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# THE IMPLICATIONS OF RELIABILITY THEORY FOR ENVIRONMENTAL INSTITUTIONAL DESIGN AND DECISION MAKING

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Fixed ends upon one side and fixed "principles" - that is authoritative rules - on the other, are props for a feeling of safety, the refuge of the timid and the means by which the bold prey upon the timid. (Dewey, p. 167)

Despite being a pillar of modern economic thinking, expected utility theory (EUT) has many limitations for explaining behavior in the presence of uncertainty. These limitations are well-known and oft-repeated (e.g. Arrow, Runge and Myers), but economists have just begun to pursue other theoretical frameworks for understanding how both market and nonmarket institutions cope with real-world uncertainty. The potential rewards of this pursuit are ample since EUT's contribution has been at the individual decision making level, whereas the most serious theoretical deficiencies are in accounting for the linkages from individual decisions to institutional formation and behavior (Coleman, p.184).

Environment

The merit of the pursuit notwithstanding, uncertainty is a difficult analytical concept because it has been confused with discussions of risk and subjective probability distributions. To further the confusion, many writers have resorted to pretentious adjectives such as "profound" and "irresolvable" (Goodin) or "structural" (Walters) to distinguish true uncertainty. In the spirit of Knight, the clearest definition of uncertainty is lack of knowledge of states or actions and, at the extreme,



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sheer ignorance.[1] Uncertainty created by imperfect knowledge and humans' limited reasoning skills is the most dominant consideration in understanding any organization or living system (Hodgson, Kay, Walters).

One key problem for any theory of institutional behavior under uncertainty is to explain the origin and stability of institutions rather than simply to treat them as exogenous. Neoclassical decision models based on EUT have limited value for this task because the market institution is the centerpiece of analysis. Other social institutions are viewed as constraints, and information problems are defined as transactions costs that only impact the allocation from exchange (e.g. Dahlman, Schmid, Williamson). As a result, the influence of uncertainty on the origin and functions of these institutions is not fully explored.[2]

The recent work of Heiner (1983, 1985, 1986) on reliability theory (RT) offers an alternative theoretical framework to explain institutions as responses to problems of uncertainty. Given that institutions are a "...regularity in social behavior" (Schotter, p. 11), RT is promising because it "...directly harnesses the determinants of uncertainty to characterize regularity in behavior" (Heiner 1983, p. 571). In the following section, we outline the basic principles of RT and contrast it with EUT. We then explore the implications of RT for the origin and stability of environmental institutions and the choice of rules by regulatory agencies. Specific consideration is given to institutional responses to problems of environmental quality and administrative rule-making. We conclude with an appraisal of RT for the study of environmental institutions.

Overview of Reliability Theory

Reliability theory describes behavior under uncertainty and derives from the traditional economic model of choice. The basic difference is that in RT, decision makers do not always behave optimally. Optimizing is a limiting case of a more general theory of behavior in which information is both costly and imperfect, and decision makers do not always use information correctly. This latter dimension, that decision makers can and do make judgment errors, leads to theoretical implications that are quite different from the traditional model.

RT can be described formally by defining S, I, and D as the set of possible states of the world, the set of information about the actual state of the world, and the set of a decision maker's potential decisions, respectively. Each state contains all potential factors that can affect the consequences of a particular decision. Set I includes all information that might be used to arrive at decisions, although normally not all potential information will be used.

Consider first the standard Bayesian decision model. The rational decision maker maximizes posterior expected utility contingent on received information. For each decision $d \in D$, let $I_d^*$ denote the subset of information for which d is optimal, that is, when d maximizes posterior expected utility. The conditional probability of making decision d when $i \in I_d^*$ is received is noted by $r_d$ and the conditional probability of making decision d when $i \notin I_d^*$ is received is $w_d$. Optimal behavior implies that $r_d^* = 1$ and $w_d^* = 0$.

But, decision makers do not always make optimal decisions, even in the choice of articles to read, and they do not always perfectly respond to information. Failure to make decisions if they are optimal ($r_d < 1$) is a Type I error. Alternatively, making a decision that is not optimal ($w_d > 0$) is a Type II error. A decision maker's reliability can be represented by the reliability ratio, $\rho_d = r_d/w_d$. Optimal Bayesian behavior produces the limiting case of perfectly reliable use of information ($\rho_d{}^* = \infty$). In general, however, $\rho$ is finite. A decision maker's reliability is a function of the gap between his or her competence and the difficulty of the decision (the C-D gap).

To extend the model, let $g_d$ be the gain in utility from selecting d when it is optimal to do so (i.e., when $i \in I_d{}^*$). Similarly, $l_d$ is the loss in utility from selecting d when it is not optimal to do so (i.e., when $i \notin I_d{}^*$). Finally, let p*(d) denote the probability of receiving information for which d is optimal. Depending on the relative incidence of Type I and Type II errors and the relative magnitudes of losses and gains, utility may or may not increase from making particular decisions. The reliability condition specifies that an agent will benefit from expanding his repertoire of decisions to include decision d if and only if the following condition holds:

$$\frac{r_d}{w_d} > \frac{l_d}{g_d} \cdot \frac{1 - p^*(d)}{p^*(d)}, \text{ or } \rho_d > T_d.$$

That is, an agent's reliability in making decision d must exceed a minimum reliability or tolerance limit, $T_d$, before the agent can benefit from allowing flexibility to make decision d.[3]

The reliability condition provides a theoretical basis for rule-governed behavior. For positive loss/gain ratios, the tolerance limit becomes arbitrarily large as $p^*(d)$ gets smaller and smaller (as the probability that a particular decision is optimal falls). As successively more decisions are involved, agents with bounded reliability cannot benefit from trying to imitate the behavior of fully optimizing agents. Instead, they come to rely on regularized decisions or rules, and their behavior is governed by 'habits', 'rules of thumb', 'administrative rules', 'routines', etc.

It is important to distinguish between costly, imperfect information and imperfectly using information, however accurate it might be. The reliability condition, as previously formulated, represents only the latter aspect. Incorporating imperfect and costly information further reduces an agents' reliability and increases the loss/gain ratio. The implications of RT for information search and use are quite different than traditional economic optimal information models. RT implies that for agents with bounded reliability, trying to use more complex or nonlocal information will eventually be counterproductive no matter how acccurate such information might be. This outcome can occur even if the information is costless. Thus, RT implies that agents will ignore highly accurate and costless information if it is sufficiently complex or nonlocal.

Bounded reliability suggests that complex social exchange systems could not have evolved without institutions to reduce the scope of nonlocal information required for agents to reliably forecast the consequences of their own behavior. These institutions provide the opportunity for predictable mutual reciprocation and reduce the scope and complexity of information that must be reliably interpreted for agents to benefit. (Heiner 1983, p. 581). In addition, the increasing uncertainty associated with larger systems implies that hierarchial structures of increasingly flexible rules will evolve to guide the more complex behavior of larger systems (Heiner 1983, p. 584).

Behavior patterns exhibit two key dynamic properties. First, relatively sudden 'switching' between different behavior patterns will occur as the reliability ratio and the tolerance limit cross over each other (Heiner 1983, p. 582). These crossovers may be triggered by changes in the agent's competence or by changes in the decision environment. Recursive decision environments can also generate systematic hysteresis effects,[4] in which the crossover point depends on the history of environmental conditions and prior behavior patterns (Heiner 1983, p. 582). The role of hysteresis in the evolution and performance of institutions has been recognized by economists (Georgescu-Roegen 1971, p. 125 and Samuelson 1972, p. 541) but given little consideration in formal theory.

The second dynamic property is that the rate of evolutionary change in behavior or institutions in response to changes in agents' competence or in the environment may be punctuated with a variety of sudden changes. The general pattern of response will initially be insensitive as new (nonlocal) information accumulates followed by relatively quick switching behavior. Consequently, transitory information may be ignored, even if it contains extremely accurate information to selectively modify behavior.

## Implications of Reliability Theory for Institutional Analysis

An institutional structure serves to assure the credibility of interpersonal exchange (Williamson) since it "...reduces the uncertainties associated with contract fulfillment as a consequence of enforcing reliable forms of exchange" (North, p.4). To illustrate the implications of RT for institutional analysis, consider the problem Sah and Stiglitz describe as the "architecture" of an institution. That is, the configuration of decision making responsibility to achieve a social objective.

Institutional Architecture

In a world of imperfect information and imperfect decision makers, alternative institutional architectures can lead to different levels of performance reliability. For example, a decentralized system (polyarchy) may have higher or lower rates of Type I and II errors than a centralized decision structure (hierarchy). Alternatively, one system may reduce Type I errors but increase the likelihood of Type II errors. RT suggests the institutional structure which more consistently satisfies the reliability condition will be selected by society. This does not imply that one structure is "optimal" since Type I and II errors will still occur, but the preferred structure provides credible performance under varying, uncertain conditions.

This perspective on institutional architecture is quite different from the optimal Bayesian decision making of traditional economic theory. For example, the choice of institutional structure for environmental quality control has been evaluated in the literature in terms of administratively decreed technological standards versus decentralized mechanisms such as marketable permits, bribes, emission taxes, etc. (Tietenberg, Bohm and Russell). The bulk of this literature has sought to prove the optimality of flexible mechanisms that allow emission sources to adjust their behavior in response to information from a central authority and others in their industry or geographic region. However, as Russell et al. wryly observe, these proofs assume that, "...not only are sources good citizens, but they are very capable citizens as well" (p. 91). In short, the qualitative results depend on perfect information and errorless decisions. More complex optimization models with imperfect information and detection and compliance failures have been considered but the general result of these inquiries is that "...there is no perfect system" (Downing, p. 223).

By contrast, RT offers a less prescriptive framework and suggests the structure which more reliably solves the problem of reducing decision errors in design, performance and enforcement will prevail. A reliability analysis would focus on the complexity of information and the competence of decision makers in the system architecture and evaluate the likelihood of decision errors. For instance, it can be hypothesized that centralized regulators more reliably evaluate social gains and losses from environmental quality changes because they are less likely to make Type I errors (not controlling when it is optimal) but more prone to Type II errors. Refutation of the hypothesis would require that decentralized decisions improve on the Type II error rate to a sufficient degree to offset higher Type I errors. Thus, the reliability condition, not the efficiency properties of a deterministic system, will bound the choice of system architecture.

In practice, the choice of institutional structure to control environmental quality has been remarkably consistent across different political systems and cultures. The vast majority of countries have adopted hierarchical control systems that centralize decision making responsibility and limit the flexibility of emission sources (Downing and Hanf). While these institutional solutions to the externality coordination problem certainly do not eliminate decision errors (a generic attribute of any structure), this consistency indicates a relatively high degree of reliability relative to more flexible alternatives.[5] Other practical examples of rigid as opposed to flexible institutions to coordinate externality problems include the use of strict liability instead of negligence standards for hazardous waste (e.g. the Comprehensive Environmental Response, Compensation, and Liability Act of 1980) and groundwater protection laws (Safe Drinking Water Act Amendments of 1986). Reliability theory suggests these structures will endure until information about an alternative with equal or greater reliability becomes sufficiently local to initiate collective action.

Administrative Rules

RT also suggests that institutions will respond to increasingly complex information by reducing the scope and complexity of information that must be interpreted by decision makers (Heiner 1983, p. 580-582). Nonlocal information that cannot be reliably interpreted will be given little weight in the decision process or it may be ignored (Heiner 1986, p. 236-242). As a result, administrative decisions and rules will tend to reflect more rigid criteria, a preference for precedence, and the neglect of complex information. Heiner (1986) cites the legal principle of stare decisis ("Let the prior decision stand") to explain how precedent and bounded decision methods are a logical product of judicial fallibility and social demand for reliability from institutions. Similarly, constitutional rules can be viewed as restraints on government action that assure reliable provision of government services and individual liberties (Aranson).

To further illustrate the principles, consider the administrative response to the Conservation Reserve Program (CRP) mandated under Title XII of the 1985 Food Security Act. Congress specified a set of objectives for the CRP which, if optimally implemented, required detailed information about future commodity prices, nonmarket values, and environmental conditions. Faced with these uncertainties, USDA adopted an implementation strategy based on a limited set of simple eligibility criteria that imperfectly, at best, approximate the legislative objectives (Reichelderfer and Boggess). While new information may become available to alter program rules, evidence from other administrative agencies' responses to complex information (Sabatier) suggest USDA's changes will be slow and imperfect.

Another example is rule making by regional councils under the Magnuson Fishery Conservation Management Act of 1976 (PL 94-265). The Act stipulated seven objectives for the councils which included optimum yield and economic efficiency. An implicit objective of the Act was to minimize intergovernmental conflicts over fishery management and allocation (Rogalski). Although economists have developed sophisticated models of efficient allocation mechanisms for the fishery (e.g. McConnell and Sutinen), in practice the councils have opted for allocations based primarily on historical shares between competing user groups (Easley and Prochaska). Economists have criticized this approach as inefficient and distributionally motivated (Karpoff), but have given little consideration to how the allocation rule minimizes conflict, provides consistency for investment decisions over time, and perpetuates the councils' ability to resolve disputes. RT suggests these latter factors are the most important determinants of the evolution and stability of allocation rules.

In summary, RT departs from EUT by recognizing the competence-difficulty gap inherent in human decision making, the fallibility of judgment, and the desire for reliable outcomes from interaction. RT disparages the reductionist myth that more information, regardless of its complexity, improves decision making and that greater flexibility necessarily improves institutional reliability. These features of uncertainty are the motivating forces for institutional evolution and stability.

An Appraisal

RT is a novel, challenging view of human decision making and interaction that provides a descriptive-explanatory framework for institutional analysis. This framework recognizes EUT as a special case but most of the insights from RT arise from the general case. The theory suggests that economists concerned about environmental institutions would benefit by recognizing the sources of uncertainty in performance and by considering how these uncertainties are influenced by alternative institutions and/or new information. The reliability condition specifies an explicit criterion to explain and evaluate institutional formation and evolution. However, this condition alone is not sufficient for the existence and performance of institutions. Other criteria such as fairness, justice, and ethics motivate social interaction and should not be neglected in institutional analysis.

As with any new theory, there are technical difficulties and conceptual ambiguities to overcome. One problem is the need for a method to quantify the amount and quality of information available to decision makers and how this information is used. One possibility is the use of the "epistemic reliability" indicators suggested by Gardenfors and Sahlin. In contrast to standard Bayesianism, this approach uses a class of alternative probability measures to represent individual knowledge and to derive indicators of the degree of reliability a decision maker ascribes to the alternative measures. In addition, the fact that true uncertainty can never be fully quantified suggests the need for modeling tools that admit this indeterminacy. Fuzzy set theory (Zimmerman) may offer some insights for this problem. More well-known approaches such as stochastic control methods could also be used to evaluate the economic consequences of reliability criteria (e.g. Milon).

A more fundamental issue, however, is the philosophical implications of RT. As reflected in the normative content of Dewey's remarks in the introduction, the rational choice framework of EUT is generally inconsistent with rule-governed behavior. From this rationality perspective, flexibility and decentralization have become the cornerstones of economic theory. RT presents a challenge to these fundamentals because it provides a logical foundation for institutions that limit individual flexibility to select optimizing behavior. The implications of this alternative perspective and the question of whether RT can be embraced within a generalized concept of rational choice are unresolved issues that invite future inquiry.

In summary, perhaps the most significant contribution of RT is that it encourages theorists and empiricists to focus on the role of imperfect judgment in human behavior and the broader social implications of individual decisions. This view of bounded rationality in institutional structure and performance is consistent with other research programs in the social and natural sciences. The promise of RT is that it may provide a lasting contribution to our understanding of the formation and evolution of social structures.

## FOOTNOTES

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1. Our favorite characterization of uncertainty is the Bag Lady's (a.k.a. Lily Tomlin) observation that, "Reality is nothing more than a collective hunch." Also popular is the (anonymous) rejoinder to Einstein, "God <u>does</u> play dice with the universe."
2. The transactions costs approach to information problems cannot explain behavioral responses to uncertainty because decision makers can not know the expected value of information <u>a priori</u>. Certainly, search costs and learning play an important role in institutional dynamics but these decision variables can be directly integrated into the reliability theory framework (e.g. Heiner 1986, p. 258-261).
3. In the limiting case of perfect information and perfect decisions, the reliability condition reduces to $(g_d \cdot p_d^*)>0$ which is the standard decision rule in expected utility theory. For the general case with imperfect information and decisions, the decision rules are not equivalent (Heiner 1986, p. 258-261).
4. A hysteretic explanation of the behavior of a system means that the history of the relevant explanatory variables is required in addition to knowledge of the present state variables; if only reference to present state variables is required, the system is ahysteretic (Cross and Allan).
5. It is useful to note that the U.S. Congress apparently recognized the propensity for Type II errors in centralized control by adding individual source variance procedures to each of the major environmental regulation acts.

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