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EPISTEMIC SYSTEMS*

ABSTRACT

Epistemic systems are social processes generating judgments of truth and falsity. I outline a mathematical theory of epistemic systems that applies widely. Areas of application include pure science, torture, police forensics, espionage, auditing, clinical medical testing, democratic procedure, and the market economy. I examine torture and police forensics in relative detail. This paper is an exercise in comparative institutional epistemics, which considers how the institutions of an epistemic system influence its performance as measured by such things as error rates and the volume of judgments generated.

I. Introduction

Pure science, police forensics, espionage, auditing, torture, clinical medical testing, judicial proceedings, private arbitrage, government investigations, and the market economy are all social processes that generate, in one way or another, judgments of truth and falsity. In each of these areas, agents must decide what is true. Because of this role for truth in these processes, I will call them "epistemic systems." I outline a relatively broad class of mathematical models that may help us study epistemic systems, and I work out two applications, one to torture and the other to police forensics.

The word "epistemics" is defined in the *Oxford English Dictionary*: "Of or relating to knowledge or degree of acceptance." Thus, epistemic systems are "epistemic" because we are interested in whether they tend to produce reliable knowledge. They are "systems" because (quoting again from the *Oxford English Dictionary*) their pieces form "a connected or complex whole;" the elements are "connected … so as to form a complex unity." To paraphrase Goldman's (1999) characterization of "veritistic social epistemology": Epistemic systems are social processes viewed from the perspective of their tendency to help or frustrate the production of true judgments.

Epistemic systems vary in their institutions. In some cases agents rely on experts. In other cases agents search the possible answers themselves. In some cases, many independent agents search for the truth in a give domain. In others, one privileged agent or small set of agents is given the exclusive right to search for the truth in the given domain. And so on.

Differing institutions are likely to produce different epistemic results. Which institutional structure is best is likely to depend on the nature of the problems involved. For example, the reliability of jury verdicts depends on the jury's ignorance of certain types of "prejudicial" evidence. In pure science, however, it is probably better to admit all forms of evidence. The institutions that produce true judgments in one context may produce false judgments in another.

We have some choice among the institutions that govern epistemic systems. Thus, it is worthwhile to enquire which institutions promote the truth. The institutional structures of some epistemic systems are easier to change than others. The institutions of science, for example, are the product of a long international tradition and not easily modified. It is even probable that we do not understand just how those institutions function (Butos and Koppl 2003). The institutions of medical testing labs may be easier to change, at least within a given political jurisdiction.

However difficult it may be to change an epistemic system, we generally have at least the ability to effect piecemeal changes. Thus, we have an incentive to learn how different institutional changes affect the epistemic properties of different epistemic systems.

In this paper I consider how the epistemic performance of a system varies with changes in the institutional structure. One might also ask how that performance varies with changes in the agents' motivations, dispositions, *etc*. (I thank Christian List for pointing out the importance of this distinction.) In mostly neglecting the second question I may be revealing the disciplinary weaknesses and excessive skepticism of someone trained as an economist. I think David Hume provided good reason, however, for giving the first question special attention and for making pessimistic assumptions about human nature while doing so. "Political writers have established it as a maxim, that, in contriving any system of government, and fixing the several checks and controuls of the constitution, every man ought to be supposed a knave, and to have no other end, in all his actions, than private interest. By this interest we must govern him, and, by means of it, make him, notwithstanding his insatiable avarice and ambition, co-operate to public good" (Hume 1777, Part I, Essay VI, "Of the Independency of Parliament," in paragraph I.VI.1). Hume here expresses the idea behind "checks and balances." In considering ways to amend our institutions so as to improve epistemic performance, it seems prudent to estimate the relative merits of different arrangements under pessimistic assumptions about human motives. Although not all of us are knaves, virtue is a scarce resource. We should therefore consider such amendments to our institutions as economize on human virtue.

The models of epistemic systems I present below may help us to understand the epistemic consequences of alternative institutions in various contexts. After commenting on the previous literature in this area, I outline a relatively broad class of mathematical models and then develop my two applications, torture and police forensics.

II. Other treatments of similar topics

The models I propose are somewhat similar to those of information theory. In an epistemic system, however, the messages are objects of strategic choice, whereas in information theory the relative frequencies with which messages are sent are data of the analysis. Indeed, the central idea is simply to remove from the message space the probability density function that information theory posits as exogenous and replace it with strategic choice of messages.

The models given below are related to a large body of past work. I cannot attempt a survey here. It is difficult even to construct a reasonably complete list of related fields, which include information economics, sociology of knowledge, judgment aggregation, science studies, philosophy of science, epistemology, economics of science, informatics, cognitive science, and social psychology. The function of an economic system is to produce utilities, not verities. But economic decisions depend on judgments of truth and falsity on many topics including the likely returns from different investments. Thus, the economist F. A. Hayek (1935) and others argued that rational economic calculation is not possible under socialism, whereas J. M. Keynes (1936) argued (in effect) that rational economic calculation was not possible under capitalism. G.L.S. Shackle (1972) first brought the term "epistemics" to economic theory, defining "epistemics" as "the theory of thoughts" (1972, p. *xx*). In philosophy, Alvin Goldman (1978, 1999, 2001) used the terms "epistemics" and "social epistemology" to refer to studies of the sort I am attempting here. Goldman's veritistic social epistemology, in which some claims to truth are better than other, contrasts sharply with theories pretending to be neutral on truth, for example that of the sociologist David Bloor (Goldman 2001). Bloor (1976) carries on the tradition of the "sociology of knowledge," which is generally traced back to Karl Mannheim (1936[1985]). Psychology, especially social psychology, addresses many of the issues I raise. The leading study in this area is probably the famous conformity study of Solomon Asch (1951), who showed that most people will (in a certain laboratory setting, at least) adjust their opinions away from the obvious truth in order to conform to majority opinion.

Formally, models of epistemic systems are game-theory models. I do not attempt to engage in the level of formalism typical in today's game

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theory literature, however, partly because I want to exclude as few readers as possible without losing any needed rigor. The models of this paper might be most closely related to two sets of results. First, there is the recent literature on "judgment aggregation." Examples include Kornhauser and Sager (1986), Kornhauser (1992), and List and Pettit (2002). Second, there is the large body of work on asymmetric information, signaling games, and sender-receiver games. Examples include Spence (1973), Blume *et al*. (1998), Green and Stokey (1980), and Crawford and Sobel (1982).

The judgment aggregation literature is close in both spirit and substance to many of the models presented below. The central problem in the judgment aggregation literature has been collective judgment, as with a committee or democratic electorate. I do not address that exact problem in this paper, but it seems likely that results from this literature should be relevant to the problems I do address. Recent results on "truth tracking," and the role of arguments and reason-giving (List 2005) seem likely to be of particular relevance.

In the asymmetric information literature, Akerlof (1970) might be closest in spirit to the models presented below. (A correspondent suggests that the sender-receiver literature was influenced by Lewis 1969, who is cited in Blume *et al*. 1998, but not Blume and Stokey 1980 or Crawford and Sobel 1982.) The models in this literature are aimed at a somewhat different group of problems than I have in mind. Spence (1973), for example, is mostly concerned with the issue of signaling one's merit as a potential employee. A college education may not improve one's job skills, but it is a signal of one's ability. In a typical model of this group, the sender knows his "type," e.g. whether he is a good worker, and chooses a (possibly costly) signal that may reveal his type or obscure it. This setup would seem to cover only some of the applications to which I hope to put the models of this paper. For example, I sometimes assume there to be more than one sender or more than one receiver. In some applications, such as pure science, I assume the set of senders and receivers is the same. My models of "discursive epistemic systems" assume the message space is the Cartesian product of a set of "arguments" and "conclusions." I am not personally aware of signaling models, sender-receiver models, or models of asymmetric information using this particular device. Although I cannot promise the reader I have missed nothing relevant in the existing body of work, I seem to be dealing with problems somewhat distinct from the sort of "information asymmetries" typically imagined in today's game theory literature.

The models below might also be considered principal-agent models, but they are not *standard* principal-agent models, wherein the principal monitors the performance of the agent. The crux of the matter here is precisely the principal's ignorance of the message space searched by the agent and his consequent inability to directly monitor the agent's performance.

The models presented below seem to represent a somewhat novel approach to issues addressed in one way or another by a large and heterogeneous literature.

III. A General Theory of Epistemic Systems

A. Overview

In this section I outline some models of epistemic systems. I will introduce the basic mathematical description of an epistemic system, provide a few simple examples, and develop some useful distinctions. In all these models, you have one or more "senders" who search a "message space," and deliver a message to one or more "receivers." Thus, a forensic scientist searches a message space with two messages: "match" and "no match." He chooses "match," say, and sends the message by testifying in open court. After receiving his message or messages, the receiver produces a "judgment." The jury, in our forensics example, decides whether the fingerprint left at the crime scene belongs to the suspect. This particular "judgment" is an input into the jury's larger deliberations. I am mostly interested in the truth value of these judgments, such as the jury's judgment that the print came from the suspect. Some arrangements induce more truthful judgments than others. For example, an arbiter for whom one party is a repeat customer is likely to be biased. An independent arbiter is more likely to give a truthful account of who is at fault in a dispute.

I start with systems having two rather restrictive properties. First, they are "closed," because the set of senders and the set of receivers are fixed. Second, they are "Delphic," because the messages in the message space contain no arguments or explanations. In the US today, forensic science tends to be a closed Delphic system. The police crime lab in a given jurisdiction is the only one likely to see criminal evidence, and the testimony given in open court is often rather cryptic, little attention being paid to how the forensic scientist arrived at his conclusions.

Later in the paper I will discuss "open" systems, in which new senders or receivers may enter. I will also discuss "discursive" systems, in which messages contain both an argument and a conclusion. A given argument may make a given conclusion likely, unlikely, impossible, or whatnot. Science is an open discursive system. The set of senders and the set of receivers are both open. There are no particular restrictions on who may send scientific messages. Even today complete amateurs can successfully enter some technical fields. Marjorie Rice, for example, found several new tessellations of the plane in the 1970s even though her only formal training in mathematics came in high school (Schattschneider 1978, p. 36). Computer scientist Richard James III is another amateur who discovered new tessellations in the same period (Schattschneider 178, pp. 34-35). Similarly, it is relatively easy to find and read scientific works, thereby becoming a "receiver" in the epistemic system of pure science.

Alchemy was an open, but largely Delphic epistemic system. The alchemists wrote treatises which sometimes contained real information. Often, however, their treatises were willfully obscure. Some of them claimed to have performed marvelous feats while keeping the supposed technique a secret. (Chapter 4 of Mackay 1852 is a history of alchemy.) The progress of science is due in part to its being a discursive system.

The example of science supports the conjecture that open, discursive epistemic systems tend to outperform other epistemic systems. My suggestions for improving forensic science (Koppl 2005) would make the system, in effect, more open and discursive. If I am right to make such a suggestion, then the distinctions between open and closed systems and between Delphic and discursive systems would seem to have at least one reasonably important field of application. The structure of our forensic science services is subject to change through the political process and it is worthwhile for some academics to think about what that structure should be. I conjecture that other policy-relevant examples exist. I turn now to the relatively formal apparatus that is the core of this paper.

B. General Framework

An ***epistemic system*** is a set of ***senders***, $\boldsymbol{S}$, a set of ***receivers***, $\boldsymbol{R}$, and a set of ***messages***, $\boldsymbol{M}$. The senders may have a probability distribution over messages, showing the subjective probability that each message is true. The senders send messages to the receivers, who somehow nominate one message from the message set and declare it "true." This is the ***judgment***, of the receiver(s). For example, we might have a system with one sender and one receiver and in which the receiver always nominates the message he gets from the sender. Typically, the senders are experts advising the receivers. (An eyewitness is an expert on the particular facts he or she witnessed.) The receivers may or may not be experts. In science, the set of receivers is identical to the set of senders. In expert testimony, the set of senders is disjoint from the set of receivers.

The ***epistemic efficiency*** of a system is an inverse measure its error rate. In what follows I will define epistemic efficiency as one minus the error rate. For particular purposes, other definitions might be applied. The epistemic efficiency of an epistemic system may be its reliability: the ratio of true judgments to total judgments. The ***relative epistemic efficiency*** of a system is its epistemic efficiency divided by the epistemic efficiency of some benchmark system, such as flipping a coin.

An epistemic system is an ordered triple, $<\boldsymbol{S}, \boldsymbol{R}, \boldsymbol{M}>$. The set $\boldsymbol{S}$ (of "senders") is indexed by $i \in I^*$. A member of $\boldsymbol{S}$ is represented by $s_i \in \boldsymbol{S}$. The set $\boldsymbol{R}$ (of "receivers") is indexed by $j \in J^*$. A member of $\boldsymbol{R}$ is represented by $r_j \in \boldsymbol{R}$. The set $\boldsymbol{M}$ (of "messages") is indexed by $h \in H^*$. A member of $\boldsymbol{M}$ is represented by $m_h \in \boldsymbol{M}$. Typically, there will be a finite number of senders and receivers. It may often be convenient to assume the message space is infinite. If I^* has a largest element,

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denote that element I. Define J and H similarly.

Senders and Receivers have value functions over messages. These might be utility functions or payoff functions. For receivers, $V_{r_j} = f_{r_j}(ms_{s_1}, ms_{s_2}, \ldots, m_{s_I})$. For senders, $V_{s_i} = f_{s_i}(V_{r_1}, V_{r_2}, \ldots, V_{r_j}; ms_{s_1}, ms_{s_2}, \ldots, m_{s_I})$. For example, the sender may be an expert witness hired by the receiver to evaluate the money value of a harm suffered by the receiver. Up to some limit of plausibility, the receiver prefers higher estimates to lower estimates. This may induce a similar preference in the sender, who wants the plaintiff's lawyer to become a repeat customer.

Sender and receiver value functions may or may not reflect a preference for the truth. In some applications, the first group of arguments of the function $f_{s_i}(\bullet)$ may fall away; in other applications, the second group may fall away. Our imagined expert witness may be interested in which answer his client prefers, whereas the eyewitness to an automobile accident may not care which party prevails in court. If there are two or more senders, they are in a position of strategic interdependence with respect to the messages they send. One may often be interested in knowing which message vectors are Nash equilibria.

Models of epistemic systems will probably be most useful when one must assume that senders, or receivers, or both place little or no value on truth. We would prefer a world in which people prefer to send and receive true messages. In many contexts, however, people prefer to send or receive false messages. Most criminals prefer to deny their crimes. Many scientists prefer their own theories to competing theories that come closer to the truth. In such contexts, models of epistemic systems may help us to amend our social institutions so as to produce more true judgments.

A simple example

Let $\boldsymbol{M} = \{0,1\}$. The receiver always nominates the sent message flawlessly. The message is sent over a noiseless channel. Figure 1 illustrates.

The dashed arrow represents the sender choosing from the message set. The solid arrows represent the transmission to the receiver and the "nomination" of a message by the receiver.

Notice that Figure 1 looks like it came from Shannon's information theory. This is no

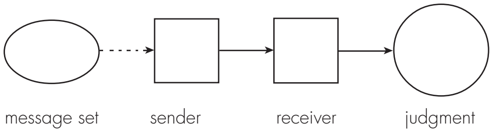

Figure 1

coincidence. As I have said, the basic idea of epistemic systems is that we eliminate from information theory the exogenously given distribution over messages and replace it with search of the message space and strategic choice of messages.

In the context of Figure 1, assume the receiver's value function is

$$U(x) = \begin{cases} 1 \text{ if } x = 0 \\ 0 \text{ if } x = 1 \end{cases}$$

In this case the receiver is interested in the content of the message (whether it is 1 or 0) but not in its truth. Assume further that the sender estimates the probability that 1 is true to be 0.75. His subjective probability that 0 is true is, therefore, 0.25. Assume the sender's value function is

$$V(x) = P(x \text{ is true})E[U(x)],$$

where $P(\bullet)$ denotes probability and $E(\bullet)$ denotes expected value. $E[U(x)]$ denotes the sender's expectation of the receiver's value function, $U(x)$. The sender, in this example, values the truth, but also wishes to please the receiver. Assume, finally, the sender knows $U(x)$. Then $E[U(x)] = U(x)$, $V(1) = 0$, and $V(0) = 0.25$. In this case, the sender sends 0 and the receiver's judgment is 0 even though the sender thinks 1 is three times more likely. This model is purposefully quite simple. In a rough and ready sort of way, however, it might apply to many command and control situations. If the receiver is in a position of dominance over the sender, the sender may craft his message to please the receiver rather than reveal the truth. It is a commonplace that dictators and Hollywood stars receive nothing but praise and celebration even under desperate circumstances.

A small variation in the simple model of this section reveals the importance of the principle of "information hiding." Borrowing a term from

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computer science (Parnas 1972), Richard Langlois (2002) has introduced the concept of "information hiding" to economics. Information hiding is "enforced ignorance among the parts" of a system (Koppl and Langlois 2001, p. 294). For example, information shared with an attorney is hidden from the jury of a criminal trial.

Imagine that the sender in the previous model does not know the receiver's utility function, $U(x)$. The sender wants to please the receiver, but does not know which message is preferred. In this situation, $E[U(x)]$ is 0.5 regardless of x. Under these assumptions $V(1) = 0.375$, and $V(0) = 0.125$. The sender sends 1 and the receiver's judgment is 1.

Recall that the sender in this model estimated the probability of 1 being true to be 0.75. Imagine this is true on average over time. In other words, the relative frequency of 1 being true is 0.75. Then information hiding raises the epistemic efficiency of this system from 0.25 to 0.75. This result illustrates the great importance of information hiding in epistemic systems. A well-designed epistemic system will typically have a modular structure with information hiding. It may seem counter-intuitive to say that we wish to hide information in order to generate better judgments about the truth. But this is done all the time. In science we have double-blind testing in which the scientist arranges to have certain information hidden from him. The law courts hide information from the jury.

In our discussion so far it is not obvious how the structure of the message set influences the behavior and epistemic efficiency of the system. The next subsection contains models with multiple senders and models in which the structure of the message set plays an important role in system behavior.

C. Discursive Systems, Both Open and Closed

The epistemic systems we have considered so far were "closed." An epistemic system is ***closed*** if the set of senders and the set of receivers are fixed. In an ***open*** epistemic system, by contrast, new senders and receivers may enter the system. The epistemic systems so far considered were also "Delphic." An epistemics system is ***Delphic*** if the messages of the senders contain no description of how the message was selected. In a ***discursive*** epistemic system every message is accompanied by an argument. Arguments, like conclusions, may be the object of strategic choice. It seems plausible to guess that discursive epistemic systems will tend to outperform Delphic systems and that open systems will tend to outperform closed systems. In many contexts, presumably, open discursive epistemic systems are preferable to closed Delphic epistemic systems.

In a discursive epistemic system, each message is an ordered pair, <*a*,*c*>, consisting of argument and conclusion. The argument set is denoted ***a***. The conclusion set is denoted ***c***. An "argument" may include evidence about actions performed by the sender, for example the bench notes of a forensic scientist. The message set is the Cartesian product, ***a***×***c***. Note that a sender may send any combination of argument and conclusion. An argument assigns a probability to each possible conclusion.

Models of discursive systems employ a notion of probability that is at least similar to the "logical probabilities" developed by Keynes (1921). (Rudolf Carnap also advocated the idea of logical probabilities. See Savage 1954, p. 61, who cites Carnap 1950.) In Keynes' system, probability is an objective relation between a body of evidence and a hypothesis. In discursive epistemic systems, the same is true *within the model*: every argument endows every conclusion with a probability. The existence of such logical probabilities in the model does not prevent the modeler from introducing other notions of probability as well. For example, senders may have subjective probabilities over the conclusion set before they begin to search the message set.

In some applications it might be preferable to assume that each argument assigns a level of "possibility" in the sense of Shackle (1972). The calculus of possibility is not that of probability. A snowstorm in June is perfectly possible, but not probable. In Shackle's system, possibility varies from 0 (perfectly impossible) to 1 (perfectly possible) just as probabilities do. Possibilities, however, typically sum to a number greater than one. When considering some problems in war and espionage, for example, it may be important to know whether an epistemic system can find contingencies and discriminate between those that are more and less possible, whereas probabilities may be impossible to assign in any very meaningful way.

Typically, one assumes the truth is more probable: there is an argument assigning a probability value to the true conclusion that exceeds the probability value assigned to false conclusions by any argument. In some cases, however, this assumption may be dropped. Special rules of the epistemic system, for example, may remove crucial arguments from the argument set. In a legal system, this would happen if inappropriate rules of evidence were applied, for example that all arguments assume the infallibility of the dictator's intuition.

The probability assignment may be direct: the message contains an explicit statement of the probability that the conclusion is true given the argument. In other words, for some purposes, it may be convenient to imagine that the probability associated with the argument is observed cost free and error free. For example, the conclusion "the patient has such-and-such a disease" has an easily computed probability implied by the results of a diagnostic test of known reliability. In other applications, however, it may be convenient to assume that the probability assignment can only be estimated by "inspecting" the argument. The receiver, perhaps, inspects the argument and assigns a probability to the conclusion. Inspections are subject to error and errors are not necessarily unbiased. Modifying our last example, the doctor may be subject to the base-rate fallacy and unable, therefore, to attach the correct probability to the conclusion that a patient has the disease in question. Inspections may not be costless. In some models, the senders may be able to survey all messages and observe the probabilities assigned by each argument. In other models, however, the senders may be able only to sample the set of arguments. They may be able to search the argument set at a cost, or to inspect messages at a cost.

Consider first systems illustrated by Figure 2, with a conclusion set given by {0,1}. In this system there are two senders and one receiver. Receivers try to pick the most probable message. Senders are perfect judges of which message is most probable, but receivers may make mistakes. The receiver is subject to error, but correctly judges relative probabilities at least half the time. Finally, for this exercise, I will assume that the message 1 is always true. Under these assumptions, as we shall see, a sender's choice depends on the structure of the message set and on what the senders and receivers can know about it. In this sort of a setup, if the receiver's errors are not too large, then the epistemic efficiency of the system will be determined by the knowledge and inspection costs of the senders, not the receiver. An example helps clarify issues.

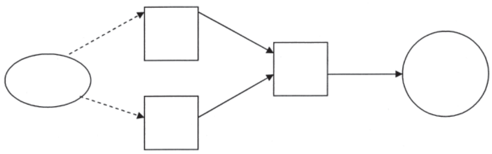

Figure 2

Let A = $\{a_1, a_2, a_3, a_4\}$ and C = {0,1}. Recall that the receiver inspects each message and chooses the message that, by the receiver's estimate, makes the corresponding conclusion more probable. A sender receives a payoff of 1 if his argument persuades the receiver, who then nominates the message. He gets 0 if his conclusion is chosen, but because of the argument of the other sender. He gets −1 if his conclusion is rejected. Finally, in case of identical messages, each sender gets 0.5.

Assume the following table reveals the probabilities each argument assigns to each conclusion. Notice that the truth, 1, cannot be known with certainty. We the god-like observers know that 1 is certainly true. But participants in the system, senders and receivers, cannot be so sure. At best they can be 90% sure that 1 is true.

First take the easy case in which senders have

	p(0)	p(1)
a_1	0.8	0.2
a_2	0.6	0.4
a_3	0.45	0.55
a_4	0.1	0.9

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perfect knowledge of the message set and receivers are perfectly able to see which of the messages they receive is most probable. In this case, each sender sends $<a_4,1>$. The receiver will always choose this message in preference to any other a sender might send. Thus, each sender recognizes that it trumps any rival message the other sender might send. In other words, sending $<a_4,1>$ is a dominant strategy. Because we have assumed 1 is always true, the epistemic efficiency of this system is 1.

Now imagine that senders have perfect knowledge of the message set, but the receiver has only a 50% chance of correctly identifying which argument renders its conclusion more plausible. As I explain presently, the expected value of a sender's message is determined entirely by whether the other sender's message has the same conclusion. Imagine both have the same conclusion. Then they chose the same arguments or different arguments. If they choose the same arguments, then their messages are identical and each gets 0.5. If they choose the same conclusions but different arguments, then one will get 0 and the other 1. Since the receiver has only a 50% chance of correctly identifying which argument renders its conclusion more plausible, each payoff, 0 and 1, gets the weight 0.5. The expected value for both senders is 0.5. If they choose different conclusions, then one gets −1 and the other 1. Since the receiver has only a 50% chance of correctly identifying which argument renders its conclusion more plausible, each payoff, −1 and 1, gets the weight 0.5. The expected value for both senders is 0. Thus, we have a simple coordination game in which the senders wish to coordinate on the same conclusion.

Assume the senders send messages randomly chosen from the message set, but that the receiver can flawlessly determine which message assigns the higher probability to its conclusion. The epistemic efficiency of this system is 0.5, the same as flipping a fair coin. Assume instead that the senders get two random draws on the message set and have a 60% chance of selecting the message whose argument renders its conclusion more probable. In this case, the epistemic efficiency is almost as low as coin flipping. If we increase the senders' discrimination the situation is hardly improved. Even when senders can flawlessly determine which of their randomly chosen messages is more persuasive, the system's epistemic efficiency is only 0.531. (I created a simple spreadsheet, available on request, to calculate this value.) The senders' limited ability to search the message space reduces the epistemic efficiency of this system to something little better than coin flipping. If the probability weights from our chart are shifted more in favor of the truth, but the rankings are not changed and the number of arguments more favorable to the truth is not changed, then the results are identical.

The results of the last subsection suggest that in systems such as that of Figure 2, epistemic efficiency depends heavily on the ability of senders to search the message space. If search is costly, they have an incentive to shirk and examine a relatively small part of the message set. In this case, the epistemic efficiency of the system may be low. This result suggests why open epistemic systems may tend toward greater epistemic efficiency. If new senders can profitably enter and deliver messages that compete with those of incumbent senders, we can expect the entry of those with a comparative advantage in searching the message space and the exit of those without such a comparative advantage.

IV. Applications

In this section I consider two reasonably well worked-out applications of the theory developed in the last section. I will then give an informal discussion of several other applications that seem worthy topics of research.

A. Torture

Torture has several functions including the gratification of sadism. Its two main political functions, however, are to serve "as a mechanism for social control and as a method for extracting information" (Wantchekon and Healy 1999, p. 597). Recently, Bagaric and Clarke (2005) have defended the morality of torture as a method for extracting information, though the "only situation where torture is justifiable is where it is used as an information gathering technique to avert a grave risk" (p. 611). They say, "The main benefit of

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torture is that it is an excellent means of gathering information" (2005, p. 588). This supposed benefit, however, is assumed and not argued.

Wantchekon and Healy (1999) have authored a pioneering, rational-choice model of torture. They note that "Emotions dominate the discussion of torture," but that "Finding solutions to seemingly intractable problems requires objective reasoning" (p. 596). Unfortunately, they explicitly "assume that the state [i.e. the torturer] has the means to verify the truthfulness of the information provided by the victim" and that "the victim can stop torture" by revealing all the information he or she has (p. 600). Their analysis assumes the universal applicability of the very conditions under which, as I will argue, torture is effective in extracting information. If these conditions are not universal, however, their analysis does not help us to determine the epistemic efficiency of torture.

Epistemic analysis shows that torture is not a useful and reliable method of gaining information except in empirically implausible cases. I will call persons subject to torture "subjects" and persons subjecting others to torture "investigators." Torture is effective only when two conditions hold. First, the investigators must be able to recognize the truth when they hear it. Second, they must be able to credibly commit to stop torture once the truth is spoken. The combination of these two conditions seems to be empirically rare. Thus, torture is not generally an effective means of gathering information. Some models illustrate the point.

I begin with the case of one person torturing just one other. Figure 1 illustrates the case. The subject is the sender and the investigator is the receiver. The investigator's problem is when to trust the message sent by the subject. The subject's problem is to understand whether speaking the truth will reduce the pain from torture. If the subject believes that more than one message will be maximally effective in reducing the pain to which he is subject, he will send the least truthful of these messages. Thus, the greater the investigator's ignorance of the message space, the less confidence he will have in the veracity of the subject's testimony. A simple maximization problem illustrates.

Let the message space be the closed unit interval, $M=[0,1]$, where, for all $x \in [0,1]$, the message x conveys the fraction x of the useful information known to the subject. Thus, the message 0 corresponds to lies or stony silence, and the message 1 corresponds to complete capitulation and cooperation. The investigator's utility is

$$U(x)=x.$$

The subject's utility is

$$V(x)=1-U(x) - f(t),$$

where t is the amount of torture he suffers and $f(t)$ is the disutility of torture. It is obvious that the subject has no incentive to speak the truth unless t is a decreasing function of x. In that case, his maximization problem is

$$\max_{x} V(x) = 1-x-f(t)$$

s.t. $t=g(x)$, where $g(\bullet)$ is a decreasing function of x.

The subject will pick an interior value of x only if there is an interior value of x for which $-1-f'g'=0$ and $-f'g'+f'g''<0$. Otherwise, he will reach a corner solution, telling all or nothing. Figure 3 illustrates the subject's maximization problem.

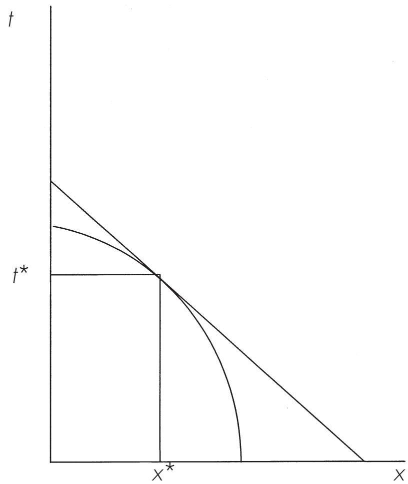

Figure 3

The subject faces a tradeoff between conveying information he does not want the investigator to have and avoiding painful torture. Torture and information revelation are "bads": the subject prefers to convey less information and suffer less torture. Thus, lower values of t and x are preferred. In the case illustrated, the subject believes that the amount of torture he suffers is a declining linear function of the amount of information he reveals. He chooses an interior solution, which conveys to an investigator only a fraction, x^*t^*, of what the subject knows.

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The investigator's epistemic problem is to know how truthful the subject's message is. If the subject sends 1, for example, it is not obvious to the investigator that the message is truthful. The message with index 1 may be a name or an address. The investigator is using torture precisely because he does not know which name or address has the index value 1. When the subject sends message, *y*, the investigator must estimate the index value of *y*. If the investigator is completely ignorant of the message space, he cannot formulate good estimates of the index value of the messages sent to him by the subject. The investigator must create the impression that he knows enough about the message space to construct a downward sloping function g(•) that is steep enough to induce truth-telling.

In the case of one investigator and one subject, the investigator finds it difficult to create the impression that *g*(•) is downward sloping in *x*. First, his ignorance of the message space renders him unable to stop or reduce torture when the truth is spoken. The investigator cannot recognize the truth when it is spoken and so cannot use it as a signal to abate torture. Second, even if the investigator could recognize the truth, he has no mechanism for making a credible commitment to stop torturing his subject once he has the desired information. In the case of one subject, torture has a low epistemic efficiency.

Now imagine the investigator has two subjects to torture. This case is illustrated by Figure 2. In this case as well, the investigator's problem is to create the impression that truth-telling will reduce torture. If the investigator is ignorant of the message space and the subjects have coordinated their efforts ahead of time, then the subjects will be able to agree on a message that seems plausible to the investigator, but conveys little information. The subjects do not convey true messages and the investigator has no satisfactory measure of the veracity of the messages he receives. In this case again, torture has low epistemic efficiency.

Torture might seem to be an effective means to extract information when 1) there are two or more subjects, 2) the subjects can survey different subsets of the message space, 3) the only element in the intersection of these subsets is the truth, 4) the investigator knows that these subsets have in common only the truth, and 5) the disutility of revealing the truth is sufficiently low that capitulation is utility maximizing. Condition 2) implies that the subjects have not pre-coordinated their actions in the case of torture. Pre-coordination would generally imply agreeing to given lie or an unhelpful mix of lies and truth.

When conditions 1) through 5) hold, one might imagine, the investigator can continue to torture his subjects until their answers coincide. Once he receives the common answer, he can infer that it is true and cease torturing his subjects. As in our previous cases, however, the investigator cannot credibly commit to stop torturing his subjects once the truth comes out.

A simple model illustrates this situation. Let us consider the case in which there are only two subjects. Because they have not pre-coordinated their testimony in the case of torture, they will give similar answers only if they tell the truth. When they invent answers, they invent different answers. (I ignore the possibility that the two subjects may be able to coordinate on some testimony that is uninformative, but "salient" in the sense of Schelling 1960.) This situation can be modeled as follows. $\mathbf{M}=[0,2]$, where 1 is the true message. Subject one can survey the subset of $\mathbf{M}$ given by $\mathbf{M}_1=[0,1]$ and subject two can survey the subset of $\mathbf{M}$ given by $\mathbf{M}_2=[1,2]$.

The investigator announces that he will continue to torture them until they tell the same story, which is the truth. If credible, this commitment creates the coordination game of Figure 4. For ease of exposition, I have invented numerical values for the payoffs.

	$m_2=1$	$m_2=i$, where $0 \leq i < 1$.
$m_1=1$	1,1	0,0
$m_1=i$, where $1 < i \leq 2$.	0,0	0,0

Subject 1 selects the row. Subject 2 selects the column. The payoffs are the same for all cases in which the subjects tell different stories, because they are subject to same amount of torture in all such cases. The payoff is highest when they tell the same story, because they are thereby relieved of the suffering of further torture. Truth telling is a dominant strategy in this case.

Figure 4

These conditions are probably met relatively infrequently. And when they are, they would seem to be quite fleeting; the population from which torture subjects are drawn will quickly learn to plan for torture and provide plausible but false messages. Thus, even if the investigator could credibly commit to stop torturing his subjects when the truth is told, the conditions favorable to the epistemic efficiency of torture are likely to be fleeting and the epistemic efficiency of torture low.

One correspondent has suggested that "There may be feedback; I want the address because the bomb is there. If it is not, I start torturing again. This also creates a partial incentive effect: If I don't stop the first time, then he has no incentive to tell the truth the second time." My correspondent offers a case in which an investigator can recognize the truth when it is spoken. The case seems relatively rare, however. In most such cases, the subject is part of a coalition with a common goal contrary to the interest of the investigator's coalition. They may fancy themselves revolutionaries. It is relatively easy for such a group to create the mobility required to make the subject's information obsolete by the time it is delivered. My correspondent also suggests that investigators may release some subjects who can then report to their coalition partners that the investigator will cease torture once the truth is told. This is a mechanism to create a credible commitment to stop torture once the truth is told. It seems a weak mechanism, however, in part because the released subject may not wish to reveal that he has told the truth. He has an incentive to misrepresent both his own behavior and that of the investigators who tortured him. It is a fair, but approximate, summary to say that, as a means of extracting information, torture works best when it is needed the least.

My generally negative assessment of the epistemic value of torture is consistent with the extensive research of Darius Rejali, who says, "torture during interrogations rarely yields better information than traditional human intelligence, partly because no one has figured out a precise, reliable way to break human beings or any adequate method to evaluate whether what prisoners say when they do talk is true" (Rejali, 2004a). He points to a case illustrating the problem that the investigator does not know the message space and cannot judge, therefore, the truthfulness of the message he extracts by torture. "One prisoner in Chile broke down several days into torture and revealed the names of the nuns and priests who had sheltered her. But the conservative and devout interrogators could not believe they were involved and continued torturing her" (Rejali 2004a).

Rejali quotes a French torturer who worked in Algiers in the 1950s: "'As the pain of interrogation began,' observed torturer Jean-Pierre Vittori, 'they talked abundantly, citing the names of the dead or militants on the run, indicating locations of old hiding places in which we didn't find anything but some documents without interest'" (Rejali, 2004b).

Darius Rejali's forthcoming book, *Torture and Democracy*, provides further empirical evidence that torture is rarely an effective means of gathering information. He has pointed out to me in a private communication that torture is widely believed to be an effective tool for gathering information in large part because of our "accepted memory" of the Battle of Algiers and Nazi torture of suspected members of the resistance. In these two important cases, Rejali tells me, "there is some strong opinion that torture worked and produced highly accurate information." He takes up these cases in *Torture and Democracy* and reaches more or less the opposite conclusion. Rejali's book examines many other factors not considered in this paper, such as organization deterioration and fragmentation of information, that are typically present and destructive of the epistemic efficiency of torture.

Bagaric and Clarke provide essentially no evidence of the efficacy of torture. Their only evidence is one case in which the threat of torture was supposed to have been effective. They repeat a story from an interview with Dershowitz (Silver 2004, as cited in Bagaric and Clarke, p.582, note 6) in which the German police had custody of a man they were sure had kidnapped a boy and collected a ransom on him. The man gave them many false stories about the boy's location until they threatened torture and the truth came out. The case is unusual, however, because the police could know perfectly well whether the subject told the truth and they could credibly

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commit to stop (or eschew) torturing the subject once he told the truth. Moreover, the child had been killed "shortly after the kidnapping," so that even in this supposedly successful case, the benefits from threatening torture were relatively low (Bagaric and Clarke 2005, p. 589). By omitting substantial argument or evidence on the efficacy of torture, Bagaric and Clarke provide a surprisingly weak argument for its use in even the few cases in which they esteem it morally justified.

One may wonder why torture is so often used if it is not an effective means of gathering information. Wantchekon and Healy (1999) claim, "Torture can be a rational choice for both the endorsing state and the individual torturer" (p. 596). This answer seems inadequate to explain torture as a means of extracting information. That use of torture might better be explained as Adam Smith explained the persistence of slavery: by the "love of domination and tyrannizing" (LJ[A] iii, 114, p. 186 of Smith 1982). Presumably, however, torture is an effective means of social control and is in that use a perfectly rational instrument of tyranny.

B. Forensics

In Koppl (2005) I report evidence that some forensic workers have a pro-police bias. Bias seems to be an important source of error in police forensics. There are two ways to handle bias: eliminate it or compensate for it. Models of epistemic systems may be useful in finding ways to compensate for bias. Epistemic analysis suggests the necessity of information hiding to prevent forensic scientists from acting on their biases. I will first discuss measures that do not rely on information hiding and then comment on how to bring information hiding into the system.

Figure 1 represents the current situation in the United States and elsewhere. The message space is given by M={0,1}, where 0 represents "no match" and 1 represents "match." This description of the message space ignores the possibility of inconclusive results and of probabilistic messages. As far as I can tell, however, dropping that simplification would not change the conclusions of my analysis. The sender is a forensics lab and the receiver is a court. (I don't think it matters for my analysis whether "a court" means a judge, a jury, or something else, perhaps more complicated.) Figure 1 reflects the current monopoly situation in forensics. Typically each jurisdiction has one crime lab. Evidence goes to one lab and it is unlikely that any other lab will examine the same evidence. Assume forensic labs are biased, preferring to send the message 1, "match." In this simple situation, the lab always sends the message 1 and the crime lab is adding no new information. In this case, forensic science does not increase the epistemic efficiency of the criminal justice system.

The situation is not helped by "mere redundancy." As explained in Koppl (2005) mere redundancy means that there is more than one sender examining evidence, but no specific incentives for one sender to discover the errors of the other(s). The redundant bits of the system just lay side by side. Figure 2 illustrates the case, assuming two senders. If both senders send the same message, the receiver's judgment is the common message. He flips a coin if they send different messages. In this model, redundancy does not alter the behavior of the senders. Each of the two senders in this model sends 1. The epistemic efficiency of the system is low because the system produces the right judgment only when the message 1 happens, coincidentally, to be true. In this case also forensic science does not increase the epistemic efficiency of the criminal justice system.

Now imagine that we have three senders. The first two send messages to the receiver who checks whether they are the same. If so, he nominates the common message. If not, he solicits the opinion of the third sender and nominates that message as the truth. This is "rivalrous redundancy." Figure 5 illustrates:

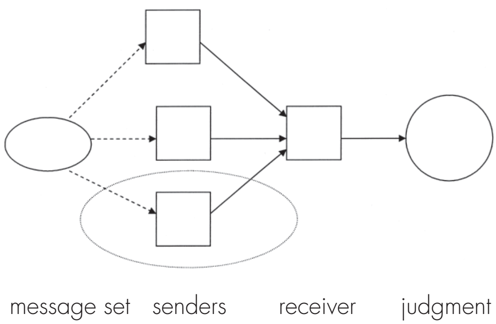

Figure 5

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The dashed circle around the third sender, whom we shall call the "arbiter," means that this sender's opinion will be solicited only if the other two send different messages. In these models everything depends, presumably, on who has what information. It matters, for example whether the third sender knows that he is the final arbiter. Thus, Figure 5 corresponds to a rather large set of models with different levels of epistemic efficiency.

Assume the identity of the arbiter is common knowledge. If the first two senders send the same message, each receives a payment. If that common message is 1, they get an additional (psychic) reward. If they send different messages, the sender whose message was rejected by the arbiter is fined and the fine is handed over to the sender whose message was confirmed by the arbiter. If the winning sender sent a 1, then he receives an additional psychic benefit. Sending a losing message of 1 does not produce a psychic payment.

If payoffs and rationality are common knowledge, then the game just described has one Nash equilibrium, in which both players send 1. The logic of this result is relatively straightforward. If the arbiter is called upon, he is sure to send the message 1. And if the arbiter is called upon, it is because one of the first two senders sent 0 and the other sent 1. But the arbiter is sure to pick 1. Thus, disagreement between the first two senders favors the sender who picks 1. Nash equilibrium requires that the first two senders agree. If they agree on 0, then either one of them could gain an advantage by switching to 1 and creating a disagreement that would, as we have just seen, help the sender choosing 1. Only when both senders send 1 does neither of them have an incentive to alter his strategic choice. The epistemic efficiency of this system is low.

Now imagine that the arbiter were known to prefer the true message. A logic like the one we just ran through shows that the first two senders will now choose the truth each time. In this case, of course, the system would have a higher epistemic efficiency. When the senders are sure of the behavior of the arbiter, the system puts out the arbiter's preferred message, even though it never calls on him to arbitrate.

The result just reviewed is driven in part by the fact that everyone knew who the arbiter was. If we now assume that none of the three senders knows which one is the arbiter, then there are two Nash equilibria. In one, everyone sends 1; in the other everyone sends 0. Here is why: Let us imagine that the first two senders disagree. In that case the arbiter is brought in to decide and his choice creates a majority. In this system, majority wins. The minority sender looses; he is fined. Thus, each of the first two senders wants to be in the majority. Now, the arbiter himself does not know whether he is an arbiter. This ignorance gives him, too, an incentive to be in the majority. All three senders want to be in the majority and there are two Nash equilibria, (0,0,0) and (1,1,1).

If the senders do not know who the arbiter is, we have a relatively weak form of information hiding. In this situation, the only two Nash equilibria are (0,0,0) and (1,1,1). Where there are multiple Nash equilibria, standard game theory cannot decide which, if any, will prevail. It is at least possible, however, that the truth may be more salient than other messages. In that case, the epistemic efficiency of this system will be relatively high and forensic science will increase the epistemic efficiency of the criminal justice system.

The legal scholar Michael Saks and others have called for an "Evidence Control Officer" to provide a "masking function" that would prevent forensics labs from knowing which result the police were looking for (Saks *et al.* 2001, Risinger *et al.* 2002, Koppl 2005). It seems evident that this form of information hiding would reduce bias. In Koppl (2005) I recommend an interlinked series of institutional changes that includes rivalrous redundancy and information hiding. Combining rivalrous redundancy with information hiding is likely to increase the epistemic efficiency of forensic science.

C. Other Applications

Models of epistemic systems may be applied widely. For example, many of the issues that arise in police forensics also show up in auditing. Auditors are hired to search for accounting irregularities. Because they are paid by the firms they audit, similar issues of bias arise. Forensic scientists are not expected to hold forth on the

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guilt or innocence of any suspects, but they are expected to correctly match fingerprints, identify blood types, and so on. Similarly, auditors are not required to say or expected to know if a firm has cheated. But they are expected to judge correctly whether the books they inspect reveal any deviation from generally accepted accounting principles. They are in a position of trust quite similar to that of forensic scientists. (I thank Colleen Cowen for this example.)

Pure science is an open, discursive epistemic system. The set of senders is approximately the same as the set of receivers. Each scientist, research team, and school of thought has a comparative advantage in searching different parts of the message set, which consists of all possible theories in a given field. Models of epistemic systems may shed light on alternative science policies and on certain aspects of the history of science, such as the consequences of falling costs of computation. Such models would complement the percolation (or "spin glass") models of David (2002) and his co-authors. Espionage presents problems similar to those of torture. Spies are motivated actors, whose messages may or may not be true. The receiver, a government, relies on spies to provide information, but lacks the ability to evaluate the information it gets. When seen in this light, it seems less surprising that good information is often ignored. The forensics application discussed earlier suggests the possibility that the epistemic efficiency of a government's system of espionage might be promoted by something similar to rivalrous redundancy. If so, it would reduce epistemic efficiency to collect all of a government's spies under one unified system of command and control.

II. Conclusion

Mathematical models of epistemic systems may help us to understand which social institutions produce truth and which do not. This strategy for the discovery of truth and the elimination of error is indirect. Rather than attempting to instruct people in how to form true opinions, we might reform our social institutions in ways that tend to induce people to find and speak the truth. Comparing the epistemic efficiency of alternative social institutions is "comparative institutional epistemics." At the margin it may be more effective to give people an interest in discovering the truth than to invoke the value of honesty or teach people the fallacies they should avoid. When we rely on experts such as forensic scientists to tell us the truth, it seems especially likely that institutional reforms will have a higher marginal value than exhortations to be good or rational. If virtue and rationality are scarce goods, we should design our epistemic institutions to economize on them.

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Note

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