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# Solomon's Knot: How Law Can End the Poverty of Nations

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# Truth-Revealing Mechanisms for Courts

by

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In trials witnesses often slant their testimony in order to advance their own interests. To obtain truthful testimony, the law relies on cross-examination under threat of prosecution for perjury. We show that perjury law is an imperfect truth-revealing mechanism. Moreover, we develop a truth-revealing mechanism for the same set of restrictions under which perjury rules operate. Under this mechanism the witness is sanctioned if a court eventually finds that the testimony was incorrect; the court need not determine that testimony was dishonest. We explain how truth-revealing mechanisms could combat distortions of observations by factual witnesses and exaggerations by experts, including "junk science." (JEL: D 82, K 41, K 42)

## *1 Introduction*

Witnesses often have a material interest in the court's judgment. The plaintiff and defendant, for example, are interested in the stakes in the dispute, and an expert has an interest in future employment as a witness.[1] In deciding legal disputes, courts must rely on observers to report facts and experts to provide opinions. The interest of the witness in the case provides an incentive to distort testimony. To obtain undistorted testimony, witnesses must face legal sanctions for distortions that offset the gain.

The law relies on cross-examination under the threat of prosecution for perjury to deter distorted testimony. Cross-examination probes the quality of testimony by the witness, searching for internal inconsistencies or contradictions with testimony

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[1] For the rapid growth of economists acting as expert witnesses see POSNER [1999a], THORNTON AND WARD [1999], MANDEL [1999], and SLOTTJE [1999]. This form of consulting is now designated "forensic economics." Several associations such as, e.g., the National Association of Forensic Economics (NAFE) as well as a couple of journals like, e.g., the *Journal of Forensic Economics* have emerged due to this boom in the demand for economists as experts.

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by other witnesses. In a criminal trial for perjury, the plaintiff must prove that the defendant lied or recklessly disregarded the truth.[2]

Establishing guilt or liability often requires more information than anyone can prove in court, so perjury trials or civil trials of false witnesses are rare. In practice, a skillful witness can slant testimony without fear of prosecution or liability. Moreover, as we show formally, even when all this information is available, perjury rules are not truth-revealing.

We apply the theory of mechanism design to the courtroom and derive a system of sanctions that is truth-revealing. To allow for a fair comparison, our sanctions work under the same set of restrictions under which perjury rules operate.[3] Their implementation replaces the fault-based perjury rule with a rule of strict liability; the witness pays a sanction for testimony that proves inaccurate, regardless of whether inaccuracy was the witness's fault. Replacing a fault-based rule with strict liability reduces the information needed by the plaintiff to impose the sanction. In principle, a rule of strict liability can deter distortions by factual witnesses and exaggerations by experts, including "junk science."[4]

To motivate our analysis, consider the following examples of testimony by witnesses to which our model applies:

*Example 1:* A suit between two motorists over an automobile accident turns on who was at fault. A pedestrian, who is neutral between the parties, observed the accident. The pedestrian testifies on the question, "Was the stoplight yellow or red?"

*Example 2:* A woman maintains a sexual liaison with a handsome poor man and an ugly rich man. When a child is born, the mother needs to establish the father's identity to win a paternity suit by testifying on the question, "Who is the child's father?"

*Example 3:* The defendant in an antitrust suit considers whether to argue that he lacks monopoly power or, alternatively, to concede that he has market power and argue that he did not use it to raise prices. The second argument undermines the first argument, so the defense attorney does not want to make both of them. The defense retains an expert to answer the questions, "Is the defendant a monopolist?" "If he is a monopolist, did he use his market power to raise prices?" The defense attorney's strategy depends on how the expert will answer these questions.

*Example 4:* The side-effects of a drug injures a consumer, who sues the pharmaceutical company in a civil law country. The judge appoints an expert to answer the

[2] For details on perjury law see COOTER AND EMONS [2000].

[3] These restrictions imply that the existence of a truth-revealing mechanism does not follow trivially from the revelation principle.

[4] Martha Nussbaum's testimony in *Romer v. Evans* seems to be an example of expert perjury. She seems to have misleadingly cited the long superseded 1897 edition of a Greek–English lexicon listing no pejorative connotation of the Greek word *tolmêma* whereas in the later 1940 edition, which she normally cites in her academic work, "shameless act" is included as a possible translation of *tolmêma*. See Lingua Franca, Sept/Oct. 1996, http://www.linguafranca.com/9609/stand.html.

question, "Was the drug defective?" The expert knows that the judge wants to end the trial quickly.

In Example 1, the pedestrian who witnesses the accident is neutral in the sense that the decision of the court does not affect her material interests. In Example 2, the mother testifying about her child's paternity has a direct material interest in the case. In Example 3, a party to the case pays an expert witness, as is the usual practice in the "adversarial" systems of the common law countries. By advancing the interests of the party retaining her, an expert witness increases her prospects for employment in subsequent cases. In Example 4, the court selects an expert witness, as is the usual practice in the "inquisitorial" systems of the civil law countries. The judge wants to end the trial quickly. By advancing the interests of the judge in Example 4, the expert witness increases her prospects of being hired by courts in subsequent cases.

All of our witnesses observe a fact that is relatively good or relatively bad for a party in the case. The witness is either certain or uncertain about the observation's accuracy. In terms of Example 1, the pedestrian may have observed that the stoplight was red, but she may be uncertain because the sun was bright. In terms of Example 2, the mother may believe confidently that the poor man is the father. In technical language, a witness receives a signal that is better or worse with high or low precision. When testifying in court, a witness reports on the signal's content (better/worse) and precision (high/low).[5] An *honest* witness reports truthfully about content, and a *dishonest* witness reports falsely about content. A *candid* witness reports accurately about precision, and a *misleading* witness reports inaccurately about precision. We use the phrase "slanted testimony" to mean testimony that is dishonest or misleading.

The court uses the available evidence, including the testimony of witnesses, to decide the case. After a witness testifies, subsequent events may prove that the testimony's content was right or wrong. To illustrate by Example 1, after the pedestrian testifies that the stoplight was red, someone may discover a photograph proving conclusively that the stoplight was yellow. In Example 2, the mother may testify that the rich man was the father and, after the trial, subsequent developments in biology may produce a proof that she was wrong. Note that evidence about the content does not prove unambiguously the quality of the testimony. Proof of the poor man being the father makes it only more likely that the mother did not tell the truth when testifying that the rich man fathered the child.

[5] In our set-up the witness can lie, i.e., report false information. There is a related literature comparing the adversarial (partisan) procedure of the Anglo–Saxon law in which partisan advocates present their cases to an impartial jury with the inquisitorial procedures of Roman–Germanic countries in which judges take an active role in investigating a case (DEWATRIPONT AND TIROLE [1999] and SHIN [1998]). In these papers a party can conceal information but *cannot* report false information. SHIN [1998] justifies the assumption of no false evidence (all reported information is verifiable) with the effectiveness of perjury rules. Our results on perjury rules tend to qualify this assumption.

Our model stylizes these facts. We assume that, after the witness testifies, the court subsequently learns with positive probability whether the testimony's content was wrong or right. The truth-revealing mechanism sanctions the witness whose testimony's content was inaccurate.

A *truth-revealing mechanism* induces honest and candid testimony in all circumstances.[6] Our mechanism has a straightforward interpretation. A witness may gain from dishonest or misleading testimony. Against this gain, the witness must balance the probability and magnitude of a sanction. A truth-revealing mechanism imposes an expected sanction greater or equal to the gain from slanted testimony.

As an illustration, consider the pharmaceutical expert Example 4. Assume her tests indicate that the drug has no defects, but she is uncertain. To promote her future business, the expert can help the judge by testifying falsely that she is certain. By doing so, however, the expert runs the risk that someone will subsequently present irrefutable proof that the drug is defective. With our truth-revealing mechanism, the expected sanction increases when the expert asserts her conclusion with certainty, and the increase exactly equals the gain to the expert from more future business.

The sanctions in the truth-revealing mechanism can be interpreted as bond forfeited by the witness in the event that evidence disconfirms her testimony.[7] Assume in Example 4 the witness reports that she is certain the drug has no defects, but the plaintiff suspects that the witness is actually uncertain. The plaintiff, consequently, challenges the witness to bond her testimony. To retain credibility, the witness has to post bond. In principle, the court or the attorneys in the case can compute the minimal sanction from the witness's gain and the probability of disconfirming evidence.

In Example 3, the testimony is more a matter of opinion than knowledge. The concept of "monopoly" is probably too imprecise for a decisive test of the expert's testimony. The truth-revealing mechanism only applies to propositions that risk disconfirmation. The cross-examining attorney must, therefore, formulate a question whose answer risks disconfirmation. For example, the cross-examining attorney might challenge the witness by asking, "Would you bond the proposition that 3 out of 4 industrial economists who examined the same evidence as you would agree with your conclusion? If not 3 out of 4, how about 2 out of 3, or 1 out of 2?" In this case, bonding serves the purpose of forcing the witness to acknowledge the extent to which her testimony is eccentric. The expert gives the court perspective on her

[6] Our aim throughout the paper is to reveal the truth. From a societal point of view there may be cases where lies are better than the truth, e.g., if somebody lies to protect a lady's honor, or if a government official lies about foreign policy event to protect ongoing dealings. In FLUET [2003] a court maximizes the *ex ante* surplus from a contractual relationship by not seeking the truth *ex post*. See POSNER [1999b] for a comprehensive economic analysis of the law of evidence with efficiency being the ultimate aim.

[7] See COOTER AND EMONS [2000] for an elaborate discussion on how truth-bonding might work in practice.

testimony by acknowledging the extent to which other scientists disagree with her. An expert remains free to defend her own opinions, regardless of their eccentricity.

Let us now turn to a limitation of our truth-revealing mechanism. In all of our examples, for given precision, the witness benefits more from testifying that she observed "better" rather than "worse."[8] Given the content, she also benefits more from testifying that she is "certain" rather than "uncertain." Accordingly, payoffs increase whenever the report's content and certainty improve. This is analogous to a portfolio of stocks becoming more valuable whenever the mean increases and/or the variance decreases.

In Example 1 the defendant gains most if the witness testifies with certainty that the stoplight was red; the second-best testimony is with certainty that the stoplight was yellow. If the witness is uncertain, the court attaches a higher probability to a green stoplight which is bad for the defendant. In Example 2 the mother gains most from testifying with certainty that the rich man is the father. Next, she gains from testifying with certainty that the poor man is the father. Her prospects for winning in court are worse when she cannot testify with certainty about the father's identity.

Example 3 also fits this pattern of reasoning. The defendant's expert benefits the defense most by asserting that the defendant is not a monopolist. Next, the expert benefits the defense by asserting that the defendant is a monopolist who did not raise prices. Given the defendant's strategy, the expert benefits the defense least by asserting that she is uncertain whether the defendant is a monopolist. This pattern of benefits, which fits the conception of the defense in *Texaco v. Pennzoil*,[9] applies whenever the defendant prefers to take a stand on only one issue.

Our mechanism no longer works in scenarios where the witness benefits from being uncertain rather than certain. Change Example 3 such that the defense wants to argue that the defendant is not a monopolist and did not raise prices. An expert advances this defense more by testifying that the defendant probably has monopoly power but she is uncertain about it, rather than testifying that the defendant certainly has monopoly power. This pattern of payoffs violates a monotonicity requirement necessary for the existence of a truth-revealing mechanism that sanctions only wrong testimony. Without monotonicity, more possibilities to sanction are necessary to induce truth-telling. We sketch such a mechanism, which also sanctions right testimony.[10]

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[8] For purposes of our analysis, the opposite is also acceptable, because "better" and "worse" are arbitrary.

[9] Texaco's lawyer refused to offer expert testimony on damages on the theory that doing so would undermine the confidence of the court that Texaco was not a fault. This proved a disastrous mistake because Pennzoil claimed damages equal to the sale value of the oil field, rather than the expected profits that the oil field would yield. See, e.g., PETZINGER [1999].

[10] In EMONS [2001] we explore this problem further. Here we have the additional problem that the defendant will not present a witness making unfavorable testimony in the first place. We have a trade-off quality versus quantity of testimony. We show that truth-revealing mechanisms produce little testimony of high quality; perjury produces

Finally, we use our model to analyze the fault-based perjury rule. Under the perjury rule if the testimony's content was wrong, the court must use this information to compute the probability that the witness was dishonest. If this probability exceeds the legal standard, the court imposes the sanction for perjury. As we show formally, these Bayesian inferences are difficult because they require much information. This fact provides one reason why perjury prosecutions are so rare.

Next we show that under perjury law a neutral witness will never report a high precision signal. Since a court is more likely to find perjury when testimony was given with certainty rather than uncertainty, a neutral witness minimizes the probability of being sanctioned for perjury by understating her certainty.

Finally, since a simple perjury rule does not adjust the sanction to the probability of detecting and prosecuting the perjury, it lacks the sophistication necessary to induce truthful testimony. Because of these limitations, a perjury rule is an imperfect truth-revealing mechanism.

The remainder of the paper is organized as follows. In the next section we describe our basic framework. In Section 3 we analyze the witness's incentives. In Section 4 we derive the truth-revealing mechanism. In Section 5 we discuss the perjury rule. The last section concludes. Proofs are relegated to the Appendix.

## 2 *The Model*

A court's decision in a case depends on the outcome of a random event. This random variable $\tilde{X}$ can take the two realizations $X = A$ and $X = B$. To illustrate, a drug may have two side-effects, one ($B$) somewhat worse than the other ($A$). Or $B$ might mean, "the defendant is a monopolist but did not raise prices" and $A$ might mean, "the defendant is not a monopolist." The court has some information about the likelihood of the two events which we denote by $\text{Prob}(X = B) := \text{Prob}(B)$ and $\text{Prob}(X = A) := \text{Prob}(A) = 1 - \text{Prob}(B)$.[11]

A party to the dispute (we will take the defendant in what follows) can base his defense on either $A$ or $B$. His case is somewhat stronger for $A$ than for $B$. A good defense for $A$ is, however, a pretty bad one for $B$ and vice versa. The defendant is, therefore, interested in obtaining as much information as possible about which state of the world will materialize. If the two states are equally likely, he prefers, of course, $A$.

A witness observes a fact with an attached probability, which we call a signal, that is relevant to the court's decision.[12] To illustrate, the witness observes a medical fact and infers a definite probability about the occurrence of the side-effects. Or the

a different amount of testimony with lower informational content. From an *ex ante* perspective all parties prefer truth-revealing mechanisms.

[11] If the court has no further information and thus no reason to discriminate between the events, by LaPlace's Principle of Insufficient Reason $\text{Prob}(B) = \text{Prob}(A) = 1/2$.

[12] As in SHIN [1998] we treat the information collection process as exogenous in order to focus on the incentives to disclose the evidence. In DEWATRIPONT AND TIROLE [1999] information gathering is costly; their focus is on the incentive to gather information.

witness runs some econometric tests and infers a definite probability of a monopoly. In notation, the witness has observed a signal $(Y, P)$, $Y \in \{A, B\}$, $P \in \{L, H\}$, meaning that the state of the world $Y$ will occur with probability $P$. The signal $(B, H)$, for example, means that the state $B$ will occur with probability $H$, which of course implies that the state $A$ occurs with probability $(1 - H)$. Similarly, the signal $(A, L)$ means that the state $A$ occurs with probability $L$, etc.

First of all we assume that all four signals reduce uncertainty; furthermore, it is convenient to define $H$ and $L$ so that one is more precise than the other in the sense of conveying more information, or formally, $1 > H > L > \max[\text{Prob}(B); \text{Prob}(A)] \geq 1/2$. By this condition, a signal $(B, L)$ or $(A, L)$ is *low precision*, and a signal $(B, H)$ or $(A, H)$ is *high precision*.

We do not further model how the court reaches its decision. All we assume is that the court is more likely decide in favor of the defendant for high rather than low precision, and for $A$ rather than $B$ signals. Therefore, the defendant prefers $(A, H)$ to $(B, H)$ to $(A, L)$ to $(B, L)$ to no signal at all.[13]

We can formalize the defendant's desire for precision by defining the indicator variable $U(A) = 1$ and $U(B) = 0$. The defendant's utility function is then given as

$$\begin{aligned} V &= E(U(\tilde{X}) \mid \textit{testimony}) - \alpha \text{Var}(U(\tilde{X}) \mid \textit{testimony}) \\ &= \text{Prob}(A \mid \textit{testimony}) - \alpha \text{Prob}(A \mid \textit{testimony}) \text{Prob}(B \mid \textit{testimony}), \end{aligned}$$

where $E$ stands for the expected value, Var for the variance of the indicator variable, $\text{Prob}(X \mid \textit{testimony})$ for the probability the court attaches to state $X$, $X = A, B$, given the testimony, and $\alpha$ measures the (dis-)taste of the associated risk. We assume $\alpha$ to be "sufficiently large," or formally, $\alpha > (L - (1 - H))/(L(1 - L) - H(1 - H))$. If $\alpha$ satisfies this condition, the defendant prefers $(A, H)$ to $(B, H)$ to $(A, L)$ to $(B, L)$ to no signal at all.

As an example consider tossing two dice. The state $A$ corresponds to the sum of the two dice exceeding 7, while $B$ occurs when the sum is 7 or less. Accordingly, $\text{Prob}(A) = 5/12$ and $\text{Prob}(B) = 7/12$. After the two dice are rolled, the witness observes something about the number on one of them. The witness observes either one of the two *high precision signals* {5,6} and {1,2,3,4}. The information that the first die is either 5 or 6 translates into the signal that the good state occurs with probability 3/4, i.e., $(A, 3/4)$ and the information that the first die is less than 5 corresponds to the signal $(B, 3/4)$. Alternatively, the witness observes one of the *two low precision signals* {4,5,6} corresponding to $(A, 2/3)$ and {1,2,3,4,5} corresponding to $(B, 2/3)$.

The witness testifies in court on her private information. She announces a state of the world and the probability with which this state will occur.[14] To avoid confusion,

[13] Our analysis carries over to the case where the defendant's preferences are $(A, H) \succ (A, L) \succ (B, H) \succ (B, L)$. In Proposition 4 we show that truth-revelation is impossible if we sanction only wrong testimony when monotonicity in the precision is violated.

[14] We thus confine our attention to direct revelation mechanisms. The revelation principle (see, e.g., MYERSON [1985]) tells us that in Bayesian decision problems without

we use small letters (rather than formally correct capital letters) for her reported values. Formally, the witness announces $(y, p)$, $y \in \{a, b\}$ and $p \in \{l, h\}$. We will use the following semantics: If $y = Y$, testimony is *honest;* otherwise, testimony is *dishonest*. If $p = P$, testimony is *candid*; otherwise, testimony is *misleading*. Our aim is, quite naturally, to get an honest and candid testimony.

Depending on her reported values, the witness receives a remuneration (wage) $w(y, p) \geq 0$ from a third party. Taking future consequences into account, remuneration is higher when the testimony is more favorable to the party for whom the testimony is given. We view testimony from the viewpoint of the defendant, who prefers high $(h)$ to low $(l)$ precision signals and better $(a)$ to worse $(b)$ news. Consequently, $w(a, h) \geq w(b, h) \geq w(a, l) \geq w(b, l)$.

The wage depends upon the legal and contractual status of the witness. An *interested witness* receives a wage for testimony that increases with the strength of her testimony. Formally, for an interested witness all three of the above wage inequalities are strict. Typically, an interested witness is a party to the suit or an expert paid by a party to the suit. Under U.S. rules, expert witnesses are interested. A *neutral witness* receives a constant wage for testifying, meaning that the equality holds in all of the above weak inequalities. If this constant wage is zero, we will call the witness *disinterested*. Under European rules, expert witnesses are more often neutral. Under European and American rules, witnesses to the facts are typically unpaid for testimony, so they are neutral unless connected to the plaintiff or defendant.[15]

After the witness has testified, further developments in the trial may reflect upon the accuracy of the witness's testimony. We stylize this fact by assuming that the court observes the true state of the world after the trial's end.[16] We will say the testimony is *right* if $X = y$; otherwise, the testimony is *wrong*. Conditional on the relationship between the testimony and the court's observation, the witness can be rewarded or sanctioned. Formally, we denote a sanction/reward by $S(X, y, p)$, where $S > 0$ is a sanction and $S < 0$ a reward. We want to derive mechanisms working under the same set of restrictions as the perjury rule.

loss of generality one can restrict attention to direct mechanisms under which agents report truthfully. In such a Bayesian decision problem players' utilities depend on the state of the world and any decision made by other players. In contrast, in our set-up wages depend on direct reports and we impose further restrictions the mechanism has to satisfy. Accordingly, truth-revelation does not automatically follow from the revelation principle.

[15] Note that we do not further analyze the relationship between the defendant and the witness. We have specified the defendant's preferences only to motivate the witness's wage schedule.

[16] MILLER [2001] uses the same timing of events as we do; he shows that perjury rules should give greater weight to information that surfaced after the witness testified. Since our witness is risk neutral, it is straightforward to extend the analysis to the case in which the court observes the true state only with a probability $\gamma < 1$. Then all the sanctions in the truth-revealing mechanism have to be multiplied by $1/\gamma$; this assumes of course that the witness has sufficient wealth. Note that we could work with any imperfect signal of the witness's observation $(Y, P)$. To save on notation we have chosen the true state of the world.

Therefore, we set the sanction equal to zero whenever the testimony is right, i.e., $S(B, b, l) = S(A, a, l) = S(B, b, h) = S(A, a, h) = 0$.

The witness's expected payoff equals her wage minus the expected sanction. Formally, the payoff is given as $w(y, p) - E(S(\tilde{X}, y, p)|Y, P)$, where $E(S(\tilde{X}, y, p)|Y, P)$ stands for the expected sanction given her reported testimony $(y, p)$ and the true information $(Y, P)$. She chooses her reported testimony $(y, p)$ so as to maximize her expected payoff.

## 3 The Incentive Constraints

We want to derive a system of sanctions that induces the witness to be honest and candid. We call such a mechanism *truth-revealing*. This means that reporting the true signal must generate at least as much payoff as announcing any other signal. Formally, this requirement means

$$w(Y, P) - E(S(\tilde{X}, Y, P)|Y, P) \geq w(y, p) - E(S(\tilde{X}, y, p)|Y, P)$$
$$\forall (y, p) \in \{b, a\} \times \{l, h\}, \forall (Y, P) \in \{B, A\} \times \{L, H\}.$$

Consider, for example, the case in which the true signal is $(Y, P) = (B, L)$. Here one of our tasks is to guarantee that announcing $(y, p) = (b, l)$ is at least as good as reporting $(a, l)$. Formally, this means $w(b, l) - (1 - L)S(A, b, l) \geq w(a, l) - LS(B, a, l)$.[17] If the witness tells the truth, she receives the wage $w(b, l)$. With probability $(1 - L)$ the state $A$ materializes and the witness has to pay the sanction $S(A, b, l)$. If, in contrast, she reports $(a, l)$, she receives the (higher) wage $w(a, l)$. Now the sanction is $S(B, a, l)$, triggered by the state $B$ which occurs with the (high) probability $L$ if $(B, L)$ is the true signal. Similarly, if the true state is $(Y, P) = (B, L)$, we must guarantee that the message $(y, p) = (b, l)$ is at least as good as the reports $(b, h)$ and $(a, h)$.

Analogous incentive constraints hold for the other 3 signals so that overall we end up with 12 incentive constraints. After some algebraic manipulation and rearranging we get the following 6 chains of weak inequalities.

(1) $$(1 - L)S(B, a, h) - (1 - L)S(B, a, l) \geq$$
$$w(a, h) - w(a, l) \geq (1 - H)S(B, a, h) - (1 - H)S(B, a, l),$$

(2) $$(1 - L)S(A, b, h) - (1 - L)S(A, b, l) \geq$$
$$w(b, h) - w(b, l) \geq (1 - H)S(A, b, h) - (1 - H)S(A, b, l),$$

(3) $$LS(B, a, l) - (1 - L)S(A, b, l) \geq$$
$$w(a, l) - w(b, l) \geq (1 - L)S(B, a, l) - LS(A, b, l),$$

(4) $$HS(B, a, h) - (1 - H)S(A, b, h) \geq$$
$$w(a, h) - w(b, h) \geq (1 - H)S(B, a, h) - HS(A, b, h),$$

[17] Recall that we set the sanction to zero whenever the testimony is right, so $S(B, b\, l) = S(A, a, l) = 0$.

$$(5) \qquad LS(B,a,h) - (1-L)S(A,b,l) \geq w(a,h) - w(b,l) \geq (1-H)S(B,a,h) - HS(A,b,l),$$

$$(6) \qquad LS(A,b,h) - (1-L)S(B,a,l) \geq w(b,h) - w(a,l) \geq (1-H)S(A,b,h) - HS(B,a,l),$$

call the first inequality in such a chain (a) and the second one (b).

Before deriving the truth-revealing mechanism in detail, we can already state a preliminary result, namely that truth-revealing mechanisms differ for interested and neutral witnesses. For a neutral witness, sanctions must be constant, whereas for an interested witness the sanctions increase with the strength of the testimony.

*Proposition 1:* Truth-revealing sanctions for interested witnesses satisfy $S(A,b,l) < S(A,b,h)$ and $S(B,a,l) < S(B,a,h)$. If the witness is neutral, $S(A,b,l) = S(A,b,h) = S(B,a,l) = S(B,a,h)$.

The intuition for this result is straightforward. An interested witness's wage increases with the strength of the testimony, being maximal for the reported value $(a,h)$. If the sanctions were, say, constant, an interested witness would always report $(a,h)$. To compensate for the increasing wage schedule, sanctions must increase with the strength of the testimony. Conversely, if the witness is neutral, the wage schedule provides no incentives not to tell the truth. In order not to distort the wage schedule's proper incentives, the sanctions must be neutral too.

## *4 The Truth-Revealing Mechanism*

Let us now determine our truth-revealing mechanism. We focus on mechanisms employing minimal sanctions and no rewards. This means first that, given no rewards, we set as many sanctions as possible to zero; second, we set those sanctions, which need to be positive, to the minimal values still providing proper incentives. Formally, we look for the mechanism $S^*(\cdot)$ satisfying $S^*(X,y,p) \geq 0\ \forall(X,y,p)$ and for any other truth-revealing sanctions using no rewards $S'(\cdot)$ it is true that $S^*(X,y,p) \leq S'(X,y,p)\forall(X,y,p)$. We make the sanctions as low as possible in order to minimize the monetary strain on the witness. See also the following discussion on individual rationality in Proposition 3. The reasons why we do not work with rewards are as follows. First, we want to keep the cost of the judicial system low and rewards are costly. A second problem arises if rewards become so high that before having observed the signal the witness knows she will receive an expected reward. Then frivolous witnesses without any knowledge of the case may try to be called upon simply to cash in on the expected reward. Third, we want to compare our truth-revealing mechanism with the perjury rule which does not use rewards either.[18]

[18] See EMONS AND SOBEL [1991] for a more elaborate discussion of the problems generated by expected rewards.

*Proposition 2:* The truth-revealing mechanism using minimal sanctions and no rewards is given by

$$S^*(X, y, p) = \begin{cases} (w(a,h) - w(a,l))/(1-L) + \\ \qquad (w(a,l) - w(b,l))/L, & \text{if } X = B,\ y = a,\ p = h; \\ (w(b,h) - w(b,l))/(1-L), & \text{if } X = A,\ y = b,\ p = h; \\ (w(a,l) - w(b,l))/L, & \text{if } X = B,\ y = a,\ p = l; \\ 0, & \text{otherwise.} \end{cases}$$

The truth-revealing mechanism obviously reflects Proposition 1. If the witness is neutral, all sanctions are zero. If the witness is interested, sanctions increase with the strength of the testimony.

The sanctions are constructed as follows. When the witness works out, for instance, whether to report the true weak or a false strong signal, she compares the increase in the wage with the increase in the expected sanction. Accordingly, all we have to do is to ensure that the increase in the expected sanction is at least as great as the increase in the wage. This task is somewhat tedious due to the stochastic nature of our problem; sanctions appear in several incentive constraints at the same time. This generates several lower bounds for certain sanctions, and of these we have to take the maximum. With this type of construction, for a certain deviation the witness is just indifferent while for other deviations the incentives are strict. Finally, we have to check that we did not overdo it, i.e., set the sanctions so high that they distort the witness' incentives elsewhere.

After all this technical parlance it seems a good idea to illustrate the truth-revealing mechanism using the dice example. Recall that $L = 2/3$ and $H = 3/4$. Let $w(b, l) = 0$, $w(a, l) = 6$, $w(b, h) = 8$, and $w(a, h) = 10$. Then $S(A, b, l) = 0$, $S(A, b, h) = 24$, $S(B, a, l) = 9$, and $S(B, a, h) = 21$.

If the witness has observed, for example, $(A, L)$, expected sanctions for the possible reports are given by Table 1. Given the true report $(a, l)$, the "marginal" expected sanctions are greater or equal the "marginal" wages, making any deviation from reporting the true signal unattractive.

Here the surprising feature is that the highest sanction is imposed when the witness has reported $(b, h)$ and $A$ materializes. This result follows immediately from (2a). Reporting $(b, h)$ rather than $(b, l)$ increases the wage by a steep 8. This increase has

*Table 1*
Truth-Revealing Mechanism for the Signal $(A, L)$

| Report | $(a, h)$ | $(b, h)$ | $(a, l)$ | $(b, l)$ |
|---|---|---|---|---|
| Wage to witness | 10 | 8 | 6 | 0 |
| Expected sanction given the signal $(A, L)$ | 7 | 16 | 3 | 0 |
| Net payoff | 3 | −8 | 3 | 0 |

to be compensated by $S(A, b, h)$ which is imposed only with the (low) probability $(1 - L) = 1/3$. We have chosen the example deliberately such that the monotonicity of the wage scheme is not entirely reflected in the sanctions; note that we are talking now about actual rather than expected sanctions. Wages are monotone increasing in the strength of the testimony, but sanctions are not. The highest sanction is imposed for the second highest testimony. Note that such non-monotone incentive schemes are the rule rather than the exception. In the principal–agent problem, for example, the agent's remuneration is typically not monotone in the outcome. See, e.g., GROSSMAN AND HART [1983].[19]

Another unpleasant feature of truth-revealing mechanisms is that agents often do worse if they participate in the mechanism than if they do not participate. In mechanism design jargon, participation in an incentive scheme with this feature is not *individually rational*. Agents do better if they stay out of the incentive scheme than if they take part: they must be forced to participate.[20] Translated into our problem, (interim) individual rationality requires that the witness's expected payoff is non-negative whatever signal she received.[21] To put it differently, expected sanctions may not exceed the wage, or formally

$$w(Y, P) - E(S(\tilde{X}, Y, P)|Y, P) \geq 0 \quad \forall (Y, P) \in \{B, A\} \times \{L, H\}.$$

Fortunately, our mechanism is well behaved.

*Proposition 3:* The mechanism $S^*(X, y, p)$ defined in Proposition 2 is individually rational.

This result, which follows more or less immediately from our construction has the implication that the witness, whatever signal she receives, need not be forced to testify in court.[22] She will do so voluntarily because her expected payoff from doing so is non-negative. *Ex post*, however, when the testimony has actually turned out to be wrong and the witness is sanctioned, she may end up with a negative payoff as can be seen by our example. We may, therefore, conclude that from an interim point of view it is individually rational to testify in court although *ex post* the witness may regret to have done so.

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[19] $S(A, b, h) > S(B, a, l) > S(A, b, l)$ holds for interested witnesses under our assumptions. $S(B, a, h) > S(A, b, h)$ holds, however, iff $w(a, h) - w(a, l)(2L - 1)/L > w(b, h) - w(b, l)(2L - 1)/L$. This condition is satisfied if either the wage increase for announcing high precision is higher for $a$ than for $b$, or if $L$ is sufficiently close to $1/2$.

[20] See, e.g., EMONS [1994] for a detailed discussion of individual rationality.

[21] Recall that under our rule the witness reports truthfully all signals. See HOLMSTRÖM AND MYERSON [1983] for a definition of the *ex ante*, *interim*, and *ex post* concepts.

[22] For a neutral, disinterested witness all truth-revealing sanctions are zero so that individual rationality is trivially satisfied.

Let us conclude this section by showing that truth-revelation is impossible when the wage is decreasing in the precision so that, e.g., $w(b, l) > w(b, h)$, meaning the defendant prefers bad news with low rather than with high precision.

*Proposition 4:* If $w(b, l) > w(b, h)$ and/or $w(a, l) > w(a, h)$, no truth-revealing mechanism with $S(X, y, p) \geq 0$ if $X \neq y$ and $S(X, y, p) = 0$ if $X = y$ exists.

If the wage increases when the reported precision decreases, the probability that triggers the sanction if the witness is misleading decreases with the wage. But then it is impossible that the expected sanction increases with the wage as is necessary for truth-telling.

The non-existence problem arises because we sanction the witness if and only if testimony is wrong. The probability of a wrong testimony is lower for the high than for the low precision signal. To provide proper incentives, however, the expected sanction for wrong testimony must be higher for the high rather than the low precision signal.

The non-existence phenomenon disappears if we also allow the witness to be sanctioned when the testimony is right, i.e., if we let $S(X, y, p) > 0$ for $X = y$. This can be seen by the following extension of our mechanism. Consider the case where $w(a, h) \geq w(a, l) \geq w(b, l) > w(b, h)$. We introduce sanctions $\sigma(y, p)$ which are levied in addition to $S(X, y, p)$. We charge the witness $\sigma(y, p)$ simply for reporting $(y, p)$, independently of whether this report turns out to be right or wrong. Let $\sigma(a, h) = \sigma(a, l) = \sigma(b, h) = 0$ and $\sigma(b, l) = w(b, l) - w(b, h)$. Then the witness's wage net of $\sigma$, $W := w - \sigma$, satisfies $W(a, h) \geq W(a, l) \geq W(b, h) = W(b, l)$. Construct $S^*(X, y, p)$ as in Proposition 2, using $W$ rather than $w$. Obviously, the extended mechanism $(\sigma(\cdot); S^*(\cdot))$ is truth-revealing.[23]

If we sanction the witness only for wrong testimony, we do not have enough leverage to induce the report $(b, h)$ rather than $(b, l)$. Letting the witness pay $\sigma(b, l) > 0$ gives us this leverage (alternatively, we can also reward the witness with $\sigma(b, h) < 0$). We plan to explore this case further in a subsequent paper.

## 5 *The Perjury Rule*

Let us now compare our truth-revealing mechanism $S^*$ with the perjury rule. We start with a straightforward formalization of the perjury rule.[24] As in our mechanism under a perjury rule the sanction is zero whenever the testimony is right. If, however, the testimony is wrong, the court uses this information to compute the probability $\phi$

[23] Even more to the point is the mechanism $\sigma(y, p) = w(y, p)\ \forall(y, p)$ and no further sanctions for wrong testimony. Under this mechanism the witness's payoff equals zero for all reports.

[24] We model a Bayesian court's decision process. There are also indications that a trial court process of fact finding and aggregation is not purely Bayesian but is constrained by rules of evidence and procedure; see, e.g., POSNER [1999b]. Therefore, DAUGHETY AND REINGANUM [2000a], [2000b] use axiomatic methods to model information and decisions in court.

that the witness did not tell the truth. If this probability exceeds a legal standard $\overline{\phi}$, the court imposes a sanction $s > 0$; if the probability $\phi$ is below the legal standard, the sanction is zero.[25] Formally,

$$S_p(X, y, p) = \begin{cases} s, & \text{if } \phi(X, y, p) \geq \overline{\phi}; \\ 0, & \text{otherwise.} \end{cases}$$

Computing the probability $\phi$ of not having reported, the truth turns out to be tricky. First, the court has to know the probabilities $\text{Prob}(B)$ and $\text{Prob}(A)$ with which the two states of nature occur. Note that we did not use this piece of information for our mechanism $S^*$. Moreover, the court needs to know the probability distribution over the signals $(Y, P)$ which we denote by $\text{Prob}((Y, P))$.[26] To have some structure, let us make the reasonable assumption that low precision signals are at least as likely as the high precision signals, i.e., $\text{Prob}((B, H)) \leq \text{Prob}((B, L))$ and $\text{Prob}((A, H)) \leq \text{Prob}((A, L))$. Note once again that for our mechanism $S^*$ we did not use the probability distribution $\text{Prob}((Y, P))$.

If the witness has reported, say, $(a, h)$ and nature has chosen $B$, the probability of not having told the truth is[27]

$$\begin{aligned} \phi(B, a, h) &= 1 - \text{Prob}((A, H)|B) = 1 - \frac{\text{Prob}(B \cap (A, H))}{\text{Prob}(B)} \\ &= 1 - \frac{\text{Prob}(B|(A, H))\,\text{Prob}((A, H))}{\text{Prob}(B)} = 1 - \frac{(1 - H)\,\text{Prob}((A, H))}{\text{Prob}(B)}. \end{aligned}$$

The probability that $(a, h)$ was not the true signal given $B$ equals the sum of the probabilities that the witness has observed $(a, l)$, $(b, l)$, and $(b, h)$ given $B$ which in turn equals 1 minus the probability that $(a, h)$ was the true signal given $B$. Analogously, we compute

$$\phi(B, a, l) = 1 - \frac{(1 - L)\,\text{Prob}((A, L))}{\text{Prob}(B)}, \quad \phi(A, b, h) = 1 - \frac{(1 - H)\,\text{Prob}((B, H))}{\text{Prob}(A)},$$
$$\text{and} \quad \phi(A, b, l) = 1 - \frac{(1 - L)\,\text{Prob}((B, L))}{\text{Prob}(A)}.$$

Let us illustrate these probabilities by means of our dice example. Before the dice are tossed, nature chooses with equal probability 1/2 whether the witness will observe high or low precision signals. If she is to observe a low precision signal and the outcome of the first toss is 4 or 5, she receives the signal $(A, L)$ and $(B, L)$ with equal probability 1/2. With this signal generating process we have $\text{Prob}((A, H)) = \text{Prob}((A, L)) = 1/6$ and $\text{Prob}((B, H)) = \text{Prob}((B, L)) = 1/3$.

[25] For $\overline{\phi} \in (0, 1)$ the perjury rule, essentially, works like a negligence rule with a "due care standard" $\overline{\phi}$. If $\overline{\phi} = 0$, the perjury rule functions like a rule of strict liability and if $\overline{\phi} = 1$ like a rule of no liability.

[26] This probability distribution depends of course on the stochastic process generating the outcomes $A$ and $B$. For an application see the following discussion of our dice example.

[27] A more precise yet more cumbersome notation for $\phi(B, a, h)$ would be $\phi(\neg(a, h)|B)$.

We then compute $\phi(B, a, h) = 13/14$, $\phi(B, a, l) = 19/21$, $\phi(A, b, h) = 4/5$, and $\phi(A, b, l) = 11/15$.

Given these four probabilities of not having told the truth, we may now state the result that a neutral witness's testimony is misleading under the perjury rule when she has observed a high precision signal.

*Proposition 5:* Under the perjury rule for a neutral witness the low precision signal weakly dominates the corresponding high precision signal.

This result is easily explained. Suppose the witness has observed the signal $(A, H)$ and she compares the honest and candid message $(a, h)$ with the honest but misleading message $(a, l)$. The probability that the testimony is wrong – the outcome which may trigger the perjury rule's sanction – is the same for both messages. Nevertheless, the probability of not having told the truth is higher for $(a, h)$ than for $(a, l)$, i.e., $\phi(B, a, h) > \phi(B, a, l)$. Consequently, the expected sanction for $(a, h)$ is at least as great as for $(a, l)$ and reporting $(a, l)$ weakly dominates $(a, h)$: If $\phi(B, a, h) < \overline{\phi}$ $[\overline{\phi} < \phi(B, a, l)]$ so that the witness is never [always] sanctioned, misleading does not hurt. If, in contrast, $\phi(B, a, l) < \overline{\phi} < \phi(B, a, h)$, being disingenuous is strictly better than being candid.[28]

Given that a neutral witness is misleading for high precision signals, the next natural question to ask is: under what conditions is her testimony under a perjury rule at least honest? Here we have the following straightforward result.

*Proposition 6:* If $\max[\phi(A, b, l), \phi(B, a, l)] < \overline{\phi}$ or $\min[\phi(A, b, l), \phi(B, a, l)] \geq \overline{\phi}$, the neutral witness' testimony is honest.

From Proposition 5 we know that the witness always reports a low precision signal. If the probabilities of untruthful testimony are below the legal standard for both relevant messages $(b, l)$ and $(a, l)$, the witness is never sanctioned and, accordingly, indifferent between the two messages. Therefore, her report is honest (though not necessarily candid). If both probabilities of being untruthful are above the legal standard, for both messages the witness is sanctioned by the amount $s$ whenever the testimony is wrong. If the victim reports honestly, the probability of being wrong ($1 - H$ resp. $1 - L$), is lower than for an dishonest report ($H$ resp. $L$).

Let us finally analyze the incentives a perjury rule gives an interested witness. As can be expected, the result is negative.

*Proposition 7:* If the witness is interested, a perjury rule is never truth-revealing.

Incentive compatibility requires for an interested witness that the sanctions increase with the strength of the testimony. To compensate for the increasing wage, the increase in the sanctions has to take on more values than the perjury rule does where

[28] See, e.g., KREPS [1990, pp. 418–421], for a discussion of the pro and cons of the concept of weak dominance. Proposition 5 is not true if, say, $\phi(B, a, h) < \phi(B, a, l)$ which, in turn, holds if $(1 - H)P(A, H) > (1 - L)P(A, L)$; high precision signals must be much more likely than low precision signals.

the sanction is either 0 or $s$. To put it differently: the binary perjury rule lacks the sophistication to give an interested witness proper incentives.

Let us discuss the informational requirements of our sanction system $S^*$ and the perjury rule $S_p$. Our mechanism focuses essentially on the witness's wage schedule and uses this information to derive the incentive compatible sanctions. The perjury rule, in contrast, focuses on the stochastic processes generating the signals and the final outcomes to determine the probability that the witness did not tell the truth. Accordingly, both mechanisms use different pieces of information.

Being a crime, one element for perjury is the intention to do wrong (*mens rea*, guilty mind) which we have not considered so far in our rule. Here we may argue that a personal gain from lying is a necessary condition for intent. A neutral witness gains nothing from lying. Accordingly, a neutral witness should not be prosecuted for perjury. Only when the witness is interested, the perjury rule $S_p$ is triggered. If we interpret perjury in this way, sanctions for a neutral witness are zero (as in our mechanism) and the incentive of a neutral witness to understate precision diminishes.[29] Note that with this interpretation of perjury the court uses the wage function to determine whether the perjury process is triggered.

We have looked at a simple, binary perjury rule. If we allowed for sophisticated perjury rules where the sanction varies with the probability of its application and the gain from wrongdoing, then we could also elicit the truth with a perjury rule. Notice, however, that the perjury rule then uses information about wages in much the same way as we do and in addition the perjury rule needs all the information about the stochastic processes. Actual perjury rules resemble simple rules more than sophisticated rules; see COOTER AND EMONS [2000].

## 6 *Conclusions*

Economists have devoted much effort to developing truth-revealing mechanisms, but only few of these developments have been applied to courts. SANCHIRICO [2000], [2001] investigates the role of evidence production in the regulation of private behavior via judicial and administrative process. BERNARDO, TALLEY, AND WELCH [2000] analyze how legal presumptions can mediate between costly litigation and *ex ante* incentives. DEWATRIPONT AND TIROLE [1999] and SHIN [1998] compare the adversarial with inquisitorial procedures in arbitration. DAUGHETY AND REINGANUM [2000a] model the adversarial provision of evidence as a game in which two parties engage in strategic sequential search. DAUGHETY AND REINGANUM [2000b] use axiomatic and Bayesian methods to model information and decisions in a hierarchical judicial system; axioms represent constraints that rules of evidence impose at the trial. MILLER [2001] shows that when the court has information when the witness testifies and information that surfaces after testimony, perjury rules should give greater weight to the latter. All of these papers are of different focus than ours.

[29] In practice the probability of prosecuting a neutral witness for perjury is close to zero; see COOTER AND EMONS [2000].

We have shown for a simple framework that existing legal practices create incentives for witnesses to give slanted or false testimony. More importantly, we have developed a mechanism that prevents slanted or false testimony.

A few qualifications are in order. First, we have looked at the incentive problem of preventing slanted testimony. We have not looked at other incentive problems, such as withholding unfavorable information.[30] Second, we did not analyze the witness's effort to gather information. The more effort a witness provides, the more precise her signal, say. If effort were observable, the court could use this information to infer the quality of the testimony. Third, we assume that the process generating the evidence confirming or disconfirming the testimony is exogenous.[31] We do not model how this evidence comes into existence and how it is brought to the attention of the court. In the inquisitorial system the court or the party against the witness has testified may create the new evidence; in the adversarial system only the latter will have an incentive to search for new evidence. Note, however, that the perjury rule also needs new evidence to be triggered. Comparing our mechanism with perjury given that new evidence pops up thus seems to be fair. Fourth, in considering implementation of truth-revelation by truth-bonds, we have not investigated the extent a market would tend to bond at the optimal level. The answer to this question determines the extent and type of regulation required in a market for truth-bonds. Fifth, POSNER [1999a] argues that reputation plays a major role in disciplining experts. Given the current discussion we have some doubts that reputation is effective; moreover, reputation does not discipline occasional witnesses. Nevertheless, it might be interesting to incorporate reputation into the analysis. These questions present interesting tasks for future research.

Many obstacles impede institutionalizing our mechanism, but a move to strict liability has the promise of significantly improving the quality of testimony in court.

## *Appendix*

### *A.1 Proof of Proposition 1*

(1a) and (2a) imply increasing sanctions for interested witnesses; constant sanctions for neutral witnesses follow from (1b) and (2b). *Q.E.D.*

### *A.2 Proof of Proposition 2*

We use the first inequalities (1a)–(6a) to determine the smallest incentive compatible sanctions. Following Proposition 1, $S(A, b, l)$ and $S(B, a, l)$ are candidates to be set to zero. Yet, if we set $S(B, a, l) = 0$ and the witness is interested, (3a) implies $S(A, b, l) < 0$. Accordingly, we set $S^*(A, b, l) = 0$. (3a) then implies $S^*(B, a, l) = (w(a, l) - w(b, l))/L$. (2a) then defines $S^1(A, b, h) = (w(b, h) - w(b, l))/(1 - L)$

[30] This problem is dealt with in EMONS [2001].

[31] We ignore, e.g., the incentives of the other party to call a witness. For example, in adversarial systems competition between advocates who cannot prove every true statement can fully inform the fact-finder LIPMAN AND SEPPI [1995].

while (6a) defines

$$S^2(A, b, h) = \frac{1}{L}\left[w(b, h) - w(a, l) + \frac{1-L}{L}\left(w(a, l) - w(b, l)\right)\right].$$

Here we have

$$S^1(A, b, h) \geq S^2(A, b, h) \quad \Leftrightarrow$$
$$[w(b, h) - w(b, l)]\left[\frac{L}{1-L} - 1\right] \geq [w(a, l) - w(b, l)]\left[\frac{1-L}{L} - 1\right],$$

which holds because $L > 1/2$. Hence, $S^*(A, b, h) = S^1(A, b, h)$.

Given this, (1a) then defines

$$S^1(B, a, h) = \frac{w(a, h) - w(a, l)}{1-L} + \frac{w(a, l) - w(b, l)}{L},$$

(5a) implies

$$S^2(B, a, h) = \frac{w(a, h) - w(b, l)}{L},$$

and (4a) defines

$$S^3(B, a, h) = \frac{w(a, h) - w(b, h)}{H} + \frac{1-H}{H}\frac{w(b, h) - w(b, l)}{1-L}.$$

While it is straightforward to see that $S^1(B, a, h) \geq S^2(B, a, h)$, proving the second inequality is more tricky. Here we have

$$\begin{aligned}
S^1(B, a, h) &\geq S^3(B, a, h) \\
&\Leftrightarrow w(a, h)\left[\frac{H}{1-L} - 1\right] + w(b, h)\left[1 - \frac{1-H}{1-L}\right] \\
&\geq w(a, l)\left[\frac{H}{1-L} - \frac{H}{L}\right] + w(b, l)\left[\frac{H}{L} - \frac{1-H}{1-L}\right] \\
&= w(a, l)\left[\frac{H}{1-L} - 1\right] + w(b, l)\left[1 - \frac{1-H}{1-L}\right] \\
&\quad + \left[\frac{H}{L} - 1\right]\left(w(b, l) - w(a, l)\right),
\end{aligned}$$

which holds given $H > L$ and our assumptions on $w(\cdot)$. Consequently,

$$S(B, a, h) = \frac{w(a, h) - w(a, l)}{1-L} + \frac{w(a, l) - w(b, l)}{L}.$$

It remains to be shown that (1b)–(6b) also hold. (1b), (2b), and (3b) are obvious. Subtracting (3b) from (2b) yields $w(b, h) - w(a, l) \geq (1-H)S(A, b, h) - (1-L)S(B, a, l) \geq (1-H)S(A, b, h) - HS(B, a, l)$, implying (6b). Adding (1b) to (3b) generates $w(a, h) - w(b, l) \geq (1-H)S(B, a, h) + (H-L)S(B, a, l) > (1-H)S(B, a, h) - HS(B, a, l)$, meaning (5b) is satisfied. Last but not least, subtracting (2b) from (5b) yields $w(a, h) - w(b, h) \geq (1-H)S(B, a, h) - (1-H)S(A, b, h) \geq (1-H)S(B, a, h) - HS(A, b, h)$ which is (4b).

It is not possible to raise one sanction and at the same time lower another sanction. To see this, suppose we raise $S(A, b, l)$. (3a) then implies that $S(B, a, l)$ goes up. $S(A, b, h)$ increases, either because $S(A, b, l)$ (by (2a)) or $S(B, a, l)$ (by (6a)) is higher. $S(B, a, h)$ goes up because $S(B, a, l)$ (by (1a)), $S(A, b, l)$ (by (5a)), or $S(A, b, h)$ (by (4a)) is higher. Increasing $S(B, a, l)$, $S(A, b, h)$, or $S(B, a, h)$ does not allow us to lower the sanctions for weaker testimony; the sanctions for stronger testimony either do not change or go up, depending on the binding constraints. *Q.E.D.*

*A.3 Proof of Proposition 3*

If $Y = (B, L)$, $w(b, l) - (1 - L)S(A, b, l) = w(b, l) \geq 0$. If $Y = (B, H)$,

$$w(b, h) - (1 - H)S(A, b, h) = w(b, h) - \frac{1 - H}{1 - L}w(b, h) + \frac{1 - H}{1 - L}w(b, l) \geq 0,$$

since $H > L$. If $Y = (A, L)$,

$$w(a, l) - (1 - L)S(B, a, l) = w(a, l)\left[1 - \frac{1 - L}{L}\right] + \frac{1 - L}{L}w(b, l) \geq 0$$

as $L \geq 1/2$. Finally, if $Y = (A, H)$,

$$w(a, h) - (1 - H)S(B, a, h) =$$
$$w(a, h)\left[1 - \frac{1 - H}{1 - L}\right] + w(a, l)\left[\frac{1 - H}{1 - L} - \frac{1 - H}{L}\right] + \frac{1 - H}{L}w(b, l) \geq 0$$

because $H > L \geq 1/2$. *Q.E.D.*

*A.4 Proof of Proposition 4*

If the true state is, e.g., $(B, L)$, reporting $(b, l)$ must be better than $(b, h)$ meaning $w(b, l) - (1 - L)S(A, b, l) \geq w(b, h) - (1 - L)S(A, b, h)$. If the true state is $(B, H)$, $(b, h)$ must be better than $(b, l)$ meaning $w(b, h) - (1 - H)S(A, b, h) \geq w(b, l) - (1 - H)S(A, b, l)$. Rearranging gives us

$$(1 - H)[S(A, b, l) - S(A, b, h)] > w(b, l) - w(b, h) > (1 - L)[S(A, b, l) - S(A, b, h)],$$

which cannot hold since $[S(A, b, l) - S(A, b, h)]$ has to be positive and $(1 - H) < (1 - L)$. The same argument applies to the signal $(A, L)$. *Q.E.D.*

*A.5 Proof of Proposition 5*

If the witness has observed the high precision signal $(B, H)$, the expected sanction equals $(1 - H)S_p(A, b, h)$ if she is honest and candid and $(1 - H)S_p(A, b, l)$ if she is honest but not candid. Since $\phi(A, b, h) > \phi(A, b, l)$, we have $S_p(A, b, h) \geq S_p(A, b, l)$. The same argument applies to the signal $(A, H)$. *Q.E.D.*

*A.6 Proof of Proposition 6*

Proposition 4 implies that the witness either reports $(b, l)$ or $(a, l)$. If $\min[\phi(A, b, l), \phi(B, a, l)] \geq \overline{\phi}$, the sanction is $s$ for both messages whenever the testimony turns out to be wrong. Suppose the witness has observed $(B, H)$. If she reports honestly (but not candidly) $(b, l)$, the expected sanction is $(1 - H)s < Hs$ which is the expected sanction when she reports $(a, l)$. The same reasoning applies to the other three signals.

If $\max[\phi(A, b, l); \phi(B, a, l)] < \overline{\phi}$, the expected sanction is zero for both, $(a, l)$ and $(b, l)$. Accordingly, the witness will provide an honest testimony. *Q.E.D.*

*A.7 Proof of Proposition 7*

(3a) implies that $S(B, a, l)$ and $S(A, b, l)$ cannot both be zero for an interested witness. This observation together with Proposition 1 means that for an interested witness incentive compatible sanctions have to take on at least three different values. The perjury rule $S_p$ takes on at most two values, 0 and $s$. *Q.E.D.*

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