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Perjury versus Truth-Revelation: Quantity or Quality of Testimony

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Abstract

In trials witnesses often slant their testimony to advance their interests. To obtain truthful testimony, courts rely on perjury rules. We show that perjury rules are not truth-revealing and we derive a truth-revealing mechanism for the same set of restrictions under which perjury rules operate. If the judge uses a truth-revealing mechanism, he will get less testimony than under perjury because the defendant will not present a witness with unfavorable news; however, testimony is of higher quality. We show that a court striving for precision prefers truth-revelation to perjury. If the court is rational in the Bayesian sense, chances for the defendant to prevail are the same under perjury and truth-revelation from an ex ante point of view. Truth-revelation thus dominates perjury even when the lower quantity of testimony is taken into account.

Keywords: litigation process, witness, truth-revelation, mechanism design, perjury rule.

Journal of Economic Literature Classification Numbers: D82, K41, K42.

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1. Introduction

Witnesses often have a material interest in the court's judgment. For example, the plaintiff and defendant 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 by other witnesses. In a criminal trial for perjury, the plaintiff must prove that the defendant lied or recklessly disregarded the truth.[2] If the law allows civil liability for false testimony, the plaintiff in a civil case usually must prove something similar to what the prosecutor must prove in a criminal case for perjury.

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 and rules of civil liability for false testimony are not perfectly truth-revealing.

We consider a model where the outcome of a case depends on the likelihood the court attaches to four states of nature; the states represent very good, good, bad, and very bad news for the defendant. To illustrate, a drug may have no, minor, major, and lethal side-effects. We assume that the defendant's (the pharmaceutical company's) chances to prevail are linear in the probabilities that the court attaches to these events after collecting all the facts and opinions. The defendant will present evidence in the courtroom so as to maximize the probability to prevail.

[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

[2]According to the Model Penal Code, perjury requires testimony in court under oath that is false and material. In addition, perjury requires knowledge that the assertion was false when made, or, possibly, that the defendant recklessly disregard for the truth. U.S. law closely resembles the Model Penal Code. False testimony in an American court cannot support a civil suit for damages, so a victim of slander or libel in court has no legal remedy. For details see Cooter and Emons (2000b).

The defendant may find a witness who observes the true state of nature. The witness testifies in court on her observation. Later the court receives a noisy signal about the witness's observation. The court uses this signal to possibly sanction the witness.

We first derive a mechanism that is fully truth-revealing: given the witness testifies in the courtroom, she will tell the truth. This mechanism essentially imposes an expected sanction on the witness equal to the gain from slanted testimony. Then we show that within our model perjury rules are not truth-revealing; they are at best partially truth-revealing, i.e., they elicit the truth for some but not for all states of nature. To allow for a fair comparison both, the truth-revealing and the perjury mechanisms work under the same set of restrictions.[3]

The at first glance desirable property of truth-revelation creates, however, a problem if the defendant decides whether or not to present the witness. If the witness has unfavorable news for the defendant and the witness reports this truthfully in court under the truth-revealing mechanism, the defendant does better not to present the witness in the first place. Accordingly, under truth-revelation only witnesses with good news will be presented in the courtroom.

Under the perjury rule as a partially truth-revealing mechanism, witnesses will report good news in the courtroom, even when the actual news is bad. Accordingly, the defendant will present a witness in the courtroom even when the actual news is bad because the witness lies under perjury. We observe, therefore, a lot of testimony of low quality under perjury, whereas under truth-revelation we have little testimony of high quality. Thus, if we take the defendant's decision to present a witness into account, we face a trade-off of quality versus quantity of testimony.

The purpose of this paper is to analyze this trade-off. We assume that the court is not interested in who wins the case. The court wants to make the "right" decision; to do so, the court wants as much information as possible. The court thus strives for precision, which we measure by the entropy.

We distinguish between the fully truth-revealing mechanism and partially truth-revealing mechanisms, such as, e.g., perjury rules. For each mechanism we specify under which conditions the defendant will present the witness in court and what the witness will report. The rational court takes both decisions into account when he updates his beliefs about the likelihoods of the states of nature.

To illustrate, if under the truth-revealing mechanism the witness is presented in the courtroom and reports good news, the court knows that this message is true. If, however, the defendant presents no witness under the truth-revealing

[3]These restrictions are given by actual perjury law and make the derivation of the truth-revealing mechanism somewhat complicated.

mechanism, the court knows that either the defendant found no witness or that he found a witness who observed bad news.

If, in contrast, the court uses a mechanism providing no incentives at all, the witness will always report good news for the defendant in the courtroom, irrespective of his actual observation. The defendant will thus always present the witness and the court will ignore her testimony altogether, i.e., the court will not update his prior beliefs.

For each possible report of the witness we compute the a posteriori probability distribution over the four states of nature and the corresponding value of the entropy, summarizing the precision obtained by the court. Then we compute the expected value of the entropy where we take the expectation over the four states of nature, reflecting the idea that the court has to choose a mechanism (a rule) from an ex ante point of view. In Proposition 1 we show that the court's ranking over the mechanisms is monotonic: the court prefers the fully truth-revealing mechanism over partially truth-revealing mechanisms over mechanisms giving no incentives at all. To put it differently, the court prefers little testimony of high quality over much testimony of low quality.

In a next step we analyze how the defendant ranks the different mechanisms. Here we also take the ex ante point of view and compute the expected probability to win the case, where we take the expectation before the defendant has found a witness and, therefore, has the same priors as the court over the different states of nature. Our result is that the expected probability to prevail is the same for all mechanisms. The defendant is, therefore, indifferent as to which mechanism is used. This result holds because we model the probability to prevail as a linear function of the court's assessments and, moreover, the court updates his beliefs rationally.

The literature of applying mechanism design to courts is rather small. Sanchirico (1997) 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 therafter, perjury rules should give greater weight to the latter. All of these papers are of different focus than ours.

Closest to this paper are Cooter and Emons (2000a, b). There we look at the problem of inducing a witness who is presented in the courtroom to tell the truth. To justify that the witness is presented by the defendant in the first place, there we assume that any observation of the witness is good for the defendant, some observations are, however, better than the others. There we describe in great detail the class of truth-revealing mechanisms, whether they are individually rational, and we distinguish between interested and neutral witnesses. Here we look only at interested witnesses and, more importantly, we take bad observations into account. Although the whole set-up is different, section 3 of this paper builds on our previous work. The three papers should be seen as complements.

In the next section we describe the basic model. In section 3 we derive the truth-revealing and the perjury mechanisms. In the subsequent section we describe the trade-off between quantity and quality of testimony. Section 5 concludes.

2. The Model

A court has to decide a case. The decision depends on the probability the court attaches to the four states $X \in \{A, B, C, D\}$. The four states are mutually exclusive, meaning that only one of them will be realized. The state A means very good news for the defendant, B means good news, C bad news, and D means very bad news.[4] To illustrate, in an antitrust case A might mean "the defendant's market share is below 20%", B "the market share is between 20% and 50%", C "the market share is in the range of 50% and 80%", and D "the market share is above 80%"; in a liability suit A might be "the defendant was certainly not negligent", B "the defendant was likely not negligent", C "the defendant was negligent and the plaintiff was probably contributorily negligent", and D "only the defendant was negligent". To keep matters simple, we assume that a priori the court considers the four events equally likely, i.e., $P(A) = P(B) = P(C) = P(D) = 1/4$.

The probability that the defendant prevails, $P(\text{win})$, depends on the probabilities the court attaches to the four states after collecting all the facts and opinions, $P(X|\cdot)$ with $\sum_{X\in\{A,B,C,D\}} P(X|\cdot) = 1$. Specifically, we assume

$$P(\text{win}) = \mathfrak{a}P(A|\cdot) + \mathfrak{b}P(B|\cdot) + \mathfrak{c}P(C|\cdot) + \mathfrak{d}P(D|\cdot)$$

with $1 \geq \mathfrak{a} > \mathfrak{b} > \mathfrak{c} > \mathfrak{d} \geq 0$.[5] This mapping from $S^3 \mapsto [\mathfrak{d}, \mathfrak{a}]$ has the following properties. Suppose $\mathfrak{a} = 1$ and $\mathfrak{d} = 0$. Then the two states A and D alone can determine the outcome: if $P(A|\cdot) = 1$, the defendant wins for sure, whereas he

[4] In a trial, news that favors one party disfavors the other party. We will view testimony from the viewpoint of one party, we will take the defendant, and scale values accordingly.

[5] See Daughety and Reinganum (2000) for the derivation of an additive liability assessment function from five axioms.

loses for sure if $P(D|\cdot) = 1$. If $\mathfrak{a} < 1$ and $\mathfrak{d} > 0$, other factors also play a role in the courts' decision: even when $P(A|\cdot) = 1$, the defendant does not win for sure but only with probability $\mathfrak{a} < 1$. The magnitude of the four parameters $\mathfrak{a}, \mathfrak{b}, \mathfrak{c}, \mathfrak{d}$ reflects the influence of the four states in the decision finding process.

We take the influence of the other factors as given, i.e., we do not further explain the magnitude of $\mathfrak{a}$, $\mathfrak{b}$, $\mathfrak{c}$, and $\mathfrak{d}$. In any case it is good for the defendant to shift mass from the bad to the good states, or, to put it differently, it is bad for the defendant if the court takes weight from the good to the bad states. To have some more structure, we assume $\mathfrak{b} > (\mathfrak{a} + \mathfrak{b} + \mathfrak{c} + \mathfrak{d})/4 > \mathfrak{c}$. Then the defendant prefers that the court puts mass one on states A and B rather than considering the four states equally likely and vice versa for C and D.

We assume that the defendant tries to maximize the probability to prevail. He will present evidence in the courtroom so as to maximize $P(\text{win})$.

The court, in contrast, is not directly interested in who wins the case. The court wants to decide the case "correctly". To do so the court wants as much information as possible as to which of the four states will materialize. The court thus strives for precision. The worst scenario for the court is that after collecting all the evidence, the four states are equally likely.

We measure precision by the entropy

$$H = -\sum_{X \in \{A,B,C,D\}} P(X|\cdot) \ln P(X|\cdot)$$

where we put $0 \ln 0 = 0$ to ensure continuity of the function $-x \ln x$ at the origin.[6]

This function has the following properties. H is non-negative and continuous for any distribution over the four states. If the probability that one state materializes equals one, i.e., if $P(X|\cdot) = 1$ for any of the four states, then $H = 0$. If uncertainty is maximal in the sense that the four states are equally likely, H is maximal, i.e., $H(1/4, 1/4, 1/4, 1/4) = -\ln 1/4$. The uniform distribution maximizes the entropy. This is just LaPlace's Principle of Insufficient Reason according to which if there is no reason to discriminate between several events, the best strategy is to consider them as equally likely. The court wishes to minimize H.[7]

[6] We use the entropy because the outcomes of the random variable "states of the world" are of qualitative nature. We cannot use, e.g., the variance which requires quantitative outcomes.

[7] See Guiasu and Shenitzer (1985) for more on the entropy as a measure of the amount of uncertainty contained in a probability distribution. Rather than working with the entropy, we could also use the normalized version of Simpson's D, $D = (4/3)[1 - \sum_{X \in \{A,B,C,D\}} P(X|\cdot)^2]$.

With probability $P(W) \in (0,1)$ the defendant finds a witness. The witness observes the state X.[8] To illustrate, the defendant may find an industrial organization expert who knows the defendant's market share; in the liability case the defendant may find an expert who can determine whether or not the defendant and/or the plaintiff were negligent.

If the defendant presents the witness in court, the witness reports $x \in \{a, b, c, d\}$ where a means that the witness has observed A, etc.[9] If $x = X$, the witness tells the truth; otherwise, the witness lies.[10] We thus confine our attention to a direct revelation problem.[11]

Depending on her reported values, the witness receives a remuneration (wage) $w(x)$ from the defendant. Taking future consequences into account, remuneration is higher when the testimony is more favorable to the defendant. We look at the case where the witness is interested, i.e., we assume $w(a) > w(b) > w(c) > w(d)$, where $w(c)$ and $w(d)$ may be negative, reflecting the fact that c and d are bad news for the defendant.[12]

After the case has been decided, the court receives a signal $\chi \in \{\alpha, \gamma\}$ about the true state; we call α the good and γ the bad signal. Think of the signal simply as the opinion of a second expert who is, e.g., less able than the original witness. Denote the a priori probability of signal χ by $P(\chi)$.

If the true state of the world is a good one, the good signal α is more likely than the bad signal γ and vice versa if the true state of the world is a bad one. Moreover, we assume that the good signal is more likely for A than for B and the bad signal is more likely for C than for D. Formally, we have $1 >$

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[8] As in Shin (1999) 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.

[9] Obviously, the actual and the reported values are in the same set and using a, b, c, d is an abuse of notation. The formally correct notation $x \in \{A, B, C, D\}$ might, however, lead to confusion in what follows.

[10] 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 (1999)). In these papers a party can conceal information but cannot report false information.

[11] The revelation principle (see, e.g., Myerson (1985)) tells us that in Bayesian decision problems without 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 that the mechanism has to satisfy. Accordingly, truth-revelation does not automatically follow from the revelation principle.

[12] If $w(a) = w(b) = w(c) = w(d)$ the witness is neutral and has no incentive to distort testimony; see Cooter and Emons (2000a,b).

$P(\alpha|A) > P(\alpha|B) > 1/2$ and $1 > P(\gamma|C) > P(\gamma|D) > 1/2$. Note that $P(\alpha|X) = 1 - P(\gamma|X),\ \forall X$. Finally, to keep matters simple, let $P(\alpha|A) = P(\gamma|C)$ and $P(\alpha|B) = P(\gamma|D)$. Note that we need these assumptions on the signal structure only to construct the truth-revealing and perjury mechanisms in a straightforward manner. We do not need these assumptions for our results in section 4.

As an example consider tossing two dice. Let

$$\begin{aligned} A &:= \{(1,1);(1,2);(1,3);(1,4);(2,1);(2,2);(2,3);(3,1);(4,1)\}, \\ B &:= \{(1,5);(1,6);(2,4);(2,5);(2,6);(3,2);(3,3);(4,2);(4,3)\}, \\ C &:= \{(3,4);(3,5);(4,4);(4,5);(5,1);(5,2);(5,3);(6,1);(6,2)\}, \text{ and} \\ D &:= \{(3,6);(4,6);(5,4);(5,5);(5,6);(6,3);(6,4);(6,5),(6,6)\}. \end{aligned}$$

Let α be "the first die equals 1,2, or 3" and γ "the first die equals 4,5, or 6". We then have $P(A) = P(B) = P(C) = P(D) = 1/4$, $P(\alpha) = P(\gamma) = 1/2$, $P(\alpha|A) = P(\gamma|C) = 8/9$ and $P(\alpha|B) = P(\gamma|D) = 7/9$.

Conditional on the relationship between the testimony x and the court's signal χ, the witness can be rewarded or sanctioned. Formally, we denote a sanction/reward by $S(\chi, x)$ where $S > 0$ is a sanction and $S < 0$ a reward. We will say that testimony is confirmed if the court receives the good signal α after reports a, b, and the bad signal γ for reports c, d; otherwise, testimony is not confirmed. We focus on mechanisms working with minimal sanctions and no rewards. Formally, within the class of truth-revealing mechanisms we look for the mechanism S^* satisfying $0 \leq S^*(X, y, p) \leq S(X, y, p)\ \forall (X, y, p)$. The main reason we do not use rewards is that we want to compare our truth-revealing mechanism with the perjury rule which doesn't use rewards either. We make the sanctions as low as possible in order to minimize the monetary strain on the witness.[13] Therefore, we set the sanction equal to zero whenever the testimony is confirmed, i.e., $S(\alpha, a) = S(\alpha, b) = S(\gamma, c) = S(\gamma, d) = 0$. The witness's expected payoff equals her wage minus the expected sanction. Formally, the payoff is given as $w(x) - E(S(\tilde{\chi}, x)|X)$ where $E(S(\tilde{\chi}, x)|X)$ stands for the expected sanction given her reported testimony x and the true information X. The witness chooses her reported testimony x so as to maximize her expected payoff.

3. The Truth-revealing and the Perjury Mechanisms

Let us now derive a system of sanctions that induces the witness to be honest. We call such a mechanism truth-revealing. This means that reporting the true signal

[13] For a further discussion of why we restrict attention to mechanisms using minimal sanctions (viz individual rationality) and no rewards (viz frivolous witnesses), see also Emons and Sobel (1991) and Emons (1994).

must generate at least as much payoff as announcing any other signal. Formally, the *truth-revealing* requirement means

$$w(X) - E(S(\tilde{\chi}, X)|X) \geq w(x) - E(S(\tilde{\chi}, x)|X)$$
$$\forall x \in \{a, b, c, d\}, \forall X \in \{A, B, C, D\}.$$

Consider, for example, the case in which the true state is C. Here one of our tasks is to guarantee that announcing $x = c$ is at least as good as reporting $x = b$. Formally, this means $w(c) - P(\alpha|C)S(\alpha, C) \geq w(b) - P(\gamma|C)S(\gamma, b)$. If the witness tells the truth, she receives the wage $w(c)$. With probability $P(\alpha|C)$ the signal α materializes and the witness has to pay the sanction $S(\alpha, C)$. If, in contrast, she reports b, she receives the higher wage $w(b)$. Now the sanction is $S(\gamma, b)$, triggered by the signal γ which occurs with the probability $P(\gamma|C)$. Recall that the signals are informative, i.e., $P(\gamma|C) > P(\alpha|C)$. Accordingly, the probability of being sanctioned is higher when the witness lies.

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 have the following 6 chains of weak inequalities.

(1) $P(\gamma|B)S(\gamma, a) - P(\gamma|B)S(\gamma, b) \geq w(a) - w(b) \geq P(\gamma|A)S(\gamma, a) - P(\gamma|A)S(\gamma, b)$,

(2) $P(\alpha|D)S(\alpha, c) - P(\alpha|D)S(\alpha, d) \geq w(c) - w(d) \geq P(\alpha|C)S(\alpha, c) - P(\alpha|C)S(\alpha, d)$,

(3) $P(\alpha|B)S(\gamma, b) - P(\gamma|B)S(\alpha, d) \geq w(b) - w(d) \geq P(\alpha|D)S(\gamma, b) - P(\gamma|D)S(\alpha, d)$,

(4) $P(\gamma|C)S(\gamma, a) - P(\alpha|C)S(\alpha, c) \geq w(a) - w(c) \geq P(\alpha|C)S(\gamma, a) - P(\gamma|C)S(\alpha, c)$,

(5) $P(\gamma|D)S(\gamma, a) - P(\alpha|D)S(\alpha, d) \geq w(a) - w(d) \geq P(\gamma|A)S(\gamma, a) - P(\alpha|A)S(\alpha, d)$,

(6) $P(\gamma|C)S(\gamma, b) - P(\alpha|C)S(\alpha, c) \geq w(b) - w(c) \geq P(\gamma|B)S(\gamma, b) - P(\alpha|B)S(\alpha, c)$;

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 requires that the sanctions increase with the strength of the testimony. Formally, truth-revealing sanctions for interested witnesses satisfy $S(\gamma, b) < S(\gamma, a)$ and $S(\alpha, d) < S(\alpha, c)$. This result follows immediately from (1) - (6).

The truth-revealing mechanism using minimal sanctions and no rewards is given by

$$S^*(\chi, x) = \begin{cases} (w(a) - w(b))/P(\gamma|B) + \\ (w(b) - w(d))/P(\alpha|B), & \text{if } \chi = \gamma,\ x = a; \\ (w(b) - w(d))/P(\alpha|B), & \text{if } \chi = \gamma,\ x = b; \\ (w(c) - w(d))/P(\alpha|D), & \text{if } \chi = \alpha,\ x = c; \\ 0, & \text{otherwise.} \end{cases}$$

The derivation is similar to Cooter and Emons (2000a) and is relegated to the Appendix. The sanctions are constructed as follows. When the witness works out whether to report the true bad or a false good 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.

Let us illustrate the truth-revealing mechanism using the dice example. Recall that $P(\alpha|A) = P(\gamma|C) = 8/9$ and $P(\alpha|B) = P(\gamma|D) = 7/9$. Let $w(d) = -6$, $w(c) = 0$, $w(b) = 2$, and $w(a) = 3$. Then $S(\alpha, d) = 0$, $S(\alpha, c) = 27$, $S(\gamma, b) = 72/7$, and $S(\gamma, a) = 207/14$.

Let us now describe the perjury rule.[14] Under a perjury rule the sanction is zero whenever the testimony is confirmed. If, however, testimony is not confirmed, the court uses this information to compute the probability ϕ that the witness did not tell the truth. If this probability exceeds a legal standard $\bar{\phi}$, the court imposes a sanction $s > 0$; if the probability is below the legal standard, the sanction is zero.[15] Formally,

$$S_P(\chi, x) = \begin{cases} s, & \text{if } \phi(\chi, x) \geq \bar{\phi}; \\ 0, & \text{otherwise.} \end{cases}$$

If the witness has reported, say a, and nature chooses γ, the probability of not having told the truth is

$$\phi(a, \gamma) = P(\neg A|\gamma) = 1 - P(A|\gamma) = 1 - (P(\gamma|A)P(A))/P(\gamma).$$

The probability that A was not the true state given γ equals the sum of the probabilities that the witness has observed B, C, or D, which in turn equals 1 minus the probability that A was the true state given γ. Analogously, we compute

$$\begin{aligned} \phi(b, \gamma) &= P(\neg B|\gamma) = 1 - (P(\gamma|B)P(B))/P(\gamma), \\ \phi(c, \alpha) &= P(\neg C|\alpha) = 1 - (P(\alpha|C)P(C))/P(\alpha), \text{ and} \\ \phi(d, \alpha) &= P(\neg D|\alpha) = 1 - (P(\alpha|D)P(D))/P(\alpha). \end{aligned}$$

In our example we compute $\phi(a, \gamma) = 17/18$, $\phi(b, \gamma) = 16/18$, $\phi(c, \alpha) = 17/18$, and $\phi(d, \alpha) = 16/18$.

[14]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,b) use axiomatic methods to model information and decisions in court.

[15]Being a crime, one element for perjury is the intention to do wrong (mens rea, guilty mind). 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, as we assume, the perjury rule is triggered.

Notice that however we set $\bar{\phi}$, the perjury rule can take on only two values, 0 and s. If we set in our example $\bar{\phi} \leq 8/9$, then $S(\gamma, a) = S(\gamma, b) = S(\alpha, c) = S(\alpha, d) = s$; if we set $\bar{\phi} > 17/18$, then $S(\gamma, a) = S(\gamma, b) = S(\alpha, c) = S(\alpha, d) = 0$; if we set $\bar{\phi} \in (8/9; 17/18]$, then $S(\gamma, a) = S(\alpha, c) = s$ and $S(\gamma, b) = S(\alpha, d) = 0$.

Note that (1a) implies $S(\gamma, a) > S(\gamma, b)$, (2a) implies $S(\alpha, c) > S(\alpha, d)$, and (3a) implies that $S(\gamma, b)$ and $S(\alpha, d)$ cannot both be zero. Accordingly, truth-revealing requires that sanctions have to take on at least three different values. The perjury rule takes on at most two values. Consequently, the perjury rule is not fully truth-revealing. The perjury rule is at most partially truth-revealing.

Suppose we set, e.g., $\bar{\phi} = 17/18$ so that $S(\gamma, a) = S(\alpha, c) = s$ and $S(\gamma, b) = S(\alpha, d) = 0$. By the appropriate choices of s we can make the witness tell the truth whenever she observed A or B. Yet the witness will always report b when she observed C and D because $w(b) > w(c) > w(d)$ and the sanction is positive for c and zero for both, b and d.

4. Quantity versus Quality of Testimony

In what follows we will call a mechanism *(fully) truth-revealing* if, given the witness testifies in court, she always reports the true state. We will call a mechanism *partially truth-revealing*, if, given the witness testifies in court, for some states of the world she will not report the truth; we will specify the witness's reporting incentives under partial truth-revelation in the context.

Let us now take the defendant's decision whether or not to present the witness in the courtroom into account. The sequencing of events is as follows. The defendant searches a witness. If he finds a witness, she reports her observation to the defendant. Then the defendant decides whether or not to present the witness.

To illustrate that this decision of the defendant is of some interest, suppose first the court employs the truth-revealing mechanism and the witness has observed D. If the witness is presented in the courtroom, she will honestly report d, which is bad for the defendant. In this case it seems better for the defendant not to present the witness and claim that he hasn't found a witness.[16]

Suppose next the court uses a partially truth-revealing mechanism of the sort we have just described and the witness has observed D: the witness tells the

[16] Suppose the defendant has approached a potential expert witness to find out her opinion about the case. If the witness indicates that the true state might be C or D, the defendant simply doesn't pursue the matter of hiring the witness any further. If the defendant approaches the witness cleverly enough (as any good lawyer can), he can always claim that he didn't find a witness. In this case asking the defendant under a truth-revealing mechanism whether or not he found a witness wouldn't help either. Accordingly, the defendant cannot concoct false evidence but may withhold information unfavorable to his cause. This assumption is a standard feature of disclosure games; see, e.g., Milgrom and Roberts (1986).

truth for A and B, but she will report b for C and D. Here it seems a good idea to present the witness because she will report b in the courtroom which is rather good news for the defendant after all. In what follows we will make these ideas precise.

Recall that the defendant finds a witness with probability $P(W)$ and that he finds no witness with $P(NW) = 1 - P(W)$. The two random variables "state of the world" and "finding a witness" are independent, so that $P(X \cap W) = (1/4)P(W)$ and $P(X \cap NW) = (1/4)P(NW)$, $X \in \{A, B, C, D\}$. If the defendant finds no witness, under any mechanism he cannot present a witness in the courtroom.

To distinguish the different mechanisms, we will from now on identify them by the number of lies by the witness they give rise to.[17] Let us start with the truth-revealing mechanism. Since under this mechanism the witness tells the truth whatever the state of world, we will call this the *no lie mechanism.* If the defendant finds a witness who observes A or B, clearly he will present her in court and the witness will report the truth. Rather than writing $W \cap a$ and $W \cap b$, we will denote these events as a shortcut simply by a and b. If, however, the witness observes B and C, under truth-revelation the defendant will claim that he found no witness which we denote by NW. Taking the defendant's presentation policy and the witness's reporting strategy into account, the court's updated probabilities of the states of the world are:

$$\begin{aligned}
P(A|a, \text{no lie}) &= 1, \quad P(B|b, \text{no lie}) = 1, \\
P(A|NW, \text{no lie}) &= P(A \cap NW)/(P(NW) + P(C \cap W) + P(D \cap W)) \\
&= (1/4)P(NW)/(P(NW) + (1/2)P(W)), \\
P(B|NW, \text{no lie}) &= (1/4)P(NW)/(P(NW) + (1/2)P(W)), \\
P(C|NW, \text{no lie}) &= \frac{P(C \cap NW) + P(C \cap W)}{P(NW) + P(C \cap W) + P(D \cap W)} \\
&= (1/4)/(P(NW) + (1/2)P(W)), \text{ and} \\
P(D|NW, \text{no lie}) &= (1/4)/(P(NW) + (1/2)P(W)).
\end{aligned}$$

[17]Note that we only count the lies of the witness to distinguish the mechanisms. We do not count the lies of the defendant.

Let us no compute the entropy. Here we have:

$$
\begin{aligned}
&H(P(X|a, \text{no lie})) = 0, \quad H(P(X|b, \text{no lie})) = 0, \quad \text{and} \\
&H(P(X|NW, \text{no lie})) = \\
&\frac{-1/2}{P(NW) + (1/2)P(W)} \left[P(NW) \ln \frac{(1/4)P(NW)}{P(NW) + (1/2)P(W)} + \right. \\
&\left. \ln \frac{1/4}{P(NW) + (1/2)P(W)} \right].
\end{aligned}
$$

Let us now look at the expected entropy. We take the expectation at the time when the defendant looks for a witness. From an ex ante point of view the expected entropy is given as

$$
\begin{aligned}
EH(\text{no lie}) &= P(A \cap W)H(P(X|a, \text{no lie})) + P(B \cap W)H(P(X|b, \text{no lie})) \\
&+ (P(NW) + P(C \cap W) + P(D \cap W))H(P(X|NW, \text{no lie})) = \\
&(-1/2)[(1 + P(NW))[\ln(1/4) - \ln(P(NW) + (1/2)P(W)) \\
&+ P(NW) \ln P(NW)].
\end{aligned}
$$

Let us now look at the other extreme and consider a mechanism providing no incentives at all. Here the witness reports a for states A, B, C, and D. Accordingly, we will call it the *3 lies mechanism*. Take, for example, the perjury rule with the legal standard $\bar{\phi}$ so high (low) that the witness is never (always) sanctioned.

Here matters are straightforward. Whenever the defendant finds a witness, he will present her in court and she will report a, whatever the true state of nature. We have thus a high quantity of low quality testimony. Anticipating this, the court will not update his beliefs and

$$P(X|a, 3 \text{ lies}) = 1/4, \ X \in \{A, B, C, D\}, \text{ so that } H(P(X|a, 3 \text{ lies})) = -\ln 1/4.$$

Similarly,

$$P(X|NW, 3 \text{ lies}) = 1/4, \ X \in \{A, B, C, D\}, \text{ and } H(P(X|NW, 3 \text{ lies})) = -\ln 1/4.$$

The expected entropy is given as

$$EH(3 \text{ lies}) = P(W)H(P(X|a, 3 \text{ lies})) + P(NW)H(P(X|NW, 3 \text{ lies})) = -\ln 1/4.$$

Now consider partially truth-revealing mechanisms. Let us start with the perjury rule where $\bar{\phi}$ and s are such that the witness tells the truth whenever she observes A and B and where the witness reports b for C and D. We will call this the *2 lies mechanism*. Here the defendant will always present the witness who reports a when the true state is A, and b when the true states are B, C, and D.

Accordingly,

$$\begin{aligned}
&P(A|a, 2 \text{ lies}) = 1, \\
&P(A|b, 2 \text{ lies}) = 0, \quad P(X|b, 2 \text{ lies}) = 1/3, \ X \in \{B, C, D\}, \text{ and} \\
&P(X|NW, 2 \text{ lies}) = 1/4, \ X \in \{A, B, C, D\}.
\end{aligned}$$

Therefore,

$$\begin{aligned}
&H(P(X|a, 2 \text{ lies})) = 0, \\
&H(P(X|b, 2 \text{ lies})) = -\ln 1/3, \text{ and} \\
&H(P(X|NW, 2 \text{ lies})) = -\ln 1/4,
\end{aligned}$$

and

$$\begin{aligned}
EH(2 \text{ lies}) &= (1/4)P(W)H(P(X|a, 2 \text{ lies})) + (3/4)P(W)H(P(X|b, 2 \text{ lies})) \\
&+ P(NW)H(P(X|NW, 2 \text{ lies})) \\
&= (3/4)P(W)(-\ln 1/3) + P(NW)(-\ln 1/4).
\end{aligned}$$

To complete the picture we look at the following *1 lie mechanism:* the witness tells the truth for A, B and D, but reports b if the true state is C. We haven't derived a mechanism giving rise to this reporting strategy but using the techniques given in the Appendix, this is a fairly straightforward task.[18] Here the defendant will present the witness in states A, B and C, but not in D. If the true state is A, the witness reports a, for B and C the witness reports B. Accordingly,

$$\begin{aligned}
P(A|a, 1 \text{ lie}) &= 1, \\
P(B|b, 1 \text{ lie}) &= 1/2, \quad P(C|b, 1 \text{ lie}) = 1/2, \\
P(A|NW, 1 \text{ lie}) &= P(A \cap NW)/(P(NW) + P(D \cap W)) = \\
&\quad 1/4P(NW)/(P(NW) + (1/4)P(W)), \\
P(B|NW, 1 \text{ lie}) &= 1/4P(NW)/(P(NW) + (1/4)P(W)), \\
P(C|NW, 1 \text{ lie}) &= 1/4P(NW)/(P(NW) + (1/4)P(W)), \text{ and} \\
P(D|NW, 1 \text{ lie}) &= (P(D \cap NW) + P(D \cap W))/(P(NW) + P(D \cap W)) = \\
&\quad (1/4)/(P(NW) + (1/4)P(W)).
\end{aligned}$$

[18] One can think of other examples of 1 lie mechanisms. The basic structure of the following arguments remain, however, the same.

Therefore,

$$H(P(X|a, 1 \text{ lie})) = 0, \quad H(P(X|b, 1 \text{ lie})) = -\ln 1/2 \quad \text{and}$$
$$H(P(X|NW, 1 \text{ lie})) =$$
$$\frac{-1/4}{P(NW) + (1/4)P(W)} \left[3P(NW) \ln \frac{(1/4)P(NW)}{P(NW) + (1/4)P(W)} + \ln \frac{1/4}{P(NW) + (1/4)P(W)} \right],$$

and

$$\begin{aligned} EH(1 \text{ lie}) &= (1/4)P(W)H(P(X|a, 1 \text{ lie})) + (1/2)P(W)H(P(X|b, 1 \text{ lie})) + \\ &\quad (P(NW) + (1/4)P(W))H(P(X|NW, 1 \text{ lie})) \\ &= (1/2)P(W)(-\ln 1/2) - 1/4 \left[3P(NW) \ln \frac{(1/4)P(NW)}{P(NW) + (1/4)P(W)} \right. \\ &\quad \left. + \ln \frac{1/4}{P(NW) + (1/4)P(W)} \right]. \end{aligned}$$

We are now in the position to state that the court prefers mechanisms giving rise to as little lies as possible. When the court has the choice between, e.g., the truth-revelation and perjury, clearly he opts for truth-revelation. To put it differently, the court prefers fewer testimony of higher quality.

Proposition 1: *For the expected entropy we have* $EH(\text{no lie}) < EH(1 \text{ lie}) < EH(2 \text{ lies}) < EH(3 \text{ lies})$ *for* $0 < P(W) < 1$.

The proof is relegated to the Appendix. The intuition for this result is straightforward. If the mechanism provides no incentives, the court gets a lot of testimony, which is, however, worthless. If the mechanism provides incentives to tell the truth, the court gets fewer testimony but this testimony is of higher quality. Moreover, even the message that the defendant found no witness is now informative: the court can infer that the bad states are more likely than the good ones. Accordingly, using high powered incentives to reveal the truth is more informative for courts even when the lower quantity of testimony is accounted for.

Given that the court prefers mechanisms giving rise to as little lies by the witness as possible, the next question to ask is how the defendant ranks the different mechanisms. Let us look at the expected probability to win the case. Here we take the expectation as in the case of the expected entropy at the time when the defendant looks for a witness. The somewhat surprising result is that with a rational (Bayesian) court, the expected probability to win the case is the same for all mechanisms.

Proposition 2: *The expected probability to prevail satisfies* $EP(\text{win}, y \text{ lies}) = (1/4)(\mathfrak{a} + \mathfrak{b} + \mathfrak{c} + \mathfrak{d}), \quad y \in \{0, 1, 2, 3\}$.

This result may be explained as follows. Suppose the court uses the truth-revealing mechanism. If the witness observes good news, this is favorable for the defendant because the court believes the testimony. If, however, the news is bad and the witness is not presented in court, this is unfavorable for the defendant because the court puts now more weight on C and D which lowers $P(\text{win})$. Since the probability to prevail $P(\text{win})$ is linear in the court's assessment, the favorable and the unfavorable effect just cancel.[19]

If we measure welfare by the expected entropy and the expected probability to prevail, we may say that the truth-revealing mechanism is better than any other mechanism in the weak Pareto sense. The court strictly prefers truth-revelation and the defendant does not care. Nevertheless, if we take the defendant's cost of hiring the witness $w(\cdot)$ into account, this welfare statement needs to be qualified. Suppose, for example, the defendant can commit ex ante not to call a witness at all in the trial. Then the defendant clearly prefers this alternative. The expected probability to win is the same as under every other mechanism and he saves the expenses of paying the witness.

6. Conclusions

In a simple framework we have analyzed the trade-off quantity versus quality of testimony. If the court uses a mechanism providing incentives to tell the truth, he obtains little testimony which is, however, of high quality. This also allows the court to make more precise inferences when he gets no testimony. If the court switches from a mechanism giving no incentives to a truth-revealing one, the defendant gains in the good states and loses in the bad states; the gains and the losses just cancel in our set-up. Overall then, we may argue that more incentives to tell the truth are better.

A few qualifications are in order. First, 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 also use this information to infer the quality of the testimony. Second, we assume that the process generating the evidence confirming or disconfirming the testimony is exogenous.[20] Third, we do not ask the question what level of disconfirming evidence provides the

[19]For the court who does not care who wins the case, any reduction in uncertainty is favorable; see Proposition 1.

[20]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; see Lipman and Seppi (1995).

best trigger for the sanction.[21] To illustrate, suppose the witness has made a statement, say b, about the defendant's market share. Disconfirming evidence γ is the observation that $z\%$ of a group of randomly chosen disinterested industrial economists disagree with the witness's statement. The optimal level of z is not addressed in our model.

[21] A related problem is analyzed by Bernardo, Talley, and Welch (1999).

Appendix

Derivation of the Truth-revealing Mechanism :

We use the first inequalities (1a)-(6a) to determine the smallest incentive compatible sanctions. Our preliminary result implies that we can set $S^*(\alpha, d) = 0$. (2a) then implies $S^*(\alpha, c) = (w(c) - w(d))/P(\alpha|D)$. (3a) then defines $S^1(\gamma, b) = (w(b) - (d))/P(\alpha|B)$ while (6a) defines

$$S^2(\gamma, b) = \frac{1}{P(\gamma|C)} \left[w(b) - w(c) + \frac{P(\alpha|C)}{P(\gamma|B)} (w(c) - w(d)) \right]$$

Since $S^2(\gamma, b) =$

$$\frac{1}{P(\alpha|B)} \left[\frac{P(\alpha|B)}{P(\gamma|C)} w(b) + w(c) (\frac{P(\alpha|B)}{P(\gamma|C)} \frac{P(\alpha|C)}{P(\gamma|B)} - \frac{P(\alpha|B)}{P(\gamma|C)}) - \frac{P(\alpha|B)}{P(\gamma|C)} \frac{P(\alpha|C)}{P(\gamma|B)} w(d) \right] \leq$$

$$\frac{1}{P(\alpha|B)} \left[\frac{P(\alpha|B)}{P(\gamma|C)} (w(b) - w(d)) \right] \leq \frac{w(b) - w(d)}{P(\alpha|B)} = S^1(\gamma, b),$$

we have $S^*(\gamma, b) = S^1(\gamma, b)$. Given this, (1a) then defines

$$S^1(\gamma, a) = \frac{w(a) - w(b)}{P(\gamma|B)} + \frac{w(b) - w(d)}{P(\alpha|B)},$$

(5a) implies

$$S^2(\gamma, a) = \frac{w(a) - w(d)}{P(\gamma|D)},$$

and (4a) defines

$$S^3(\gamma, a) = \frac{w(a) - w(c)}{P(\gamma|C)} + \frac{P(\alpha|C)}{P(\gamma|C)} \frac{w(c) - w(d)}{P(\alpha|D)}.$$

While it is straightforward to see that $S^1(\gamma, a) \geq S^2(\gamma, a)$, proving the second inequality is more tricky. Here we have $S^1(\gamma, a) \geq S^3(\gamma, a) \Leftrightarrow$

$$w(a) \left[\frac{P(\gamma|C)}{P(\gamma|B)} - 1 \right] + w(c) \left[1 - \frac{P(\alpha|C)}{P(\gamma|B)} \right] \geq$$

$$w(b) \left[\frac{P(\gamma|C)}{P(\alpha|D)} - \frac{P(\gamma|C)}{P(\alpha|B)} \right] + w(d) \left[\frac{P(\gamma|C)}{P(\alpha|B} - \frac{P(\alpha|C)}{P(\alpha|D)} \right] =$$

$$w(b) \left[\frac{P(\gamma|C)}{P(\gamma|B)} - 1 \right] + w(d) \left[1 - \frac{P(\alpha|C)}{P(\gamma|B)} \right] + \left[\frac{P(\gamma|C)}{P(\alpha|B)} - 1 \right] (w(d) - w(b))$$

which holds given $P(\gamma|C) > P(\alpha|B)$ and our assumptions on $w(\cdot)$. Consequently,

$$S^*(\gamma, a) = \frac{w(a) - w(b)}{P(\gamma|B)} + \frac{w(b) - w(d)}{P(\alpha|B)}.$$

It remains to be shown that (1b)-(6b) also hold. (1b), (2b), and (3b) are obvious. Subtracting (2b) from (3b) yields $w(b) - w(c) \geq P(\alpha|D)S(\gamma, b) - P(\alpha|C)S(\alpha, c) \geq P(\alpha|D)S(\gamma, b) - P(\gamma|D)S(\alpha, c)$, implying (6b) since $P(\gamma|D) = P(\alpha|B)$. Adding (1b) to (3b) yields $w(a) - w(d) \geq P(\gamma|A))S(\gamma, a) + (P(\alpha|A) - P(\alpha|B))S(\gamma, b) > P(\gamma|A)S(\gamma, a) -$

$P(\alpha|A)S(\gamma,b)$, meaning (5b) is satisfied. Last but not least, adding (1b) to (6b) yields $w(a)-w(c) \geq P(\gamma|A)S(\gamma,a) + (P(\alpha|A)-P(\alpha|B))S(\gamma,b) - P(\alpha|B)S(\alpha,c) \geq P(\alpha|C)S(\gamma,a) - P(\gamma|C)S(\alpha,c)$ which is (4b).

Q.E.D.

Proof of Proposition 1:

a)

$$EH(\text{no lie}) =$$
$$(-1/2)[(1+P(NW))[\ln(1/4) - \ln(P(NW)+(1/2)P(W)) + P(NW)\ln P(NW)] <$$
$$-\frac{1}{2}P(W)\ln\frac{1}{2} - \frac{1}{4}\left[3P(NW)\ln\frac{(1/4)P(NW)}{P(NW)+(1/4)P(W)}\right.$$
$$\left. + \ln\frac{(1/4)}{P(NW)+(1/4)P(W)}\right] = EH(1 \text{ lie}) \quad \Leftrightarrow$$
$$2P(W)\ln 1/2 + (P(NW)-1)\ln 1/4 + P(NW)\ln P(NW) - (1+3P(NW))\cdot$$
$$\ln(P(NW)+(1/4)P(W)) < -2(1+P(NW))\ln(P(NW)+(1/2)P(W)) \quad \Leftrightarrow$$
$$P(NW)\ln P(NW) - (1+3P(NW))\ln(1/4+(3/4)P(NW)) <$$
$$-2(1+P(NW)\ln(1/2+(1/2)P(NW))$$

which holds for $P(NW) \in (0,1)$.
b)

$$EH(1 \text{ lie}) < EH(2 \text{ lies}) = (-3/4)P(W)\ln 1/3 - P(NW)\ln 1/4 \quad \Leftrightarrow$$
$$(1-P(NW))[3\ln 1/3 - 2\ln 1/4] - 3P(NW)\ln P(NW)$$
$$+(1+3P(NW))\ln[1/4+(3/4)P(NW)] < 0$$

which holds for $P(NW) \in (0,1)$.
c) $EH(2 \text{ lies}) < EH(3 \text{ lies}) = -\ln 1/4$ which holds for $P(NW) \in (0,1)$.

Q.E.D.

Proof of Proposition 2:

Under the 3 lies mechanism whenever the defendant finds a witness, he will present her in court and she will report a. Accordingly, the court will not update his beliefs and

$$EP(\text{win, 3 lies}) = (1/4)(\mathfrak{a}+\mathfrak{b}+\mathfrak{c}+\mathfrak{d}).$$

Under the 2 lies mechanism

$$EP(\text{win, 2 lies}) = P(W)(1/4)\mathfrak{a} + P(W)(1/4)(\mathfrak{b}+\mathfrak{c}+\mathfrak{d}) +$$
$$P(NW)(1/4)(\mathfrak{a}+\mathfrak{b}+\mathfrak{c}+\mathfrak{d}) = (1/4)(\mathfrak{a}+\mathfrak{b}+\mathfrak{c}+\mathfrak{d})$$

Under the 1 lie mechanism

$$EP(\text{win, 1 lie}) = P(W)(1/4)\mathfrak{a} + P(W)(1/4)(\mathfrak{b}+\mathfrak{c}) +$$
$$(P(NW) + \frac{1}{4}P(W))\left[\frac{(1/4)P(NW)}{P(NW)+(1/4)P(W)}(\mathfrak{a}+\mathfrak{b}+\mathfrak{c}) +\right.$$
$$\left.\frac{1/4}{P(NW)+(1/4)P(W)}\mathfrak{d}\right] = (1/4)(\mathfrak{a}+\mathfrak{b}+\mathfrak{c}+\mathfrak{d})$$

Under the no lie mechanism

$$EP(\text{win, no lie}) = P(W)(1/4)\mathfrak{a} + P(W)(1/4)\mathfrak{b} +$$
$$(P(NW) + (1/2)P(W))\left[\frac{(1/4)P(NW)}{P(NW)+(1/2)P(W)}\mathfrak{a} + \frac{(1/4)P(NW)}{P(NW)+(1/2)P(W)}\mathfrak{b} +\right.$$
$$\left.\frac{1/4}{P(NW)+(1/2)P(W)}(\mathfrak{c}+\mathfrak{d})\right] = (1/4)(\mathfrak{a}+\mathfrak{b}+\mathfrak{c}+\mathfrak{d})$$

Q.E.D.

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