

Probability Thresholds

Marcello Di Bello and Rafal Urbaniak

SAMLE CHAPTER PLAN UPDATE

I am now realizing that perhaps the structure of the chapter could be further broken down into three chapters:

1. A chapter that shows how probabilistic thresholds are good as analytical tools, despite implementation or practical difficulties with them. This chapter would include discussions of expected utility, minimizing errors, signal detection theory, etc. A lot of this stuff is already in the extended version of the SEP entry. So main claim of this chapter is: yes, probabilistic thresholds are not good practically, but they can still be good as analytical tools. Title: "Probability Thresholds as Analytical Models of Trial Decision Making"
2. Two chapters that look at the two theoretical difficulties (naked stats and conjunction paradox, and also problem of priors). One chapter on naked statistical evidence and our informal solutions to it, based either on LR or on specific narratives (this should be followed by another chapter with the formal details).
3. Another chapter on conjunction paradox and our informal solution to it, maybe in terms of LR, BF or narratives (followed by another chapter in which the formal details are spelled out).
4. A chapter that formally addresses the two theoretical difficulties, perhaps using Bayesian Networks. This need not be included in the sample chapters we sent out. Title: "Addressing the Proof Paradoxes with Bayesian Networks".

SAMPLE CHAPTER PLAN

In rethinking the sample chapter, we should perhaps stick to a simpler structure, trying to offer a more focused and compelling argument. Right now I think we have too many possible accounts under consideration, and the structure is not very tight or cohesive. It feels more like a literature review, especially the first few sections.

So here is how I proposed we do it:

1. Begin by stating the simplest probabilistic account based on a threshold for the posterior probability of guilt/liability. The threshold can be variable or not. Add brief description of decision-theoretic ways to fix the threshold. (Perhaps here we can also talk about intervals of posterior probabilities or imprecise probabilities.)
2. Formulate two common theoretical difficulties against this posterior probability threshold view: (a) naked statistical evidence and (b) conjunction. (We should state these difficulties before we get into alternative probabilistic accounts, or else the reader might wonder why so many different variants are offered of probabilistic accounts).

R: Yes. That's what I thought.

We might also want to add a third difficulty: (c) the problem of priors (if priors cannot be agreed upon then the posterior probability threshold is not functionally operative). Dahlman I think has quite a bit of stuff on the problem of priors.

3. As a first response to the difficulties, articulate the likelihood ratio account. This is the account I favor in my mind paper. Kaplow seems to do something similar. So does Sullivan. So it's a popular view, worth discussing in its own right. You say that Cheng account is one particular variant of this account, so we can talk about Cheng here, as well.
4. Examine how the likelihood ratio account fares against the two/three difficulties above. One could make an argument (not necessarily a correct one) that the likelihood ratio account can address all

- the two/three difficulties. So we should say why one might think so, even though the argument will ultimately fail. I think this will help grab the reader's attention. This is what I have in mind:
- 4a: the LR approach solves the naked stat problem because $LR=1$ (Cheng, Sullivan) or $L1=unknown$ (Di Bello).
- 4b: the LR approach solves the conjunction problem because – well this is Dawid's point that we will have to make sense of the best we can
- 4c: the LR approach solves the priors problem b/c LR do not have priors.
5. Next, poke holes in the likelihood ratio account:
- against 4a: you do not believe $LR=1$ or $LR=unknown$, so we should talk about this
- against 4b: this is your cool argument against Dawid
- against 4c: do you believe the argument in 4c? we should talk about this
- In general, we will have to talk to see where we stand. As of now, I tentatively believe that the likelihood ratio account can solve (a) and (c), and you seem to disagree with that. Even if I am right, the account is still not good enough because it cannot solve (b).
6. Articulate (or just sketch?) a better probabilistic account overall. Use Bayesian networks, narratives, etc. I am not sure if this should be another paper. That will depend on how much we'll have to say here.

Contents

1 SAMPLE CHAPTER TITLE - "Probability Thresholds as Analytical Models of Trial Decision Making"	2
2 Introduction	2
3 Probability thresholds	3
3.1 The basic idea	4
3.2 Mixed reactions from legal practitioners	4
3.3 Implementation and idealization	5
3.4 Minimizing expected costs: higher cost ratio, higher threshold	7
3.5 Beyond just costs: the benefits of correct decisions	8
3.6 SUGGESTION	11
3.7 Minimizing overall errors	12
3.8 Interval thresholds (Finkelstein)	16
4 Theoretical challenges - NEW CHAPTER WOULD START HERE	16
4.1 The problem of priors	16
4.2 Naked statistical evidence	16
5 Conjunction paradox – NEW CHAPTER HERE DEVOTED TO PROBABILITY BASED SOLUTIONS	17
5.1 The problem	18
References	19

1 SAMPLE CHAPTER TITLE - "Probability Thresholds as Analytical Models of Trial Decision Making"

2 Introduction

After the evidence has been presented, examined and cross-examined at trial, trained judges or lay jurors must reach a decision. In many countries, the decision criterion is defined by law and consists of a standard of proof, also called the burden of persuasion. So long as the evidence against the defendant meets the requisite proof standard, the defendant should be found liable.

In criminal proceedings, the governing standard is ‘proof beyond a reasonable doubt.’ If the decision makers are persuaded beyond a reasonable doubt that the defendant is guilty, they should convict, or else they should acquit. In civil cases, the standard is typically ‘preponderance of the evidence.’ The latter is less demanding than the former, so the same body of evidence may meet the preponderance standard, but not meet the beyond a reasonable doubt standard. A vivid example of this difference is the 1995 trial of O.J. Simpson, who was charged with the murder of his wife. He was acquitted of the criminal charges, but when the family of the victim brought a lawsuit against him, they prevailed. O.J. Simpson did not kill his wife according to the beyond a reasonable doubt standard, but he did according to the preponderance standard. An intermediate standard, called ‘clear and convincing evidence,’ is sometimes used for civil proceedings in which the decision is particularly weighty, for example, a decision whether someone should be committed to a hospital facility.

Not sure if it is clear what you mean by this.

How to define standards of proof—and whether they should be even defined in the first place—remains contentious (Diamond, 1990; Horowitz & Kirkpatrick, 1996; Laudan, 2006; Newman, 1993; Walen, 2015). Judicial opinions offer different, sometimes conflicting, paraphrases of what these standards mean. The meaning of ‘proof beyond a reasonable doubt’ is the most controversial. It has been equated with ‘moral certainty’ or ‘abiding conviction’ (Commonwealth v. Webster, 59 Mass. 295, 320, 1850) or with ‘proof of such a convincing character that a reasonable person would not hesitate to rely and act upon it in the most important of his own affairs’ (US Federal Jury Practice and Instructions, 12.10, at 354, 4th ed. 1987). But courts have also cautioned that there is no need to define the term because ‘jurors know what is reasonable and are quite familiar with the meaning of doubt’ and attempts to define it only ‘muddy the water’ (U.S. v. Glass, 846 F.2d 386, 1988).

To further complicate things, differences between countries and legal traditions exist. The tripartite distinction of proof standards—beyond a reasonable doubt; preponderance; clear and convincing evidence—is common in Anglo-american jurisprudence. It is not universal, however. Different countries may use different standards. France, for example, uses the standard of ‘intimate conviction’ for both civil and criminal proceedings. Judges deciding cases ‘must search their conscience in good faith and silently and thoughtfully ask themselves what impression the evidence given against the accused and the defence’s arguments have made upon them’ (French Code of Criminal Procedure, art. 353). German law is similar. Germany’s Code of Civil Procedure, Sec. 286, states that ‘it is for the court to decide, based on its personal conviction, whether a factual claim is indeed true or not.’

R: check the formulation in Poland

While there are inevitable differences between legal traditions, the question of how strong the evidence should be to warrant a finding of civil or criminal liability has universal appeal. Any system of adjudication whose decisions are informed by evidence will confront this question in one way or another. Not all legal systems will explicitly formulate standards of proof for trial decisions. Some legal systems may specify rules about how evidence should be weighed without formulating decision criteria such as standards of proof. But even without explicit proof standards, the triers of facts, judges or jurors, will have to decide whether the evidence is sufficient to judge the defendant legally liable.

Need to revise this when the chapter is done.

We will not survey the extensive legal literature and case law about proof standards. We will instead examine whether or not probability theory can bring conceptual clarity to an otherwise heterogeneous legal doctrine. This chapter outlines different probabilistic approaches, formulates the most common challenges against them, and offers a number of responses from the perspective of legal probabilism. The legal and philosophical literature has focused on the theoretical and analytical challenges. We will do the same here. We will focus on two key theoretical challenges that have galvanized the philosophical literature: the problem of naked statistical evidence and the conjunction paradox. One reason to choose these two in particular is that it would be desirable to be able to handle basic conceptual difficulties before turning to more complex issues or attempting to implement probabilistic standards of proof in trial proceedings.

Here you sound like you’re gonna list a bunch of reasons but you give only one. Consider adding reasons or reformulating this bit.

3 Probability thresholds

Imagine you are a trier of fact, say a judge or a juror, who is expected to make a decision about the guilt of a defendant who faces criminal charges. The prosecution presents evidence to support its accusation, and the defense offers counterevidence. As a trier of fact, you are confronted with the question whether the totality of the evidence presented at trial warrants a conviction. More specifically, the question is whether the evidence as a whole establishes the defendant’s guilt beyond a reasonable doubt.

3.1 The basic idea

Legal probabilists have proposed to interpret proof beyond a reasonable doubt as the requirement that the defendant's probability of guilt, given the evidence presented at trial, meet a threshold (see Bernoulli, 1713; Dekay, 1996; Kaplan, 1968; Kaye, 1979a; Laplace, 1814; Laudan, 2006). On this interpretation, so long as the defendant's guilt is established with a sufficiently high probability, say 95%, guilt is proven beyond a reasonable doubt and the defendant should be convicted. If the probability of guilt does not reach the requisite threshold, the defendant should be acquitted. This interpretation can be spelled out more formally by means of conditional probabilities. That is, a body of evidence E establishes guilt G beyond a reasonable doubt if and only if $P(G|E)$ is above the threshold.

This interpretation is, in many respects, plausible. From a legal standpoint, the requirement that guilt be established with high probability, still short of 100%, accords with the principle that proof beyond a reasonable doubt is the most stringent standard but does not require—as the Supreme Court of Canada put it—'proof to an absolute certainty' and thus 'it is not proof beyond any doubt' (*R v Lifchus*, 1997, 3 SCR 320, 335). The plausibility of a probabilistic interpretation is further attested by the fact that such an interpretation is tacitly assumed in empirical studies about people's understanding of proof beyond a reasonable doubt (Dhami, Lundrigan, & Mueller-Johnson, 2015). This research examines where decision-makers set the bar for convictions, say at 80% or 90% probability, but does not question the assumption that standards of proof function as probabilistic thresholds of some kind.

Reliance on probability is even more explicit in the standard 'preponderance of the evidence'—also called 'balance of probabilities'—which governs decisions in civil disputes. This standard can be interpreted as the requirement that the plaintiff—the party making the complaint against the defendant in a civil case—establish their version of the facts with greater than 50% probability. The 50% threshold, as opposed to a more stringent threshold of 95% for criminal cases, reflects the fact that preponderance is less demanding than proof beyond a reasonable doubt. The intermediate standard 'clear and convincing evidence' is more stringent than the preponderance standard but not as stringent as the beyond a reasonable doubt standard. Since it lies in between the other two, it can be interpreted as the requirement that the plaintiff establish their versions of the facts with, say, 75-80% probability.

3.2 Mixed reactions from legal practitioners

When appellate courts have examined the question whether standards of proof can be quantified using probabilities, they have often answered in the negative. One of the clearest opposition to quantification was formulated by Germany's Supreme Court, the Federal Court of Justice, in the case of Anna Anderson who claimed to be a descendant of the Tsar family. In 1967, the Regional Court of Hamburg ruled that Anderson failed to present sufficient evidence to establish that she was Grand Duchess Anastasia Nikolayevna, the youngest daughter of Tsar Nicholas II, who allegedly escaped the murder of the Tsar family by the Bolsheviks in 1918. (Incidentally, DNA testing later demonstrated that Anna Anderson had no relationship with the Tsar family.) Anderson appealed to Germany's Federal Court, complaining that the Regional Court had set too demanding a proof standard. Siding with the lower court, the Federal Court made clear that '[t]he law does not presuppose a belief free of all doubts', thus recognizing the inevitable fallibility of trial decisions. The Court warned, however, that it would be 'wrong' to think that a trial decision could rest on 'a probability bordering on certainty' (Federal Court of Justice, February 17, 1970; III ZR 139/67).

The Anderson decision is all the more interesting as it applies to a civil case. The German court did not think trial decisions could rest on a probability, not even in a civil case. The same conclusion would be less surprising if it applied to a criminal case. For example, Buchak (2014) has argued that an attribution of criminal culpability is an ascription of blame which requires a full belief in someone's guilt, and a proposition that is highly probable on the evidence, no matter how high its probability, cannot amount to a full belief. One is left wondering, however, if a high probability of guilt short of 100% isn't enough and certainty cannot be required either, how else could the standard of proof be met? The question becomes more pressing in civil cases if we replace 'guilt' with 'civil liability'. Anticipating this worry, Germany's Federal Court in the Anderson case endorsed a conception of proof standards that acknowledges the inevitable fallibility of trial decisions while at the same time maintaining the need for certainty. The Federal Court wrote that a judge's decision must satisfy 'a degree of certainty which is useful for practical life and which makes the doubts silent without completely excluding them' (Federal Court of Justice, February 17, 1970; III ZR 139/67).

The words of Germany's Federal Court echo dilemmas that bedeviled early theorists of probability and evidence law. When Jacob Bernoulli—one of the pioneers of probability theory—discusses the requirement for a criminal conviction in his *Ars Conjectandi* (1713), he writes that 'it might be determined whether 99/100 of probability suffices or whether 999/1000 is required' (part IV). This is one of the earliest suggestions that the criminal standard of proof be equated with a threshold probability of guilt. A few decades later, the Italian legal penologist Cesare Beccaria in his celebrated treatise *On Crimes and Punishments* (1764) remarks that the certainty needed to convict is 'nothing but a probability, though a probability of such a sort to be called certainty' (chapter 14). This suggestive yet admittedly elusive remark indicates that the standard of decision in criminal trials should be a blend of probability and certainty. But what this blend of probability and certainty should be like is unclear. At best, Beccaria's suggestion brings us back to paraphrases of proof beyond a reasonable doubt such as 'moral certainty' or 'abiding conviction'.

Not all legal practitioners, however, resist a probabilistic interpretation of standards of proof. Some actually find such interpretation plausible, even obvious. For example, Justice Harlan of the United States Supreme Court writes:

... in a judicial proceeding in which there is a dispute about the facts of some earlier event, the factfinder cannot acquire unassailably accurate knowledge of what happened. Instead, all the factfinder can acquire is a belief of what probably happened. The intensity of this belief – the degree to which a factfinder is convinced that a given act actually occurred – can, of course, vary. In this regard, a standard of proof represents an attempt to instruct the factfinder concerning the degree of confidence our society thinks he should have in the correctness of factual conclusions for a particular type of adjudication.¹

After this methodological premise, Justice Harlan explicitly endorses a probabilistic interpretation of standards of proof, using the expression 'degree of confidence' instead of 'probability':

Although the phrases 'preponderance of the evidence' and 'proof beyond a reasonable doubt' are quantitatively imprecise, they do communicate to the finder of fact different notions concerning the degree of confidence he is expected to have in the correctness of his factual conclusions.

Justice Newman of United States Court of Appeals for the Second Circuit proposes a similar definition. He worries that words such as 'probability' or 'likelihood' may confuse jurors, as these words often qualify predictions about future events that may or may not occur. Instead, Newman prefers the expression 'degree of certainty'. In characterizing proof beyond a reasonable doubt, he writes:

Were I the trier of fact, I would think about my own degree of certainty about the defendant's guilt, and, with a scale of 0 to 100 in mind, not vote to convict unless my degree of certainty exceeded 95 on that scale (p. 269) CITED FROM: Jon O. Newman (2006), Quantifying the standard of proof beyond a reasonable doubt: a comment on three comments. *Law, Probability and Risk*, 5, pp. 267-269

OTHER EXAMPLES TO CHECK. SEE REFERENCES BELOW:

FRANKLIN, J. (2006) Case Comment-United States v. Copeland, 369 F. Supp. 2d 365 (E.D.N.Y. 2005): quantification of the 'proof beyond reasonable doubt' standard. *Law, Probability and Risk*, 5, 159-165.

TILLERS, P. and GOTTFRIED, J. (2006) Case Comment-United States v. Copeland, 369 F. Supp. 2d 365 (E.D.N.Y. 2005): A Collateral Attack on the Legal Maxim That Proof Beyond a Reasonable Doubt Is Unquantifiable? *Law, Probability and Risk*, 5, 135-157.

WEINSTEIN, J. B. and DEWSBURY, I. (2006) Comment on the meaning of 'proof beyond a reasonable doubt'. *Law, Probability and Risk*, 5, 167-173.

3.3 Implementation and idealization

The remarks by Justice Harlan, Newman and others notwithstanding, legal practitioners seem in general opposed to quantifying standards of proof probabilistically. This resistance has many causes. One key factor is the conviction that a probabilistic interpretation of legal standards of proof is unrealistic because its implementation would face unsurmountable challenges. How can the relevant probabilities—such as the probability of someone's guilt—be quantified? How will the triers of facts apply probabilistic

¹ In re Winship, 397 U.S. 358, 370 (1970). This is a landmark decision by the United States Supreme Court establishing that the beyond a reasonable doubt standard must be applied to both adults and juvenile defendants.

You only talk about Harlan; it would be nice to have more examples of people embracing probabilistic explications. M: GOOD POINT. ADDED MORE. NEED TO ADD EVEN MORE.

thresholds? Should the application of the thresholds be automatic—that is, if the evidence meets the threshold, the triers of fact should find against the defendant (say, convict in a criminal trial) and otherwise find in favor of the defendant? The challenge, in general, is to articulate how probabilistic thresholds can be operationalized as part of trial decisions. This is by no means obvious. Judges and jurors do not weigh evidence in an explicitly probabilistic manner. Nor do they explicitly use probability thresholds to guide their decisions. CITE EMPIRICAL EVIDENCE HERE FOR NARRATIVE AND PLAUSIBILITY THEORY AGAINST PROBABILISTIC APPROACH. And even if judges and jurors were to change the way they assess, and reason about, the evidence presented at trial there would remain the problem of computational tractability. How could all the variables needed to assess the relevant probabilities be taken into account in a computationally tractable way? CITE ALLEN. SAY MORE ABOUT COMPUTATIONAL TRACTABILITY EVEN FOR BAYESIAN NETWORK.

To alleviate the force of these worries, the probabilistic interpretation of proof standards can be broken down into two separate claims, what we might call the ‘quantification claim’ and the ‘threshold claim’. In a criminal trial, these claims would look as follows:

QUANTIFICATION CLAIM a probabilistic quantification of the defendant’s guilt can be given through an appropriate weighing of all the evidence available (that is, of all the evidence against, and of all the evidence in defense of, the accused).

THRESHOLD CLAIM an appropriately high threshold guilt probability, say 95%, should be the decision criterion for criminal convictions.

Those worried about implementation might reason thusly. If guilt cannot be quantified probabilistically—for example, in terms of the conditional probability of G given the total evidence E —no probabilistic threshold could ever be used as a decision criterion. Since the quantification claim is unfeasible and the threshold claim rests on the quantification claim, the threshold claim should be rejected.

One way to answer this objection is to bite the bullet. Legal probabilists can admit that probabilistic thresholds constitute a revisionist theory. If they are to be implemented in trial proceedings, they will require changes. Jurors and judges will have to become familiar with probabilistic ideas. They will have to evaluate the strength of the evidence numerically, even for evidence that is not, on its face, quantitative in nature. But this response will simply heighten the resistance toward a probabilistic interpretation of proof standards, or at least, the likelihood of success of such a program of radical reform of trial proceedings is uncertain. But there is a less radical way for legal probabilists to respond, one that admits that legal probabilism tacitly assumes a certain degree of idealization.

Legal probabilists can admit they are not—at least, not yet—engaged with implementation or trial reform. More specifically, the quantification claim can be interpreted in at least two different ways. One interpretation is that a quantification of guilt—understood as an actual reasoning process—can be effectively carried out by the fact-finders. The quantification claim can also be understood as an idealization or a regulative ideal. For instance, the authors of a book on probabilistic inference in forensic science write:

the ... [probabilistic] formalism should primarily be considered as an aid to structure and guide one’s inferences under uncertainty, rather than a way to reach precise numerical assessments. ... (Taroni, Biedermann, Bozza, Garbolino, & Aitken, 2014, (p. xv))

Even from a probabilist standpoint, the quantification of guilt can well be an idealization which has, primarily, a heuristic role. MAYBE ALSO ADD THAT RONALD ALLEN WOULD NOT OBJECT TO THIS, AS HE THINKS THAT PROBABILITY ARE TOOLS IN PLAUSIBILITY REASONING. ADD CITATION.

Just as the quantification claim can be interpreted in two different ways, the same can be said of the threshold claim. For one thing, we can interpret it as describing an effective decision procedure, as though the fact-finders were required to mechanically convict whenever the defendant’s probability of guilt happened to meet the desired probabilistic threshold. But there is a second, and less mechanistic, interpretation of the threshold claim. On the second interpretation, the threshold claim would only describe a way to understand, or theorize about, the standard of proof or the rule of decision. The second interpretation of the threshold claim—which fits well with the ‘idealization interpretation’ of the quantification claim—is less likely to encounter resistance.

Lawrence Tribe, in his famous 1971 article ‘Trial by Mathematics’, expresses disdain for a trial process that were mechanically governed by numbers and probabilities. He claims that under this scenario judges and jurors would forget their humanizing function. He writes:

Guided and perhaps *intimidated by the seeming inexorability of numbers*, induced by the persuasive force of formulas and the precision of decimal points to perceive themselves as performing a largely mechanical and automatic role, *few jurors ... could be relied upon to recall, let alone to perform, [their] humanizing function.* (Tribe, 1971)

But this worry does not apply if we interpret the threshold claim in a non-mechanistic way. This is the interpretation we shall adopt in this chapter. To avoid setting the bar for legal probabilism too high, we will not be concerned with practical issues that arise if we wanted to deploy a probabilistic threshold directly. We will grant that, at least for now, successful implementation of such thresholds is not viable. For the time being, probabilistic thresholds are best understood as offering a theoretical, analytical model of trial decisions. The fact that this theoretical model cannot be easily operationalized does not mean that the model is pointless. There are multiple ways in which such a model, even if unfit for direct deployment in trial proceedings, can offer insights into trial decision-making.

3.4 Minimizing expected costs: higher cost ratio, higher threshold

Let's start with the simplest illustration of how the probabilistic interpretation of proof standards can serve as a theoretical, analytical tool for conceptual clarification. Standards of proof are usually ranked from the least demanding, such as preponderance of the evidence, to the most demanding, such as proof beyond a reasonable doubt, even though this distinction has not always been around.² Can we give a principled justification for the use of multiple standards and their ranking? A common argument is that more is at stake in a criminal trial than in a civil trial. A mistaken conviction will unjustly deprive the defendant of basic liberties or even life. Instead, a mistaken decision in a civil trial would not encroach upon someone's basic liberties since decisions in civil trials are mostly about imposing monetary compensation. This difference in the stakes warrants different standards of proof, more stringent for criminal than civil cases. This informal argument can be made precise by pairing probability thresholds with expected utility theory, a well-established paradigm of rational decision-making used in psychology and economic theory.

At its simplest, decision theory based on the maximization of expected utility states that between a number of alternative courses of action, the one with the highest expected utility (or with the lowest expected cost) should be preferred. This theory can be applied to a variety of situations, including civil or criminal trials. To see how this works, note that trial decisions can be factually erroneous in two ways. A trial decision can be a false positive—i.e. a decision to hold the defendant liable (to convict, in a criminal case) even though the defendant committed no wrong (or committed no crime). A trial decision can also be a false negative—i.e. a decision not to hold the defendant liable (or to acquit, in a criminal case) even though the defendant did commit the wrong (or committed the crime). Let $\text{cost}(CI)$ and $\text{cost}(AG)$ be the costs associated with the two decisional errors that can be made in a criminal trial, convicting an innocent (CI) and acquitting a guilty defendant (AG). Let $P(G|E)$ and $P(I|E)$ be the guilt probability and the innocence probability estimated on the basis of the evidence presented at trial. Given a simple decision-theoretic model (Kaplan, 1968), a conviction should be preferred to an acquittal whenever the expected cost resulting from a mistaken conviction—namely, $P(I|E) \cdot \text{cost}(CI)$ —is lower than the expected cost resulting from a mistaken acquittal—namely, $P(G|E) \cdot \text{cost}(AG)$. That is,

$$\text{convict provided } \frac{\text{cost}(CI)}{\text{cost}(AG)} < \frac{P(G|E)}{P(I|E)}.^3$$

For the inequality to hold, the ratio of posterior probabilities $\frac{P(G|E)}{P(I|E)}$ should exceed the cost ratio $\frac{\text{cost}(CI)}{\text{cost}(AG)}$. So long as the costs can be quantified, the probability threshold can be determined. For example, suppose mistaken conviction is nine times as costly as a mistaken acquittal. The corresponding probability threshold will be 90%. On this reading, in order to meet the standard of proof beyond a reasonable doubt, the prosecution should provide evidence that establishes the defendant's guilt with at least 90% probability, or in formulas, $P(G|E) > 90\%$. The higher the cost ratio $\frac{\text{cost}(CI)}{\text{cost}(AG)}$, the higher the requisite

²See e.g. *United States v. Feinberg*, 140 F.2d 592 (2d Cir. 1944): “to distinguish between the evidence which should satisfy reasonable men, and the evidence which should satisfy reasonable men beyond a reasonable doubt. While at times it may be practicable to deal with these as separate without unreal refinements, in the long run the line between them is too thin for day to day use” (594).

³This follows from $P(I|E) \cdot \text{cost}(CI) < P(G|E) \cdot \text{cost}(AG)$.

threshold. The lower the cost ratio, the lower the requisite threshold. For example, if the cost ratio is 99, the threshold would be as high as 99%, but if the cost ratio is 2, the threshold would only be 75%.

The same line of argument applies to civil cases. Let a false attribution of liability FL be a decision to find the defendant liable when the defendant committed no civil wrong (analogous to the conviction of an innocent in a criminal case). Let a false attribution of non-liability FNL be a decision not to find the defendant liable when the defendant did commit the civil wrong (analogous to the acquittal of a factually guilty defendant in a criminal case). Let $P(L|E)$ and $P(NL|E)$ be the liability probability and the non-liability probability given the evidence presented at trial. So long as the objective is to minimize the costs of erroneous decisions, the rule of decision would be as follows:

$$\text{find the defendant civilly liable provided } \frac{\text{cost}(FL)}{\text{cost}(FNL)} < \frac{P(L|E)}{P(NL|E)}.^4$$

If the cost ratio $\frac{\text{cost}(FL)}{\text{cost}(FNL)}$ is set to 1, the threshold for liability judgments should equal 50%, a common interpretation of the preponderance standard in civil cases. This means that $P(L|E)$ should be at least 50% for a defendant to be found civilly liable.

The difference between proof standards in civil and criminal cases lies in the different cost ratios. The cost ratio in civil cases, $\frac{\text{cost}(FL)}{\text{cost}(FNL)}$, is typically lower than the cost ratio in criminal cases, $\frac{\text{cost}(CI)}{\text{cost}(AG)}$, because a false positive in a criminal trial (a mistaken conviction) is considered a more harmful error than a false positive in a civil trial (a mistaken attribution of civil liability). This difference in the cost ratio can have a consequentialist or a retributivist justification (Walen, 2015). From a consequentialist perspective, the loss of personal freedom or even life can be considered a greater loss than being forced to pay an undue monetary compensation. From a retributivist perspective, the moral wrong that results from the mistaken conviction of an innocent person can be regarded as more egregious than the moral wrong that results from the mistaken attribution of civil liability. This difference in consequences or moral wrongs can be captured by positing a higher cost ratio in criminal than civil cases.

Along similar lines, Justice Harlan of the United Supreme Court draws a clear difference in the cost ratio between criminal and civil litigation:

In a civil suit between two private parties for money damages, for example, we view it as no more serious in general for there to be an erroneous verdict in the defendant's favor than for there to be an erroneous verdict in the plaintiff's favor . . . In a criminal case, on the other hand, we do not view the social disutility of convicting an innocent man as equivalent to the disutility of acquitting someone who is guilty. In *Re Winship* (1970), 397 U. S. 358, 371.

To underscore the differences in the cost ratios, Harlan cites an earlier decision of the United States Supreme Court that emphasizes how a defendant's liberty has a transcending value:

[t]here is always in litigation a margin of error . . . , representing error in factfinding, which both parties must take into account . . . [w]here one party has at stake an interest of transcending value – as a criminal defendant his liberty – . . . this margin of error is *reduced* as to him by the process of placing on the other party [i.e. the prosecutor] the standard of . . . persuading the factfinder at the conclusion of the trial of his guilt beyond a reasonable doubt. *Speiser v. Randall* (1958), 357 U.S. 513, 525-26.

Justice Newman of the United States Court of Appeals for the Second Circuit made a similar point by linking directly the ratio of errors and the degree of certainty required for a conviction:

... all must recognize that factfinders are fallible and that any system of adjudicating guilt will inevitably run some risk of both convicting the innocent and acquitting the guilty....Whatever ratio [of false conviction to false acquittals] we find acceptable, one of the major variables in achieving that ratio is the degree of certainty we impose on factfinders. (p. 980) QUOTED FROM: Jon O. Newman (1993), *Beyond Reasonable Doubt*, New York University Law Review, 68(5), pp. 979-1002

3.5 Beyond just costs: the benefits of correct decisions

The analysis provided so far is limited since it only weighs the costs of mistaken decisions, but leaves out the benefits of correct decisions. A more comprehensive analysis should consider both. Even though the basic idea is the same—that is, trial decision-making is viewed as an instrument for maximizing

⁴This follows from $P(NL|E) \cdot \text{cost}(FL) < P(L|E) \cdot \text{cost}(FNL)$

overall social welfare (Dekay, 1996; Laudan, 2016; Posner, 1973)— a mre comprehensive analysis would afford a more nuanced understanding. It is therefore instructive to explore the implications of weighing the costs of incorrect decisions as well as the benefits of correct decisions.

For simplicity, we will quantify costs and benefits with units of utility using the abbreviation $ut(\dots)$. Benefits will correspond to positive numbers and costs to negative numbers. In a criminal trial, the (negative) utility of a mistaken conviction should be weighed together the (negative) utility of an incorrect acquittal: $ut(CI)$ v. $ut(AG)$. In addition, the (positive) utility of a correct conviction should be weighed together with the (positive) utility of a correct acquittal: $ut(CG)$ v. $ut(AI)$. Given this set-up, a conviction would be justified provided its expected utility—that is, $P(G|E) \cdot ut(CG) + P(I|E) \cdot ut(CI)$ —exceeds the expected utility of an acquittal—that is, $P(G|E) \cdot ut(AG) + P(I|E) \cdot ut(AI)$. By elementary algebraic steps, the threshold is identified by the equation:

$$P(G|E) > \frac{1}{1 + \frac{ut(CG)-ut(AG)}{ut(AI)-ut(CI)}}.^5$$

In a number of cases, this new formula returns the same threshold as the earlier one. If the benefits of convictions and acquittals are zero, this inequality identifies the same threshold as the earlier inequality that only considered costs. For example, if the costs of a mistaken conviction is nine times the cost of a mistaken acquittal, that is, $\frac{ut(CI)}{ut(AG)} = 9$, while the benefits are zero, the decision threhsold should be a guilt probability of $\frac{1}{1+(1/9)} = 0.9$, as before. Or suppose the magnitude of the benefits resulting from acquitting an innocent defendant (say +9 units of utility) is the same as the magnitude of the costs resulting from convicting an innocent (-9 units of utility). Similarly, suppose the magnitude of the benefits resulting from convicting a guilty defendant (say +1 unit of utility) is the same as the magnitude of the cost resulting from acquitting a guilty defendant (say -1 unit of utility). Again, the threshold would be $\frac{1}{1+(1+1)/(9+9)} = 0.9$.

But consider now the following utility assignments: $ut(CI) = -9$, $ut(AG) = -1$, $ut(CG) = 5$, and $ut(AI) = 5$. The correspoding threshold would be $\frac{1}{1+(5+1)/(5+9)} = 0.7$, significantly below the 90% threshold. If the benefits of correct decisions are further increaesed, say at 7 units of utility each, the threshold would be lowered further to 66% since $\frac{1}{1+(7+1)/(7+9)} = 0.66$. So the the benefits of correct decisions are not at all inconsequential. In order to keep the threshold for criminal convictions releatively high the benefit of correct conviction would have to be close to zero (as seen before) or alternatively, the benefit of a correct acquittals would have to be significantly higher than the benefit of correct conviction. Say $ut(CG) = 2$ but $ut(AI) = 18$, while still $ut(CI) = -9$, $ut(AG) = -1$, the threshold would be $\frac{1}{1+(2+1)/(18+9)} = 0.9$.

The new inequality shows that the threshold depends on the ratio of the difference between utilities, not so much the cost ratio or the benefit ratio. A given cost and benefit ratio may correspond to different thresholds. In the examples above, even though the cost ratio was fixed at 9:1 and the benefit ratio at 1:1, the threshold was 70% in one case and 66% in the other. The difference in the threshold is due to the difference in the absolute magnitude of the benefits resulting from correct decisions, increased from +5 units of utility to +7 units of utility.

A question suggests itself. How should utilities be assigned? The assignments may be a moral question (what the right conception of justice dictates), an empirical question (what the majority thinks the utilities should be), or a political question (how political ideologies affect utility assignments). For one thing, elected officials should set the appropriaate assignments of utilities, and elected officials should represent the will of the people. On other hand, it is curious that the standard of proof should be allowed to vary depending on the political party who is is charge at the moment. Perhaps, standards of proof should be part of a country's constitution and not vary depending on the political party in power.

We will now explore different strategies for assigning utility to correct and incorrec trial decisions. One stratgy is to identify the main sources of harm and the main sources of benefits reslting from trial decision. The weight placed on each diferent harms or benefits is likely to be a matter of political ideology.

Let's start with a politically neutral assignment of utilities. Consider the loss resulting from convicting an innocent defendant. This loss includes: the inappropriate assignment of culpability (-1); damaged reputation (-1); loss of income (-1); severance from family members (-1); putting other citizens at risk

⁵SHOW COMPUTATIONS HERE

of victimization by failing to convict the actual perpetrator (-1); weakening the deterrence function of the trial system by failing to apprehend the perpetrator (-1). This is a total utility loss of -6. What about the correct acquittal of an innocent? There would be no inappropriate assignment of culpability (0); no reputational damage (0); no loss of income (0); no severance from family members (0). The actual perpetrator, however, could still victimize others (-1) and deterrence would be weakened (-1). The innocent defendant who is acquitted could still experience damaged reputation and other harms, but we shall leave these details aside. All in all, trying an innocent defendant, no matter the final decision, carries the baseline costs of failing to identify the true perpetrator (-1) and putting other citizens at risk of victimization (-1). This baseline cost increases when an innocent person is wrongly convicted. So, by adding everything up, $ut(AI) - ut(CI) = -2 + 6 = +4$. Next, consider the loss resulting from acquitting a guilty defendant. This will include putting other citizens at risk of victimization by the perpetrator who is not convicted (-1) and possibly weaken the deterrence function of the trial system (-1). There would be no inappropriate assignment of culpability (0); no damaged reputation (0); no loss of income (0); no severance from family members (0). What about the conviction of a guilty defendant? The defendant would still experience damaged reputation (-1); loss of income (-1); severance from family members (-1). However, citizens would enjoy a lower risk of victimization (+1) and the deterrence function of the trial system would be reaffirmed (+1). There would also be no incorrect assertions about the citizen's culpability (0). All things considered, $ut(CG) - ut(AG) = -1 + 2 = +1$. So, assuming the utilities are correctly assigned, the threshold for a criminal conviction should be $\frac{1}{1+\frac{1}{4}} = 0.8$, lower than the earlier 90% threshold. (Incidentally, if the correct assignment of culpability is counted as a positive benefits (say +1) from a correct conviction, then $ut(CG) - ut(AG) = 0 + 2 = +2$ and the threshold would be $\frac{1}{1+\frac{1}{2}} = 0.6666$, an even lower threshold.)

The above analysis is—arguably—politically neutral because it takes into account the costs of a conviction, even for those who are factually guilty, such as loss of income and severance from family members. These are issues often emphasized by those on the left who are wary of the costs of criminalization and punitiveness, even for those who, strictly speaking, did commit a crime. At the same time, the above analysis also takes into account the negative consequences that result from failing to apprehend the actual perpetrator, such as heightened crime victimization for others, a point often made by people on the right who are concerned with so-called “law and order”.

Suppose someone is extremely concerned about risk of victimization for different reasons, such as more conservative political views or having grown up in a high crime area. Suppose the costs resulting from the risk of victimization resulting from a false acquittal or the trial of an innocent are increased from -1 to -3. Conversely, the benefits resulting from lower risk of victimization associated with a correct conviction are also increased from +1 to +2. Then, $ut(AI) - ut(CI) = +4$, as before, but $ut(CG) - ut(AG) = 0 + 3 = +3$. The threshold would be $\frac{1}{1+\frac{3}{4}} = 0.57$, significantly lower than before. Unsurprisingly, someone who is very concerned with the risk of victimization will favor a lower threshold for conviction in criminal cases. (CITE LAUDAN and SAUNDERS HERE).

Let's now explore the view of someone—perhaps more progressive, liberal and left-leaning—who is more concerned about negative effects of criminalization, such as loss of income and severance from family members. Suppose the utility loss is increased from -1 to -2 for each of these items. Then, $ut(AI) - ut(CI) = -2 + 8 = +6$, as before, but $ut(CG) - ut(AG) = -3 + 2 = -1$. The threshold would be $\frac{1}{1+\frac{-1}{6}} = 1.2$. Interestingly, under this assignment of utilities, convicting a defendant never maximizes expected utility unless the evidence establishes guilt with 120% probability. This is clearly impossible. In other words, if the costs of criminalization are so high, convicting anyone is never justified, not even someone whose guilt is 100% probable.

This conclusion could show one of two things. First, it could show that the assignment of utility above is non-sensical, because it leads to the non-sensical conclusion that no one should ever be convicted. Alternatively, those who stand by that assignment of utilities (or one like that) will be committed to say that the practice of convicting people as we know it should be abolished, at least until the cost of criminalization become less burdensome. The latter view is by no means a non-starter, as it agrees with radical proposals about prison abolition. (CITE APPROPRIATE REFERENCES ABOUT PRISON ABOLITION).

As the above discussion shows, probabilistic thresholds, when paired with expected utility theory, provide an analytical framework to justify, or at least meaningfully debate, different degrees of stringency necessary for decision criteria—i.e. legal proof standards—in criminal trials. The same discussion could

be had for civil trials.

This analytical framework allows for even finer distinctions, not explicitly codified in the law. The law typically makes coarse distinctions between standards of proof, such as ‘proof beyond a reasonable doubt’ for criminal cases, ‘preponderance of the evidence’ for civil cases and ‘clear and convincing evidence’ for a narrow subset of civil cases in which the accusation against the defendant is particularly serious. But for rather different crimes, associated with rather different punishments, say murder and grand theft, the same standard of proof is applied for both. It is not obvious why this should be so, except that a finer distinction may cause more confusion than there need be. If the probability required for a conviction or a finding of civil liability against the defendant is a function of weighing the costs and benefits that would result from true and false positives (as well as true and false negatives), the stringency of the threshold should depend on costs and benefits, and thus different cases may require different thresholds. Cases in which the charge is more serious than others—say, murder compared to grand theft—may require higher thresholds so long as the cost of a mistaken decision against the defendant is more significant. In countries that allow for the death penalty or life imprisonment for certain crimes but not others, the cost of a mistaken conviction would be more serious for crimes with harsher punishments, other things being equal. Thus, the threshold should be placed appropriately higher. We could even think that the threshold should vary across individual cases even for defendants charged with the exact same crime, provided the costs are different for different individuals. However, whether or not standards of proof should vary in this way is debated (Kaplow, 2012; Picinali, 2013). Ultimately, the question is what considerations should be admissible in the calculus of costs and benefits.

The discussion so far might have proceeded from the wrong assumption. To weigh the costs and benefits of convictions and acquittals, correct and incorrect, is one thing. It is another to weigh the costs and benefits of punishment. So perhaps the calculus should only strictly apply to trial decisions, not to what flows from them.

NEEDS MORE EXPLANATION HERE

- 1) OTHER QUESTION TO ADDRESS IS WHAT COST AND BENEFITS? MAYBE ONLY COSTS AND BENEFIT OF A CONVICTION (BLAME ATTRIBUTION), NOT EVERYTHING THAT FOLLOWS FROM A CONVICTION.
- 2) RELATED POINT. SOME COSTS AND BENEFITS ARE ASSOCIATED WITH LITIGATION PER SE, OTHERS WITH PUNISHMENT, SO IN TALKING ABOUT COSTS AND BENEFITS OF TRIAL DECISION PERHAPS WE SHOULD TAKE A MORE NARROW APPROACH. WHAT ARE THE UNIQUE COSTS AND BENEFITS OF TRIAL DECISION?
- 3) SOME COSTS AND BENEFITS ARE SHARED BY MULTIPLE TYPES OF DECISIONS. E.G. CONVICTION ALL DEPRIVE THE DEFENDANT OF INCOME AND FAMILY TIES, WHETHER THE DEFENDANT IS GUILTY OR INNOCENT. DOES THIS MEAN THESE COSTS AND BENEFITS ARE IRRELEVANT FOR THE CALCULUS OF UTILITY?
- 4) WHAT THE ANALYSIS IS MISSING A LARGER LOOK AT THE CONTEXT OF THE TRIAL, PLEASE BARGAINING, THE CRIMINAL JUSTICE SYSTEM AND SOCIETY MORE GENERALLY. MULTI STAGE ANALYSIS. THE MAXIMIZATION OF EXP UTILITY FRAMEWORK OBSCURES THIS COMPLEXITY.
- 5) COMPLEXITY PROBLEM. ALLEN.

3.6 SUGGESTION

MARCELLO: IF WE END UP DIVIDING THIS CHAPTER INTO TWO OR THREE SEPARATE CHAPTERS, WE COULD CONTINUE THE DISCUSSION OF THE ANALYTICAL POWER OF THE PROBABILISTIC APPROACH MORE IN DETAIL HERE, DRAWING ON SOME OF THE MATERIALS ALREADY IN THE LONGER VERSION OF THE SEP ENTRY.

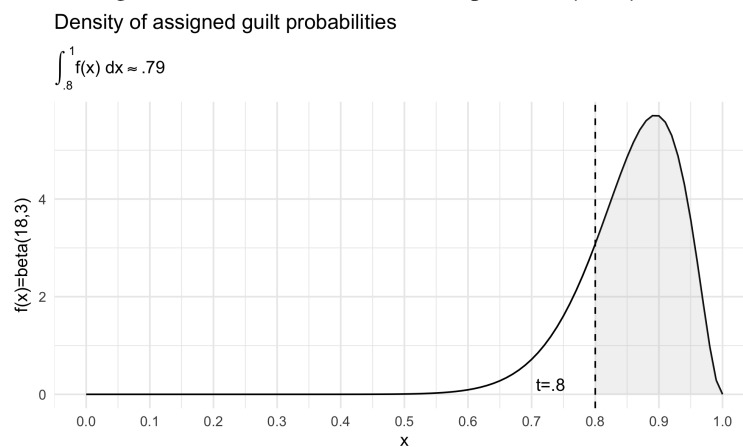
HERE IS A TENTATIVE IDEA OF WHAT TO DISCUSS:

- (1) SIMPLE EXPECTED UTILITY MODEL - **DONE, SEE ABOVE**
- (2) LAUDAN MODEL, THIS IS A MORE COMPLICATED EXPECTED UTILITY MODEL, PARTLY BORROWED FROM LAPLACE - **YET TO BE DONE**
- (3) SIGNAL DETECTION THEORY MODEL - **YET TO BE DONE, ONLY PARTLY DONE**
- (4) HAMER MODEL AND KAYE MODEL FOR ERROR MINIMIZATION (DISCUSSED IN THE SEP ENTRY, INTEGRALS, DERIVATIVES, ETC.) - **DONE SEE BELOW**
- (5) GOOD AND BAD THINGS ABOUT THESE MODELS, BUT OVERALL THEY SHOW THAT

3.7 Minimizing overall errors

Instead of maximizing expected utility (or minimizing expected costs), standards of proof can be analyzed as decision criteria that have long term effects on the epistemic performance of the trial system. Think about the criminal justice as a whole, making decisions about the guilt and innocence of thousands of defendants facing trial. The system will make a number of decisional errors, committing type I and type II errors. Viewing standards of proof as probability thresholds helps to understand how decisional errors are managed and allocated at this systemic level.

Consider an idealized model of the criminal trial system. Each defendant is assigned a probability x of criminal liability (or guilt) based on the evidence presented at trial. As is customary, this probability ranges between 0 and 1, or 0% and 100%. Since over a period of time many defendants face charges, the guilt probability will have its own distribution. Extreme guilty probabilities set at 0% or 100%, presumably, are assigned rarely in trials if ever, while values between 40% and 80% are more common. A rigorous way to express this distribution is by means of a probability density function, call it $f(x)$. The figure below uses a right skewed distribution, for example, $\text{beta}(18,3)$.

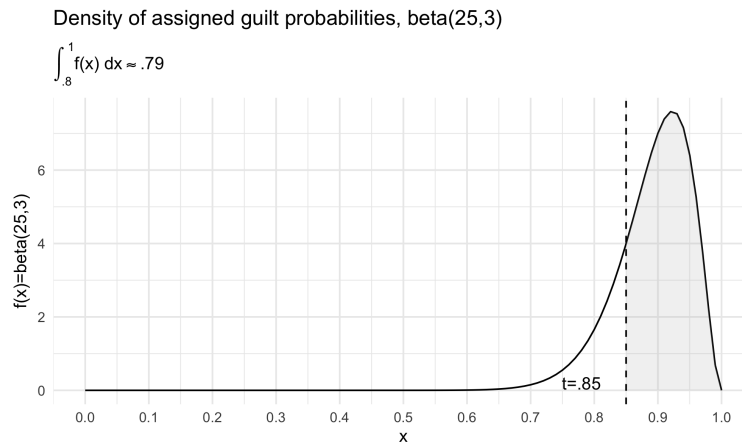


What does the distribution represent? Does it represent the probability of guilt assigned to defendants at the beginning or the end of the trial? There should be a difference between the two—hopefully—or else trial proceedings would be useless. Suppose that the distribution represents the guilt probabilities as they are assigned to defendants at the end of the trial, once all the evidence, counterevidence, arguments and counterarguments have been proffered and weighed appropriately.

The choice of the distribution is for illustrative purposes only. There are no empirical data suggesting this is the right distribution to use. But its choice is not arbitrary either. The right skew of the distribution reflects the assumption that defendants in criminal cases are prosecuted only if the incriminating evidence against them is strong. It should be no surprise that most defendants are assigned a high probability of guilt. This is plausible in principle. For people should not be prosecuted if the evidence against them is weak. The distribution of the probability of liability in civil cases over a period of time might look quite different, perhaps centered around 50% or 60%.

In the figure above, the threshold for conviction is set at $> 80\%$, and the area under the curve to the right of the threshold is about .79. According to this model, 79% of defendants on trial are convicted and 21% acquitted. These figures are close to the rates of conviction and acquittal in many countries (REFERENCES?). Since $f(x)$ is a probability density, the total area under the curve adds up to 1, encompassing all defendants, both convicted and acquitted defendants.

If the threshold becomes more stringent—for example, it moves up to 85%—the rate of conviction would decrease. This holds provided the underlying distribution does not change. But, if the threshold is set higher, those who are prosecuted will tend to face comparatively stronger evidence and thus the distribution will become more skewed toward the right—say $\text{beta}(25,3)$. As a consequence, the rate of conviction could still be about 79% even with a more stringent threshold of 85%.



The two graphs above depict the rate of conviction among those who are facing trial, not the rate of conviction in the general population overall. As just shown, the rate of conviction could remain the same even if the probability threshold is made more stringent. But, the rate of conviction in the general population is likely to diminish so long as higher thresholds, by acting as deterrents against prosecution, make it less likely that people would be prosecuted.

This formal model does not yet make any distinction between factually guilty and factually innocent defendants. But, presumably, some defendants committed the acts they are accused of and others did not. This is not a clear-cut distinction, however. Some defendants may have committed the acts they are accused of to some extent, but not to the full extent they are accused of, while others may be completely innocent of any crime whatsoever. Leaving this subtlety aside, the formal model can be refined to distinguish between factually innocent and guilty defendants.

The simplest refinement would create two separate distributions, one distribution for the factually innocent defendants and the other for the factually guilty defendants. The problem with this is that we have little idea about what these distributions should look like in the first place. Hopefully, the innocent distribution will be more left skewed and the guilty distribution more right skewed. Guilty defendants should be assigned, on average, higher guilt probabilities than innocent defendants. The two distributions could still overlap to some extent as some guilt defendants could be assigned as low guilt probabilities as some innocent defendants and conversely some innocent defendants could be assigned as high guilt probabilities as some guilty defendants. This is unfortunate, but also an inevitable consequence of the fallibility of the trial system.

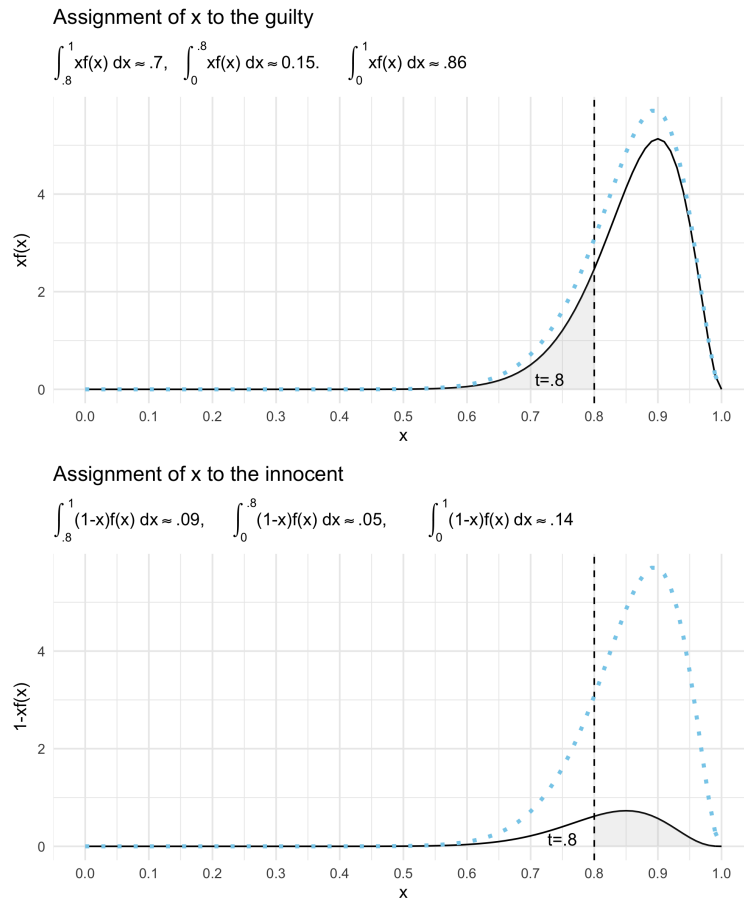
A more principled way to add two separate distributions to the model, one for guilty and another for innocent defendants, would be to derive them from the overall distribution of defendants. This can be done by following the simple principle that, among those defendants who are assigned a probability of, say, 80%, there should be a corresponding proportion of 80% guilty people and 20% innocent people. These are of course expected values, not actual values. Say you are throwing a fair six-faced die. In the long run, you would expect that in 1/6 of the throws the die would land, say on “4”.

The expected proportion of guilty and innocent defendants on trial, out of all defendants, can be inferred from the density distribution $f(x)$ under certain assumptions. Suppose each defendant is assigned a guilt probability based on the best and most complete evidence. From the perspective of judges and jurors (or anyone who has access to the evidence and evaluates it the same way), $x\%$ of defendants who are assigned $x\%$ guilt probability are expected to be guilty and $(1 - x)\%$ innocent. For example, 85% of defendants who are assigned a 85% guilt probability are expected to be guilty and 15% innocent; 90% of defendants who are assigned a 90% guilt probability are expected to be guilty and 10% innocent; and so on.

So the expected guilty distribution as a function of x will be $xf(x)$, while the expected innocent distribution will be $(1 - x)f(x)$. In other words, the function $xf(x)$ describes the (expected) assignment of guilt probabilities for guilty defendants, and similarly, $(1 - x)f(x)$ the (expected) assignment of guilt probabilities for innocent defendants. Neither of these functions is a probability density, since $\int_0^1 xf(x) dx = 0.86$ and $\int_0^1 (1 - x)f(x) dx = 0.14$. These numbers express the (expected) proportion of guilty and innocent defendants out of all defendants on trial, respectively 86% and 14%.

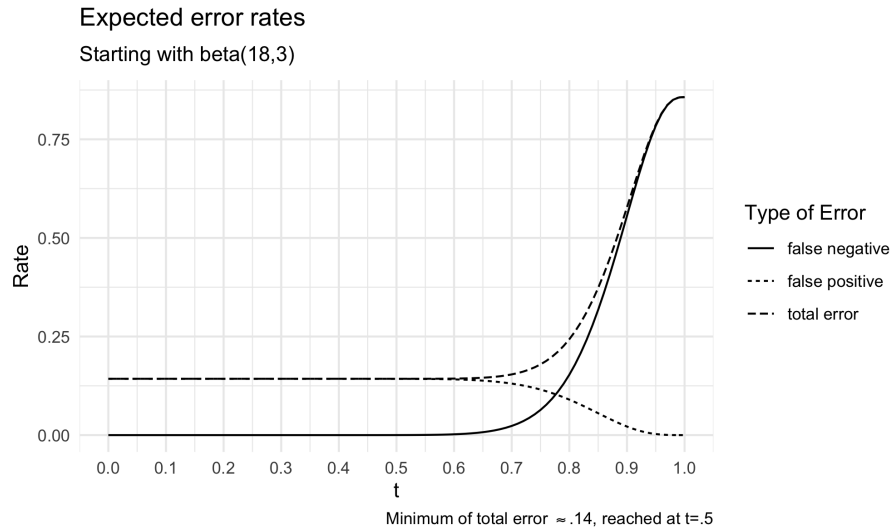
The rates of incorrect decisions—false convictions and false acquittals or more generally false positives and false negatives—can be inferred from this model as a function of the threshold t (Hamer,

2004, 2014). The integral $\int_0^t x f(x) dx$ equals the expected rate of false acquittals, or in other words, the expected proportion of guilty defendants who fall below threshold t (out of all defendants), and the integral $\int_t^1 (1-x)f(x) dx$ equals the expected rate of false convictions, or in other words, the expected proportion of innocent defendants who fall above threshold t (out of all defendants). The rates of correct decisions—true convictions and true acquittals or more generally true positives and true negatives—can be inferred in a similar manner. The integral $\int_t^1 x f(x) dx$ equals the expected rate of true convictions and $\int_0^t (1-x)f(x) dx$ the expected rate of true acquittals. In the figure below, the regions shaded in gray correspond to false negatives (false acquittals) and false positives (false convictions). The remaining white regions within the solid black curve correspond to true positives (true convictions) and true negatives (true acquittals). Note that the dotted blue curve is the original overall distribution for all defendants.



The size of the grey regions in the figures above—which correspond to false positives and false negatives—is affected by the location of threshold t . As t moves upwards, the rate of false positives decreases but the rate of false negatives increases. Conversely, as t moves downwards, the rate of false positives increases but the rate of false negatives decreases. This trade-off is inescapable so long as the underlying distribution is fixed. We have already remarked on the possibility that the distribution would change in shape as a result of changes in the probability threshold. We will return to this point later in the chapter.

Below are both error rates—false positives and false negatives—and their sum plotted against a choice of t , while holding fixed the density function `binom(18,3)`. The graph shows that any threshold that is no greater than 50% would minimize the total error rate % (comprising false positives and false negatives). A more stringent threshold, say $> 90\%$, would instead significantly reduce the rate of false positives but also significantly increase the rate of false negatives, as expected.



In general, the threshold that minimizes the expected rate of incorrect decisions overall, no matter the underlying distribution, lies at 50%. The claim that setting threshold at $t = .5$ minimizes the expected error rate holds given the distribution $f(x) = \text{beta}(18,3)$ as well as any other distribution (???). To show this, let $E(t)$ as a function of threshold t be the sum of rates of false positive and false negative decisions:

$$E(t) = \int_0^t x f(x) dx + \int_t^1 (1-x) f(x) dx.$$

The overall rate of error is minimized when $E(t)$ is the lowest. To determine the value of t for which $E(t)$ is the lowest, set the derivative of $E(t)$ and $R(t)$ to zero, that is, $\frac{d}{dt} E(t) = 0$. By calculus, $t = 1/2$.⁶ This claim holds when the two decisional errors are assigned the same weight, or in other words, the costs of false positives and false negatives are symmetric. The $> 50\%$ threshold therefore should be most suitable for civil trials. In criminal trials, however, false convictions are typically considered significantly more costly than false acquittals, say a cost ratio of 9:1 (but see (Epps, 2015)). The sum of the two error rates can be weighted by their respective costs:

$$E(t) = \int_0^t x f(x) dx + 9 \int_t^1 (1-x) f(x) dx.$$

Given a cost ratio of 9:1, the optimal threshold that minimizes the (weighted) overall rate of error is no longer $1/2$, but rather, $t = 9/10 = 90\%$.⁷

Whenever the decision threshold is more stringent than $> 50\%$, the overall (unweighted) error minimization may be sacrificed to pursue other goals, for example, protecting more innocents against mistaken convictions, even at the cost of making a larger number of mistaken trial decisions overall.

The standard ‘proof beyond a reasonable doubt’ is often paired with the Blackstone ratio, the principle that it is better that ten guilty defendants go free rather than even just one innocent be convicted. The

⁶Note that $\frac{d}{dt} E(t)$ is the the sum of the derivatives of $\int_0^t x f(x) dx$ and $\int_t^1 (1-x) f(x) dx$, that is,

$$\frac{d}{dt} E(t) = \frac{d}{dt} \int_0^t x f(x) dx + \frac{d}{dt} \int_t^1 (1-x) f(x) dx.$$

By the fundamental theorem of calculus,

$$\frac{d}{dt} \int_0^t x f(x) dx = t f(t) \text{ and } \frac{d}{dt} \int_t^1 (1-x) f(x) dx = -(1-t) f(t).$$

By plugging in the values,

$$\frac{d}{dt} E(t) = t f(t) - (1-t) f(t).$$

Since $\frac{d}{dt} E(t) = 0$, then $t f(t) = (1-t) f(t)$ and thus $t = 1-t$, so $t = 1/2$ or a $> 50\%$ threshold.

⁷The proof is the same as before. Since $t f(t) = 9(1-t) f(t)$, it follows that $t = 9/10$.

exact ratio is a matter of controversy (Volokh, 1997). It is tempting to think that, say, a 99% threshold guarantees a 1:99 ratio between false convictions and false acquittals. But this would be hasty for at least two reasons. First, probabilistic thresholds affect the expected rate of mistaken decisions. The actual rate may deviate from its expected value (??-). Second, if the threshold is 99%, *at most* 1% of decision against defendants are expected to be mistaken (false convictions) and *at most* 99% of the decisions in favor of the defendant are expected to be mistaken (false acquittals). The exact ratio will depend on the probabilities assigned to defendants and how they are distributed (?). The (expected) rate of false positives and false negatives—and thus their ratio—depend on where the threshold is located but also on the distribution of the liability probability as given by the density function $f(x)$.

3.8 Interval thresholds (Finkelstein)

The prior probability cannot be easily determined (Friedman, 2000). Even if it can be determined, arriving at a posterior probability might be impractical because of lack of adequate quantitative information. Perhaps, decision thresholds should not rely on a unique posterior probability but on an interval of admissible probabilities given the evidence (Finkelstein & Fairley, 1970). Perhaps, the assessment of the posterior probability of guilt can be viewed as an idealized process, a regulative ideal which can improve the precision of legal reasoning. (CITE BIEDERMAN TARONI).

→

4 Theoretical challenges - NEW CHAPTER WOULD START HERE

Let's take stock. We briefly examined difficulties in implementation for probabilistic standards of proof and set those aside. We then offered a few illustrations how probabilistic standards can be used as analytical tools to theorize about decision-making at trial. But even if probabilistic thresholds are used solely as analytical tools, legal probabilists are not yet out of the woods. Even if the practical problems can be addressed or set aside, theoretical difficulties remain. We will focus on three in particular: the problem of priors; naked statistical evidence; and the difficulty about conjunction, also called the conjunction paradox. The latter two are difficulties that any theory of the standard of proof – not just a probabilistic theory – should be able to address. The first difficulty is peculiar to the probabilistic interpretation of standards of proof. We will examine each difficulty in turn and then examine a promising line of response within legal probabilism based on likelihood ratios instead of posterior probabilities.

4.1 The problem of priors

4.2 Naked statistical evidence

Suppose one hundred, identically dressed prisoners are out in a yard during recreation. Suddenly, ninety-nine of them assault and kill the guard on duty. We know that this is what happened from a video recording, but we do not know the identity of the ninety-nine killers. After the fact, a prisoner is picked at random and tried. Since he is one of the prisoners who were in the yard, the probability of his guilt would be 99%. But despite the high probability, many have the intuition that this is not enough to establish guilt beyond a reasonable doubt. Hypothetical scenarios of this sort suggest that a high probability of guilt, while perhaps necessary, is not sufficient to establish guilt beyond a reasonable doubt.

Perhaps, the resistance in the prisoner scenario lies in the fact that the prisoner was picked at random, and that any prisoner would be 99% likely to be one of the killers. Since the statistics cannot single out the one innocent prisoner, they are bad evidence. But consider this case. Suppose two people enter a department store. There are no other customers in the store. After they exit the store, a member of the staff finds that an item of merchandise is missing. Since no staff member could be culpable—they are strictly surveilled—the culprit must be one of the customers. One of the customers, John, has scored high in a compulsivity test and has been arrested for stealing in department stores several times in the past. The other customer, Rick, has never been arrested for stealing in a department store and shows no sign of high compulsivity. Statistics show that people with a high degree of compulsivity and who

have stolen merchandise in department stores before are more likely than others to steal merchandise if they are unsupervised. So John is most likely the culprit. Suppose studies show that people like John, when unsupervised, will steal 99 times out of 100 times. Instead, people like Rick, when unsupervised, will only steal 1 time out of 100 times. So John is 99 times more likely than Rick to have stolen the merchandise. Can these statistics be enough to convict John? Again, it seems not. There is no evidence against him specifically, say, no merchandise was found on him that could link him to the crime. Many would feel uneasy about convicting John despite the fact that, between the two suspects, he is the one who is most likely the culprit.

A similar hypothetical can be constructed for civil cases. Suppose a bus company, Blue-Bus, operates 90% of the buses in town on a certain day, while Red-Bus only 10%. That day a bus injures a pedestrian. Although the buses of the two companies can be easily recognized because they are respectively painted blue and red, the pedestrian who was injured cannot remember the color of the bus involved in the accident. No other witness was around. Still, given the statistics about the market shares of the two companies, it is 90% probable that a Blue-Bus bus was involved in the accident. This is a high probability, well above the 50% threshold. Yet the 90% probability that a Blue-Bus bus was involved in the accident would seem—at least intuitively—insufficient for a judgment of liability against Blue-Bus. This intuition challenges the idea that the preponderance standard in civil cases only requires that the plaintiff establish the facts with a probability greater than 50%.

Confronted with these hypotheticals, legal probabilists could push back. Hypotheticals rely on intuitive judgments, for example, that the high probability of the prisoners's guilt in the scenario above does not amount to proof beyond a reasonable doubt. But suppose we changed the numbers and imagined there were one thousand prisoners of whom nine hundred and ninety-nine killed the guard. The guilt probability of a prisoner picked at random would be 99.9%. Even in this situation, many would insist that guilt has not been proven beyond a reasonable doubt despite the extremely high probability of guilt. But others might say that when the guilt probability reaches such extreme values, values as high as 99.9% or higher, people's intuitive resistance to convicting should subside (Roth, 2010). A more general problem is that intuitions in such hypothetical scenarios are removed from real cases and thus are potentially unreliable as a guide to theorize about standards of proof (Allen & Leiter, 2001; Hedden & Colyvan, 2019; Lempert, 1986).

Another reason to be suspicious of these hypotheticals is that they seem to amplify biases in human reasoning. Say an eyewitness was present during the accident and testified that a Blue-Bus bus was involved. Intuitively, the testimony would be considered enough to rule against Blue-Bus, at least provided the witness survived cross-examination. We exhibit, in other words, an intuitive preference for judgments of liability based on testimonial evidence compared to judgments based on statistical evidence. This preference has been experimentally verified (Arkes, Shoots-Reinhard, & Mayes, 2012; Niedermeier, Kerr, & Messeé, 1999; Wells, 1992) and exists outside the law (Ebert, Smith, & Durbach, 2018; Friedman & Turri, 2015; Sykes & Johnson, 1999). But testimonial evidence is no less prone to error than statistical evidence. In fact, it may well be more prone to error. The unreliability of eyewitness testimony is well-known, especially when the environmental conditions are not optimal (Loftus, 1996). So are we justified in exhibiting an intuitive preference for eyewitness testimony as opposed to statistical evidence, or is this preference a cognitive bias to avoid?

These reservations notwithstanding, the puzzles about naked statistical evidence cannot be easily dismissed. Puzzles about statistical evidence in legal proof have been around for a while (Cohen, 1977; Kaye, 1979b; Nesson, 1979; Thomson, 1986). Philosophers and legal scholars have shown a renewed interest in both criminal and civil cases (Blome-Tillmann, 2017; Bolinger, 2018; Cheng, 2012; Di Bello, 2019; Enoch, Spectre, & Fisher, 2012; Ho, 2008; Moss, 2018; Nunn, 2015; Pardo, 2018; Pritchard, 2005; Pundik, 2017; Redmayne, 2008; Roth, 2010; Smith, 2018; Stein, 2005; Wasserman, 1991). Given the growing interest in the topic, legal probabilism cannot be a defensible theoretical position without offering a story about naked statistical evidence.

5 Conjunction paradox – NEW CHAPTER HERE DEVOTED TO PROBABILITY BASED SOLUTIONS

Another theoretical difficulty that any theory of the standard of proof should address is the conjunction paradox or difficulty about conjunction. First formulated by Cohen (1977), the difficulty about

conjunction has enjoyed a great deal of scholarly attention every since (Allen, 1986; Allen & Stein, 2013; Allen & Pardo, 2019; Haack, 2014; Schwartz & Sober, 2017; Stein, 2005). This difficulty arises when an accusation of wrongdoing, in a civil or criminal proceeding, is broken down into its constituent elements. The basic problem is that the probability of a conjunction is often lower than the probability of the conjuncts. Thus, even if each conjunct meets the requisite probability threshold, the conjunction does not. This chapter examines the difficulty about conjunction and how legal probabilists can respond.

5.1 The problem

Suppose that in order to prevail in a criminal trial, the prosecution should establish by the required standard, first, that the defendant caused harm to the victim (call it claim A), and second, that the defendant had premeditated the harmful act (call it claim B). Cohen (1977) argues that common law systems subscribe to a conjunction principle, that is, if A and B are established according to the governing standard of proof, so is their conjunction (and vice versa). If the conjunction principle holds, the following must be equivalent, where S is a placeholder for the standard of proof:

Separate	A is established according to S and B is established according to S
Overall	The conjunction $A \wedge B$ is established according to S

Let $S[X]$ mean that claim or hypothesis X is established according to standard S . Then, in other words, the conjunction principles requires that:

$$S[A \wedge B] \Leftrightarrow S[A] \wedge S[B].$$

The conjunction principle is consistent with—perhaps even required by—the case law. For example, the United States Supreme Court writes that in criminal cases

the accused [is protected] against conviction except upon proof beyond a reasonable doubt of *every fact* necessary to constitute the crime with which he is charged. In re Winship (1970), 397 U.S. 358, 364.

A plausible way to interpret this quotation is to posit this identity: to establish someone's guilt beyond a reasonable doubt *just is* to establish each element of the crime beyond a reasonable doubt. Thus,

$$\text{BARD}[A_1 \wedge \dots \wedge A_n] \Leftrightarrow \text{BARD}[A_1] \wedge \dots \wedge \text{BARD}[A_n],$$

where the conjunction $A_1 \wedge \dots \wedge A_n$ comprises all the material facts that, according to the applicable law, constitute the crime with which the accused is charged.

The problem for the legal probabilist is that the conjunction principle conflicts with a threshold-based probabilistic interpretation of the standard of proof. For suppose the prosecution presents evidence that establishes claims A and B , separately, to the required probability, say about 95% each. Has the prosecution met the burden of proof? Each claim was established to the requisite probability threshold, and thus it was established to the requisite standard (assuming the threshold-based interpretation of the standard of proof). And if each claim was established to the requisite standard, then (i) guilt as a whole was established to the requisite standard (assuming the conjunction principle). But even though each claim was established to the requisite probability threshold, the probability of their conjunction—assuming the two claims are independent—is only $95\% \times 95\% = 90.25\%$, below the required 95% threshold. So (ii) guilt as a whole was *not* established to the requisite standard (assuming a threshold-based probabilistic interpretation of the standard). Hence, we arrive at two contradictory conclusions: (i) that the prosecution met its burden of proof and (ii) that it did not meet its burden.

The difficulty about conjunction—the fact that a probabilistic interpretation of the standard of proof conflicts with the conjunction principle—does not subside when the number of constituent claims increases. If anything, the difficulty becomes more apparent. Say the prosecution has established three separate claims to 95% probability. Their conjunction—again if the claims are independent—would be about 85% probable, even further below the 95% threshold. Nor does the difficulty about conjunction subside if the claims are no longer regarded as independent. The probability of the conjunction $A \wedge B$, without the assumption of independence, equals $P(A|B) \times P(B)$. But if claims A and B , separately, have been established to 95% probability, enough for each to meet the threshold, the probability of $A \wedge B$ could still be below the 95% threshold unless $P(A|B) = 100\%$. For example, that someone premeditated a harmful act against another (claim B) makes it more likely that they did cause harm in the end (claim

A). Since $P(A|B) > P(A)$, the two claims are not independent. Still, premeditation does not always lead to harm, so $P(A|B)$ should be below 100%. Consequently, in this case, the probability of the conjunction $A \wedge B$ would be below the 95% threshold.

False in whole generality, give a counterexample with more specific numbers. M: I changed things a bit. Maybe not it's clear now. The counterexample is basically $P(A)=P(B)=0.95$, but $P(AB)=Pr(A)*P(A|B)$ and since $P(A|B)$ is below 1, then $P(AB)$ is below 0.95.

References

- Allen, R. J. (1986). A reconceptualization of civil trials. *Boston University Law Review*, 66, 401–437.
- Allen, R. J., & Leiter, B. (2001). Naturalized epistemology and the law of evidence. *Virginia Law Review*, 87(8), 1491–1550.
- Allen, R. J., & Stein, A. (2013). Evidence, probability and the burden of proof. *Arizona Law Journal*, 55, 557–602.
- Allen, R., & Pardo, M. (2019). Relative plausibility and its critics. *The International Journal of Evidence & Proof*, 23(1-2), 5–59. <https://doi.org/10.1177/1365712718813781>
- Arkes, H. R., Shoots-Reinhard, B. L., & Mayes, R. S. (2012). Disjunction between probability and verdict in juror decision making. *Journal of Behavioral Decision Making*, 25(3), 276–294.
- Bernoulli, J. (1713). *Ars conjectandi*.
- Blome-Tillmann, M. (2017). “More likely than not” — Knowledge first and the role of bare statistical evidence in courts of law. In A. Carter, E. Gordon, & B. Jarvi (Eds.), *Knowledge first—approaches in epistemology and mind* (pp. 278–292). Oxford University Press. <https://doi.org/10.1093/oso/9780198716310.003.0014>
- Bolinger, R. (2018). The rational impermissibility of accepting (some) racial generalizations. *Synthese*, 1–17.
- Buchak, L. (2014). Belief, credence, and norms. *Philosophical Studies*, 169(2), 285–311.
- Cheng, E. (2012). Reconceptualizing the burden of proof. *Yale LJ*, 122, 1254.
- Cohen, J. (1977). *The probable and the provable*. Oxford University Press. <https://doi.org/10.2307/2219193>
- Dekay, M. L. (1996). The difference between Blackstone-like error ratios and probabilistic standards of proof. *Law and Social Inquiry*, 21, 95–132.
- Dhami, M. K., Lundrigan, S., & Mueller-Johnson, K. (2015). Instructions on reasonable doubt: Defining the standard of proof and the jurors task. *Psychology, Public Policy, and Law*, 21(2), 169178, 21(2), 169–178.
- Diamond, H. A. (1990). Reasonable doubt: To define, or not to define. *Columbia Law Review*, 90(6), 1716–1736.
- Di Bello, M. (2019). Trial by statistics: Is a high probability of guilt enough to convict? *Mind*.
- Ebert, P. A., Smith, M., & Durbach, I. (2018). Lottery judgments: A philosophical and experimental study. *Philosophical Psychology*, 31(1), 110–138.
- Enoch, D., Spectre, L., & Fisher, T. (2012). Statistical evidence, sensitivity, and the legal value of knowledge. *Philosophy and Public Affairs*, 40(3), 197–224.
- Epps, D. (2015). The consequences of error in criminal justice. *Harvard Law Review*, 128(4), 1065–1151.
- Finkelstein, M. O., & Fairley, W. B. (1970). A bayesian approach to identification evidence. *Harvard Law Review*, 489–517.
- Friedman, O., & Turri, J. (2015). Is probabilistic evidence a source of knowledge? *Cognitive Science*, 39(5), 1062–1080.
- Friedman, R. D. (2000). A presumption of innocence, not of even odds. *Stanford Law Review*, 52(4), 873–887.
- Haack, S. (2014). Legal probabilism: An epistemological dissent. In *Haack2014-HAAEMS* (pp. 47–77).
- Hamer, D. (2004). Probabilistic standards of proof, their complements and the errors that are expected to flow from them. *University of New England Law Journal*, 1(1), 71–107.
- Hamer, D. (2014). Presumptions, standards and burdens: Managing the cost of error. *Law, Probability and Risk*, 13, 221–242.
- Hedden, B., & Colyvan, M. (2019). Legal probabilism: A qualified defence. *Journal of Political Philosophy*, 27(4), 448–468. <https://doi.org/10.1111/jopp.12180>

- Ho, H. L. (2008). *A philosophy of evidence law: Justice in the search for truth*. Oxford University Press.
- Horowitz, I. A., & Kirkpatrick, L. C. (1996). A concept in search of a definition: The effect of reasonable doubt instructions on certainty of guilt standards and jury verdicts. *Law and Human Behaviour*, 20(6), 655–670.
- Kaplan, J. (1968). Decision theory and the fact-finding process. *Stanford Law Review*, 20(6), 1065–1092.
- Kaplow, L. (2012). Burden of proof. *Yale Law Journal*, 121(4), 738–1013.
- Kaye, D. H. (1979a). The laws of probability and the law of the land. *The University of Chicago Law Review*, 47(1), 34–56.
- Kaye, D. H. (1979b). The paradox of the Gatecrasher and other stories. *The Arizona State Law Journal*, 101–110.
- Laplace, P. (1814). *Essai philosophique sur les probabilités*.
- Laudan, L. (2006). *Truth, error, and criminal law: An essay in legal epistemology*. Cambridge University Press.
- Laudan, L. (2016). *The law's flaws: Rethinking trials and errors?* College Publications. Retrieved from <https://books.google.pl/books?id=MvkWvgAACAAJ>
- Lempert, R. O. (1986). The new evidence scholarship: Analysing the process of proof. *Boston University Law Review*, 66, 439–477.
- Loftus, E. F. (1996). *Eyewitness testimony (revised edition)*. Harvard University Press.
- Moss, S. (2018). *Probabilistic knowledge*. Oxford University Press.
- Nesson, C. R. (1979). Reasonable doubt and permissive inferences: The value of complexity. *Harvard Law Review*, 92(6), 1187–1225. <https://doi.org/10.2307/1340444>
- Newman, J. O. (1993). Beyond “reasonable doubt”. *New York University Law Review*, 68(5), 979–1002.
- Niedermeier, K. E., Kerr, N. L., & Messeé, L. A. (1999). Jurors’ use of naked statistical evidence: Exploring bases and implications of the Wells effect. *Journal of Personality and Social Psychology*, 76(4), 533–542.
- Nunn, A. G. (2015). The incompatibility of due process and naked statistical evidence. *Vanderbilt Law Review*, 68(5), 1407–1433.
- Pardo, M. S. (2018). Safety vs. Sensitivity: Possible worlds and the law of evidence. *Legal Theory*, 24(1), 50–75.
- Picinali, F. (2013). Two meanings of “reasonableness”: Dispelling the “floating” reasonable doubt. *Modern Law Review*, 76(5), 845–875.
- Posner, R. (1973). *The economic analysis of law*. Brown & Company.
- Pritchard, D. (2005). *Epistemic luck*. Clarendon Press.
- Pundik, A. (2017). Freedom and generalisation. *Oxford Journal of Legal Studies*, 37(1), 189–216.
- Redmayne, M. (2008). Exploring the proof paradoxes. *Legal Theory*, 14(4), 281–309.
- Roth, A. (2010). Safety in numbers? Deciding when DNA alone is enough to convict. *New York University Law Review*, 85(4), 1130–1185.
- Schwartz, D. S., & Sober, E. R. (2017). The Conjunction Problem and the Logic of Jury Findings. *William & Mary Law Review*, 59(2), 619–692.
- Smith, M. (2018). When does evidence suffice for conviction? *Mind*, 127(508), 1193–1218.
- Stein, A. (2005). *Foundations of evidence law*. Oxford University Press.
- Sykes, D. L., & Johnson, J. T. (1999). Probabilistic evidence versus the representation of an event: The curious case of Mrs. Prob’s dog. *Basic and Applied Social Psychology*, 21(3), 199–212.
- Taroni, F., Biedermann, A., Bozza, S., Garbolino, P., & Aitken, C. (2014). *Bayesian networks for probabilistic inference and decision analysis in forensic science* (2nd ed.). John Wiley & Sons.
- Thomson, J. J. (1986). Liability and individualized evidence. *Law and Contemporary Problems*, 49(3), 199–219.
- Tribe, L. H. (1971). Trial by mathematics: Precision and ritual in the legal process. *Harvard Law Review*, 84(6), 1329–1393.
- Volokh, A. (1997). N guilty men. *University of Pennsylvania Law Review*, 146(2), 173–216.
- Walen, A. (2015). Proof beyond a reasonable doubt: A balanced retributive account. *Louisiana Law Review*, 76(2), 355–446.

Wasserman, D. T. (1991). The morality of statistical proof and the risk of mistaken liability. *Cardozo L. Rev.*, 13, 935.

Wells, G. (1992). Naked statistical evidence of liability: Is subjective probability enough? *Journal of Personality and Social Psychology*, 62(5), 739–752. <https://doi.org/10.1037/0022-3514.62.5.739>