strategy S_c as $\pi \to ½$. Indeed, as $r \to 1$, $B \to E$.[6] Notice, however, that for any $r<1$, the agent is better off following a rule (always choose action a_2 or a_1) as π approaches 0 or 1. That is, imperfect perceptual ability leads the agent to behave more predictably ($B=0$) when the environment is more predictable ($E \to 0$). In fact, when perceptual ability is high but imperfect ($1>r>P_3/P$), we see predictable behavior *only* when the environment is predictable.

As perceptual ability drops below P_3/P, of course, the agent does become predictable ($B=0$) no matter how volatile the environment is. In this example, however, increased environmental entropy ($\pi \to ½$) leads not to a greater degree of rule-following behavior but to the following of a different sort of rule. In the region in which $P_3/P>r>0$, $B=0$ everywhere. The effect of an increase in E is that the agent switches from the state-specific actions a_1 and a_2 to a more generalized action a_3 (see also Bookstaber and Langsam, 1985, pp. 573-574). The payoff to the state-specific action is higher (if the agent takes the action at the right time), but the payoff to the general action doesn't depend on the state of the environment.

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6 Even when environmental (and thus behavioral) entropy is at its highest, however, an outside observer would see the payoffs as having low entropy since, as $r \to 1$, the agent is almost always able to obtain a payoff of P and almost never gets zero. Thus, in order to keep the entropy of the payoffs low, the agent must increase behavioral entropy to match environmental entropy. This is an instance of what in cybernetics is called the law of requisite variety (Ashby, 1956, Chapter 11).

On the one hand, the agent whose best strategy is to play S_3 is less "flexible" than the agent who plays S_c, in that the former is bound to a simple rule and constrained from fine-tuning behavior to the state of the environment. On the other hand, the action a_3 is less specialized and thus more "flexible" than a_1 or a_2. The first kind of (in)flexibility, with which Heiner is concerned, is what we might call *action flexibility*, while the second is what we might call *state flexibility* (Langlois, 1986, p. 179). In this sense, then, Heiner's claim that uncertainty leads to less flexible behavior (less fine-tuning) is not incompatible with the hoary observation in economics that uncertainty breeds greater flexibility (less specialization).[7]

The important implication of this result is that a stable environment can lead to more specialization and thus higher payoffs. If we view the game as one against other players rather than against nature, then constraining the behavior (reducing the action flexibility) of one player can lead to less state-flexible (and thus more productive) behavior by the other player. One way to do this is through social convention (Schotter, 1981, pp. 142-143); another might be through a credible commitment like a hostage (Williamson, 1983). An example of the former might be the judicial practice of *stare decisis* (decision by precedent), which creates an environment in which agents can better predict the legal consequences of their actions (Heiner, 1989; Miceli and Cosgel, 1994).

There is also another way to interpret the model we have just presented. Suppose that, rather than being a general-purpose action, a_3 represents a decision by the agent to expend resources to identify the state of nature or the characteristics of his or her adversary

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7 A classic discussion of this phenomenon is Stigler (1939).

(Frank, 1990; Kaplow, 1990). For example, by spending c, the agent can observe whether x_1 or x_2 has occurred and take the appropriate specialized action. This implies that $P_3=P-c$.[8] In this interpretation, S_3 is a strategy to learn the state of nature, while S_c is a strategy to act based on one's "best guess" about the state of nature. The choice between these strategies weighs the cost of the former, c, against the cost of the latter, the possibility of taking the wrong action. The formal analysis of this choice is identical to that described in conditions (2)-(7) above.

Uncertainty, Perception, and Predictability

Notice that in the example we have used to far, uncertainty *per se* does not appear to be an origin of predictable behavior in Heiner's sense. To see this more clearly, consider the simpler case in which there are only actions a_1 and a_2 and no general action a_3:

	x_1	x_2
a_1	P	0
a_2	0	P

With all variables, including strategies, defined as before, this game generates the picture in Figure 2. If we hold r – the probability of detecting the correct state of the environment

8 Our earlier condition that $P3/P>1/2$ now becomes $(P-c)/P>1/2$, or $P>2c$.

– constant, then an increase in environmental entropy ($\pi \rightarrow ½$) does *not* decrease behavioral entropy, that is, it does not lead to more predictable behavior. For $r < ½$, behavioral entropy is always zero, and for $r > ½$, behavioral entropy *increases* with environmental entropy as the agent switches from S_1 or S_2 to S_c as $\pi \rightarrow ½$.

The reason we get this result, however, is that we have tacitly violated one of Heiner's assumptions. In his work, it is clear that we *cannot* hold r constant while increasing π. In effect, increasing volatility in the environment *degrades* the probability that the agent is able to detect the correct state of the world. Heiner (1986, p. 70) defines uncertainty as a vector-valued function $\mathbf{U}=u(\mathbf{p,e})$, where $\mathbf{p}$ is a vector representing perceptual capabilities, and $\mathbf{e}$ is a vector representing environmental variables. For our purposes, we can simplify this to scalars and write

$$r = r(p,e)$$

$$\pi = \pi(e).$$

Inverting $\pi(e)$ and substituting into $r(p,e)$ yields

$$r = r(p,e(\pi)).$$

Increasing uncertainty, in Heiner's sense, comes from lower p, higher e, or both. In effect, Heiner assumes that p – perceptual variables – can change without affecting the environment, but that e – the environment – cannot change without affecting perceptual ability.[9] Holding p constant, we say that r degrades as environmental entropy reaches its maximum by saying, in this two-state world, that

$$\partial r/\partial\pi < 0 \quad \text{for} \quad \pi \in [0,½)$$

$$\partial r/\partial\pi > 0 \quad \text{for} \quad \pi \in (½,1]$$

This implies that the relationship between r and π is one of the possibilities depicted in Figure 3. Superimposing these functional forms over the partitioned space in Figure 2, we see that behavior does become more predictable as the environment becomes more volatile, but not unambiguously so.

Indeed, "reswitching" in the agent's behavior is possible. In Figure 4, the agent switches from S_c to S_1 or S_2 as $\pi \to ½$. But it is possible that the agent could also switch back to S_c near $\pi = ½$. In this picture, r always degrades as $\pi \to ½$, but it does so at a decreasing rate, and never falls below the critical value of ½. Figure 5 may represent a more typical scenario, n which the agent's behavior is predictable when the environment is stable, becomes less predictable as environmental complexity increases, and then becomes predictable again as environmental complexity increases further. This latter lapse into predictability is the result of the Heiner effect, whereas the first episode of predictability is the result of adaption to an environment that is itself predictable.

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9 Bookstaber and Langsam (1985) argue that it is a misspecification to assume that π is only a function of e. Instead, they argue that it should depend on both e and p. We nevertheless retain Heiner's specification so as to re-examine his argument on its own terms.

Conclusion.

This paper is an attempt to unpack Ronald Heiner's theory of predictable behavior using some simple examples. The points we make are the following:

- Heiner's observation that uncertainty can be a source of predictable behavior does not undercut entirely the classical observation that a *lack* of uncertainty can also be a source of predictable behavior.

- Heiner's notion of flexibility is somewhat different from the more traditional notion, a difference we encapsulate with the distinction between action flexibility and state flexibility.

- Increasing uncertainty does not necessarily lead monotonically to increased predictability of behavior, and, depending upon the functional relationship between r and π, "reswitching" is possible.

- The most plausible scenario is one in which behavior is predictable when uncertainty is low; becomes less predictable for intermediate ranges of uncertainty; and then becomes predictable again at high levels of uncertainty because of the Heiner effect.

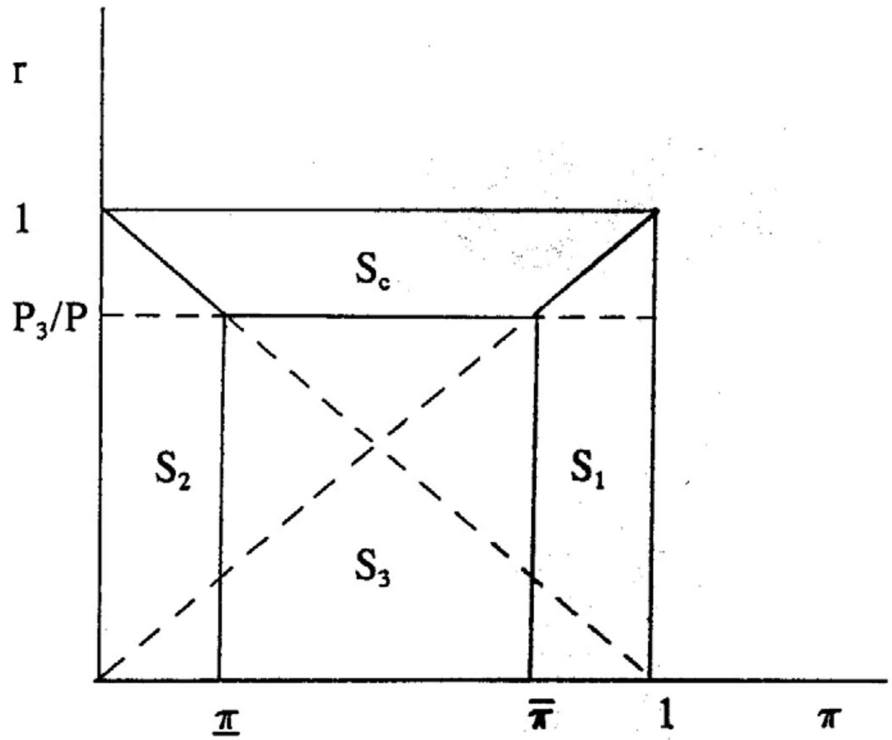

Figure 1

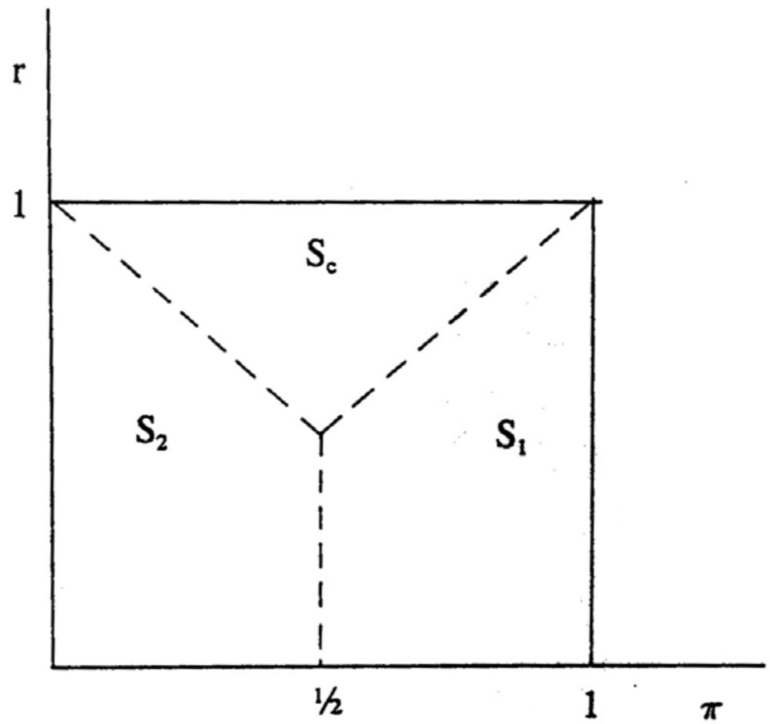

Figure 2

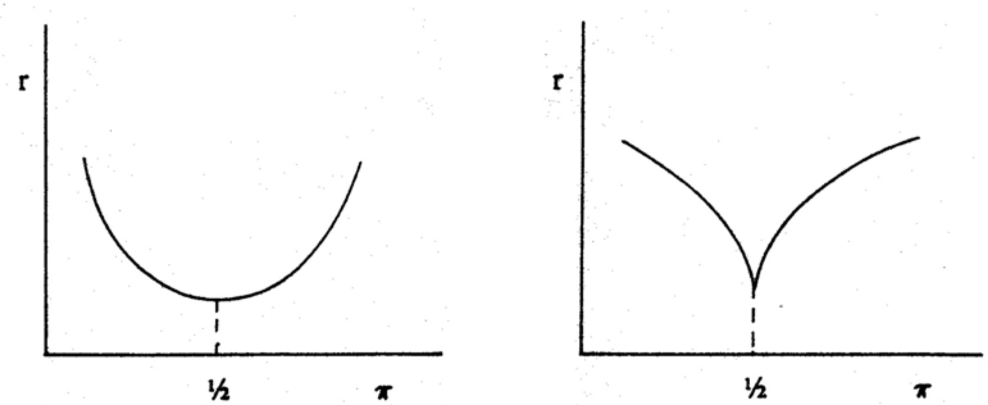

Figure 3

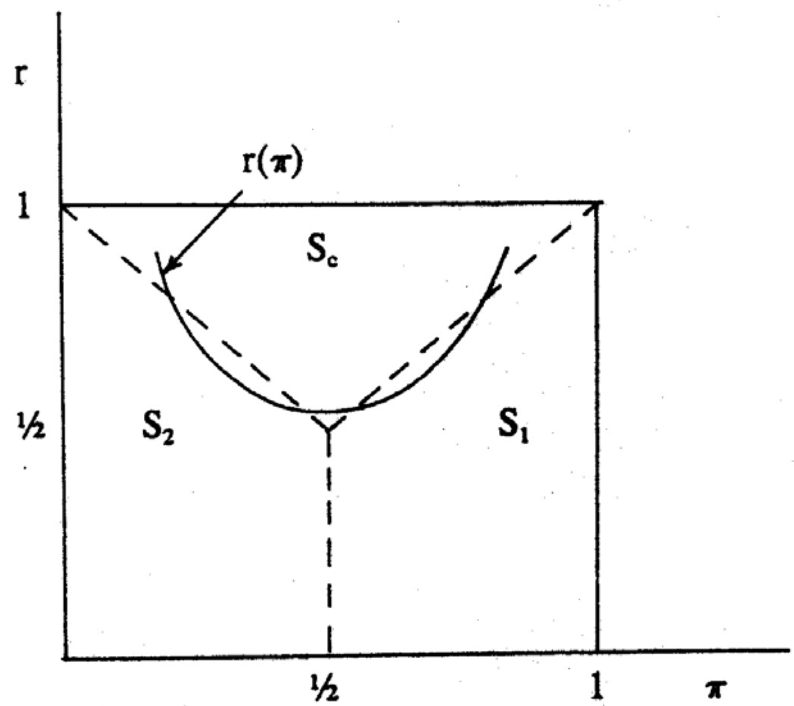

Figure 4

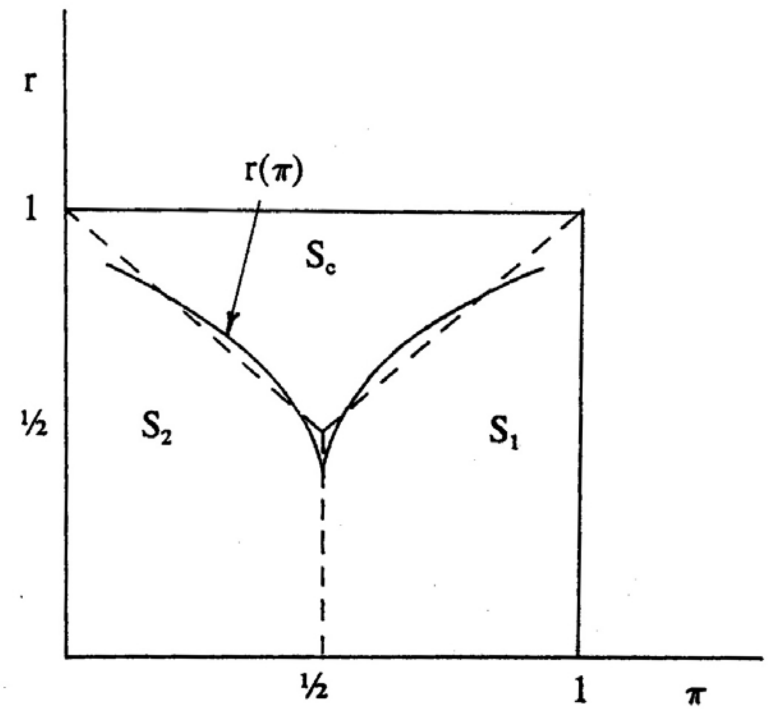

Figure 5

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