

# WHEN OBSTINACY IS A BETTER (COGNITIVE) POLICY

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## Abstract

For epistemic subjects like us, updating our credences incurs *epistemic* costs. Expending our limited processing power and working memory to properly update our credences by some information can come at the cost of not responding to other available information. It is thus desirable to flesh out and compare alternative ways of taking information into account in light of cognitive shortcomings like our own. This paper is a preliminary attempt to do so. I argue that it is better, in a range of circumstances and from the point of view of expected credal accuracy, for epistemic subjects like us *not to update* on available information that bears on propositions for which substantial evidence has been gathered than it is to update on information as it presents itself. In order to clarify the argument, and enable comparisons between information-response policies more generally, I develop a queue-theoretic model of learning for subjects with cognitive limitations. The model characterizes how policies for responding to information interact with a subject's limitations to yield confidences. Finally, I discuss implications of the discussion for work on confidence, outright belief, and the relationship between those two states. The comparison of information-response policies helps to (i) explain how some of the "biases" revealed by psychological research might be cognitively valuable, (ii) clarify views that take outright belief to be a kind of epistemic plan that resists reconsideration, and (iii) assuage certain "demandingness" worries for the hypothesis that we are credal reasoners.

## 1. Epistemic value

Demonstrations to the effect that epistemic subjects should always update on *any* information they come across assume that updating is epistemically cost-free for the subjects of interest.<sup>1</sup> But this is not true

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1. See, for example, (Oddie, 1997), where it is argued that one does better from the point of view of epistemic value if one gathers *all and any* information that would make a difference to one's cognitive state when one updates by conditionalization — and under the assumption that updating is *cost-free*. (Good, 1967) also makes the assumption explicitly as a part of a similar argument for

for epistemic subjects like us, whose capacities are far from being epistemically ideal. For creatures like us, taking available information into account taxes our processing resources and available working memory. Consequently, taking information into account incurs epistemic opportunity costs — when there is enough available information, resources spent taking some subset of our available information into account is time not spent processing other available information. Given this shortcoming, it is unclear whether the policy of responding to *every* relevant piece of information we can is best *for us*. Our epistemic ends might be better served under a different policy. This paper explores that possibility.

Doing so assumes that cognitive value comparisons are a useful way of assessing human cognitive activities. This assumption is controversial, so the remainder of this section looks at the primary reasons to deny it, in order to clarify the domain of applicability of cognitive value comparisons. Ultimately, I will defend the use of cognitive value comparisons for a range of ends. Since the cognitive goal that we will focus on is that of promoting accurate representations of the world and stymieing inaccurate ones, we will fix on that in what follows.<sup>2</sup>

One type of worry for projects that rely on cognitive value comparisons centers on whether “veritistic” considerations can ground epistemic norms. The concern picks up on a structural feature of goal-furthering views of norms, namely that they accept that rationality sometimes requires trading off the furthering of goals in some domain in order to further them in some other domain.<sup>3</sup> But it often seems ir-

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the practical value of gathering information.

2. It is worth noting here that this sort of cognitive value has a fairly direct tie to practical value: generally, more accurate beliefs put us in a better position to make practical decisions. Nevertheless, cognitive value and practical value are distinct. Epistemic value makes the most practical impact when it concerns practically relevant propositions. I discuss how the framework that I develop might accommodate practical considerations in §3 — especially fn. 12. I would like to thank an anonymous reviewer from *Philosophers’ Imprint* for pressing me to make this explicit.

3. This point, and my statement of this problem for end-promoting theories of epistemological norms, draws on Selim Berker’s (2013) extended criticism of

rational to trade off epistemic gains with respect to some propositions for gains on others, whether those gains are veritistic or otherwise cognitively valuable.<sup>4</sup> To take a stock example: it seems epistemically irrational for me to believe that smoking does not cause cancer even if, were I to believe it, a tobacco company (with impeccable access to my cognitive states) would give me a grant to research artificial lungs with the consequence that I would learn any number of important truths and cease to believe many falsehoods. By increasing the number of important truths learned and falsehoods abandoned in the case, we can guarantee that forming the problematic belief will yield a net positive cognitive gain under any plausible way of weighing cognitive gains. So, epistemic norms cannot be (fully) explained in terms of furthering epistemic goals — or so the thought goes.

While I agree that these cases do put pressure on the idea that epistemic value facts are *sufficient* to ground epistemic norms, they do not repudiate the idea that epistemic value is important to epistemology and should not deter theorists from pursuing epistemic value comparisons, for several reasons. First, it is not clear that the impermissibility of epistemic trade-offs thesis is fully general. Sometimes trading off a gain in cognitive value with respect to some propositions for a guaranteed loss with respect to others seems permissible. To illustrate, consider a case in which you start out believing some well-confirmed scientific theory. I take it that it is rational to have beliefs of this kind.<sup>5</sup> Now imagine that you learn of another independently but equally well-confirmed theory that ranges over a largely separate domain. Suppose further that you are shown (perhaps by being presented with a non-constructive proof) that the two theories are in tension with one an-

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these views. Other important statements of this worry can be found in (Jenkins, 2007) and (Greaves, 2013) and trace back to (Firth, 1998). For a catalog of important examples of resistance to the view that cognitive value comparisons ground epistemic norms, see (Berker, 2013, fn. 38).

4. Berker’s label for the “no trade-offs” thesis is ‘the separateness of propositions’.

5. Though see (van Fraassen, 1980) for an important criticism of this (standard) view.

other so that at least one of them must be incorrect in some of the details, but the parts of the theories that are in tension have yet to be isolated. All of the earmarks of belief could be present in the case: It could be rational to act as though both theories obtained, treat them as true in reasoning, resist reconsidering them, and so on. In that case, it is arguably rational to believe both theories. But, for that to be right, it must sometimes be permissible to trade off believing at least one falsehood in order to believe other truths. As a consequence, facts about when trade-offs are epistemically permissible do not preclude cognitive value from playing some role in explaining epistemic norms.

Properly understood, then, the force of the purported counterexamples is to prevent us from directly reading the normative facts off of facts about cognitive value. But that doesn't delegitimize investigation into cognitive value, nor even using facts about cognitive value as defeasible evidence for normative theory in non-problematic cases.

Second, setting the appropriateness of trade-offs to the side, epistemic norms that fail to further veritistic goals do not seem worth following, and it is difficult to envision criteria of successful inquiry that fail to be truth-directed. This supports the idea that promoting the dual cognitive values of forming true beliefs and avoiding false ones play a role in (partially) grounding epistemic principles.<sup>6</sup> Here it is worth drawing the parallel between furthering veritistic aims in epistemology and promoting the good in moral theory. While many reject the idea that the right act is the one that results in the most good, few think that doing good is morally irrelevant. This suggests that we should treat the epistemic case in the same way.<sup>7</sup> We should still be interested

6. In fact, several prominent epistemologists appeal to veritistic value to do just that. Selim Berker convincingly shows that central figures on either side of the internalism/externalism debate rely on justifications of this kind — (Alston, 2005, p. 29), (BonJour, 1985, pp. 7–8), and (Goldman, 2001, p. 31) provide paradigmatic exemplars — and presents an impressive list of philosophers who endorse something like this view at (2013, fn. 27).

7. Notably, Berker would disagree on this point, taking the upshot of the impermissibility of epistemic trade-offs to be that the two domains are disanalogous here.

in truth-conduciveness even if we don't think that it is the only thing that matters.

Lastly, *evaluations* of cognitive states or processes in terms of veritistic value have a payout in the philosophy of mind and in theories of epistemic resource allocation even when they don't underpin epistemic *prescriptions* or norms. For instance, the applications of the particular policy comparisons in §5 pay out in a deepened understanding of our limitations and the kinds of cognitive architectures that are possible for subjects like us.<sup>8</sup>

With our defense of cognitive value comparisons complete, we will now look at some information-response policies, present a framework that characterizes our cognitive limitations, and use that framework to precisely evaluate those policies from the point of view of expected accuracy.

## 2. Two information-response policies

Reasoners who are not subject to cognitive limitations should process any available information relevant to propositions of interest. A subject with cognitive limitations like our own might reason like an ideal reasoner, and to the same effect when not cognitively overburdened, by instantiating the following policy:

**The naïve policy.** Take information into account for further processing on a “first-come, first-served” basis whenever sufficient cognitive resources are available — no matter how much other information one is thinking through, or how much information is expected to arrive in the future, and whether or not it is expected to be evidentially weighty.

Is this policy a good one? Plausible assumptions are sufficient to establish that better policies are possible when it comes to subjects like us. Since we can only hold a limited amount of information before

8. For a discussion of the difference between “evaluative principles” and “normative principles”, see (Smith, 2005).

our minds and we have limited processing power, it is very likely that there will be circumstances in which we can properly process only a proper subset of our available information. From this, and barring certain “funny business” that the more precise formal model will rule out, we can expect that it is better from the point of view of *overall* accuracy to process information that will have a greater impact on our confidence levels than a lesser impact when we cannot process all of the available information.<sup>9</sup>

Since the naïve policy doesn’t prioritize processing information by its impact, a subject will generally do better by acting in accordance with another policy that processes high-impact information at the expense of low-impact information. Moreover, as the amount of available information increases, the situations where we can process only a subset of our available information will become more common, amplifying the effect and justifying a more extreme prioritization of high-impact information over low-impact information.

As a first step in the investigation of appropriate prioritizations, I will focus on cases where inquiry is both initially fruitful and subject to diminishing returns in the sense that processing *initial* information on a question of this kind yields substantial evidence for deciding it and paying further attention to relevant information does not greatly improve the accuracy of our judgment on that issue. One kind of case like this focuses on ordinary mid-sized dry goods. For example, when a subject is interested in whether there is peanut butter sandwich in

the fridge, looks in the fridge, and observes that there is a peanut butter sandwich in it. After this initial observation, she can be near certain that there is a peanut butter sandwich in the fridge. The evidence gained by picking up the sandwich, looking at it from another angle, smelling it, or tasting it won’t usually make much more progress on the question. But, even in the rare case that there is also an almond butter sandwich in the fridge, so that the first impression is not decisive, any of *these* additional pieces of information will usually be weighty enough.

The phenomenon also presents itself in cases where the observations are independent given the proposition of interest, as is often the case when one’s evidence is the result of random sampling. For example, suppose that you are eating at a recommended tapas bar. You know that if the head chef is cooking, then 90% of the dishes will be excellent, while only 30% of the dishes will be excellent in her absence. In that case, you can be pretty confident whether the head chef is cooking after ordering and assessing a few dishes, but if you know whether the head chef is cooking, the quality of next dish will be approximately independent of the last (assuming cooking “hot streaks”, etc. are negligible). The case is similar if I am interested in the hypothesis that a given coin is significantly biased towards heads and the evidence stream consists in unrelated tosses of the coin. In such cases, fairly short sequences of evidence are sufficient to establish its bias.<sup>10</sup>

Focusing on this range of cases has several advantages. Cases where inquiry is both initially fruitful and subject to diminishing returns form a substantial part of our everyday investigations.<sup>11</sup> Consequently, seeing how well a policy for responding to information deals with these cases provides insight into how the policy will do more generally. We

9. The ‘funny business’ qualifier is essential here. Consider the case where our subject receives two pieces of evidence  $e$  and  $e'$  such that the evidential effect of  $e$  alone is to raise our confidence in the proposition of interest  $p$  dramatically, the effect of  $e'$  alone is to slightly raise our confidence, but the effect of  $e$  together with  $e'$  is to raise our confidence only slightly. In this particular case, the evidence is mutually undermining. Similarly, in cases where a piece of evidence turns out to be misleading, it will be *locally* better to update by the piece of evidence that makes the smaller impact. Consequently, this informal presentation of the argument relies on the (plausible, I think) further assumption that such cases are not the norm. The formal model developed below rules out these sorts of cases. I thank a referee for providing me with the first sort of helpful case and for suggesting that I clarify this point here.

10. These cases are closely related to the “stopping rules” literature in statistics and philosophy, which looks at the costs and benefits of evidence search and continued experimentation. For a good philosophical discussion of stopping rules, see (Heesen, 2015).

11. See (Cherniak, 1983, p. 177) for a psychologically informed affirmation of this point and (Heesen, 2015) for examples drawn from the sciences.

will designate these learning scenarios as our “focus cases” in what follows.

Second, in the focus cases: (i) quantity of information gathered on a given proposition, (ii) rational closeness of credence to the truth in that proposition, and (iii) rational resilience of credence in that proposition, or diminishing rational impact of further evidence, are expected to go hand in hand. Inquiry initially progresses quickly in these cases, and, once substantial information has been gathered on a question, future information tends to make less of an impact — our attitude becomes more robust, and more rationally robust. A nice consequence of this relationship is that results concerning policies for responding to information that are spelled out in terms of any one of these epistemically interesting properties will have (rough) correlate results for the others. Because of this, we will focus on policies that track quantity of evidence gathered, which are easily modeled — even though the other properties are *prima facie* at least as relevant to which future information will have the greatest expected rational impact on our confidences. We can then get a handle on which policies are better in the general case by taking into account how differences in the properties used to characterize them will generate different outcomes outside of the restricted range.

With these qualifications in mind, one simple and tractable policy — or policy type, since it might itself be developed in several ways — that favors responding to high-impact information over low-impact information is the following:

**The obstinate policy.** Disregard any available information as bearing on a proposition once substantial information for that proposition has been processed; otherwise proceed naïvely.

This policy prioritizes high-impact evidence over low-impact evidence in cases where inquiry is subject to diminishing returns. Assuming that more information presents itself than can be processed on average, it is reasonable to expect that subjects like us who adhere to it will be in a more accurate credal state than those who adhere to the naïve policy.

The considerations offered in support of the obstinate policy over the naïve one are general, but their imprecision makes it difficult to properly assess the argument. I now turn my attention to developing a precise framework for comparing policies like those under discussion.

### 3. A queue-theoretic model

Imagine that you are at a research presentation. The author has clearly laid out the premises of her argument. You attempt to follow along with the defense of the premises. However, the talk is rich and the evidence being offered in support of the premises continues to pour in at a random rate. The time it takes you to process each piece of evidence varies randomly too. As each piece of evidence is processed, you adjust your confidence accordingly. But, since you can hold only a few pieces of evidence in front of your mind at a time, there are points in the talk where you are overwhelmed by information. At times like these, some pieces of evidence cannot be taken into account — you can’t process everything.

This section presents and defends a “queue-theoretic” framework for understanding cases like these — cases where subjects with cognitive limitations like our own have to respond to information as it arrives. After presenting and defending the framework for the remainder of this section, we use it to spell out the two policies for responding to information advanced above and compare them from the point of view of expected accuracy over a range of focus cases in §4.

The rough idea is straightforward. Assume that there are  $n$  logically independent propositions whose truth values are of interest for a reasoner — the four premises in our example above.<sup>12</sup> Information

12. Working under the assumption that there is a clear distinction between theoretical reasons on the one hand and practical or moral reasons on the other, we will take these propositions of interest to be those that ground epistemic value. It is worth noting, however, that the framework leaves open whether practical considerations constrain which propositions matter. It is also possible to extend the framework to allow certain propositions to count for more, either practically or epistemically, by considering policies for responding to information that give evidence for certain propositions priority in evaluation

relevant to those propositions will come in over time in a random way, with some probability of the next piece of information being relevant to one or another of these propositions. Our reasoner will have a “working memory” that can store a small number of pieces of information during processing, before it is stored in long-term memory.<sup>13</sup> The amount of time it takes to process each piece of information stored in working memory will also be subject to random variation. As a piece of information comes in, our reasoner can begin updating on that information as long as she has space in her working memory. Otherwise, the reasoner is assumed to have too much on her epistemic plate and the information must go unnoticed.

More formally, for each of those  $n$  propositions of interest, let each of  $p_1, \dots, p_n$  pick out the truth on that matter, so that if whether  $q$  obtains is of interest and  $q$  is in fact false, then one of the  $p_i$  will be not- $q$ . We treat the event that the next piece of information relevant to some  $p_i$  arrives by future time  $t$  as a random variable  $X_i$  for  $i \in \{1, 2, \dots, n\}$  with distribution  $\mathcal{D}_i$  and  $\lambda_i$  the corresponding rate of arrivals, with  $\frac{1}{\lambda_i}$  arrivals of that type over a period of a specified duration on average. Our subject is assumed to have a working memory capable of storing up to  $m$  pieces of information for processing. Then we treat how information is processed in a similar way. The event that a piece of information stored in working memory will be processed by our reasoner by future time  $t$  is a random variable  $Y_\mu$  with distribution  $\mathcal{D}_\mu$ , where  $\mu$  is the mean number of pieces of information processed in a period of a specified duration.

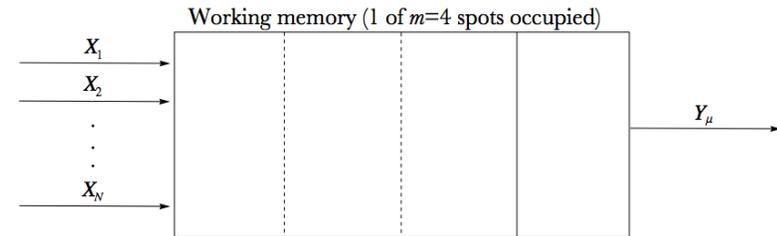
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and weighing their value score accordingly. I note this here as an interesting complication to explore in future research.

13. It is plausible that how much one can store in working memory depends not only on the count of pieces of information but also the relative informativeness of that information (Awh et al., 2007). The model can track total informativeness by letting the slots in the queue correspond to minimal units of information — analogous to bits in computer memory — or at least a decent approximation if there is no easily identifiable minimal unit. Alternately, the correct picture might instead turn out to be a hybrid of the “slot-based” and “total informativeness” models; however, hybrid views are currently underdeveloped (Brady et al., 2011).

The system can thus be depicted as in Figure 1. Here each  $X_i$  feeds

Figure 1: The general model of epistemic inquiry.



its information into the working memory queue of length  $m$ . If the queue is full, any arriving piece of information is discarded. Otherwise, another spot in the queue becomes filled, reducing the available spots for further pieces of information by one. Finally, the number of empty spots in the queue increases by one according to the distribution  $Y_\mu$ .

This queue-theoretic framework provides a model of responding to information with memory and processing limitations. How exactly our reasoners update their credal states upon processing the information can then be specified externally, along with a way of scoring accuracy, to calculate the expected accuracy of adopting a policy for responding to information.

There is much to recommend this framework as a model of cognitive beings with limitations like our own. First, it builds in the idea that our memory has a “duplex” or multiple-tiered structure with one volatile tier of working memory for holding information for processing while another tier (or tiers) of long-term memory store information in a way that is less easily manipulated and must be activated to play a role in most cognitive operations. This idea is standard in empirical psychology’s verbal and visual learning and memory traditions, where

it structures many fruitful research programs.<sup>14</sup> The “duplex hypothesis” has also been given a compelling philosophical defense by Christopher Cherniak in his (1983) ‘Rationality and the Structure of Human Memory’, where he argues that it explains common lapses from ideal rationality. In particular, he argues that the hypothesis explains cases where we fail to close our beliefs under logical consequence when it is practically relevant, like when we fail to conclude that we should bring our keys to the office even though we know both that (i) if we want to work in our office we should bring our keys, and that (ii) we want to work in our office. The hypothesis explains this by allowing that the beliefs needed to draw out those consequences might not all be *available* in memory to perform inferences on at the same time. On the other hand, it is hard to see why we wouldn’t draw the relevant inference on views where our entire stock of beliefs is available for logical manipulation, especially when doing so would be very practically valuable.

Second, the framework is very general — though we will mainly focus on an informative simple case in what follows. For example, since the framework leaves open the update procedure, it can model subjects who update by conditionalization at one extreme, or subjects who use simple heuristic update rules at the other. Manipulating the input distributions allows for a general treatment of how information presents itself to a subject, while manipulating the output distribution captures differences in information processing abilities.<sup>15</sup>

14. See (Brady et al., 2011) for a recent survey of some of these programs in visual memory.

15. In addition, by co-varying the input distributions, output distribution(s), and how processing impacts credences, one can also use the framework to characterize more complicated policies for responding to information, including ones that offload information into long-term memory to later feed it back into working memory for processing. A detailed examination of these models and the policies that depend on them is beyond the scope of the present work. But it is worth pointing out that it is doubtful whether policies spelled out using these models will be beneficial for creatures with cognitive limitations like our own, since research suggests that it is cognitively costly for us to convert short-term memory into long-term memory in a way that can be easily recalled

#### 4. Comparing the policies

We can use this framework to compare the obstinate and naïve policies in a more nuanced way. Setting the parameters of the model to specific values, and clarifying the policies within the framework, yields definite predictions about the expected accuracy of the cognitive state of a subject who adopts one of the precisified policies over the other. By repeating this for a range of parameter values, we develop an understanding of the circumstances under which one policy is to be preferred to the other.

Let us begin by formally specifying the impact of information on the subject’s confidences. At a minimum, the non-skeptical premise of the preliminary argument for obstinance sketched in §2 requires that our subject’s experiences are expected to be truth-tracking in that they expect their respective confidences to become more accurate as they update on more information. The initial argument for obstinance also assumed that the epistemic returns of information for a given proposition are expected to be diminishing in the sense that as the information a subject has processed on a question becomes substantial, further evidence is expected to rationally make less and less of an impact on that subject’s confidences.

Here we will accommodate these assumptions by restricting the scope of the argument to our focus cases in which our subject’s confidences in each of the true propositions  $p_1, \dots, p_n$  are expected to be increasing functions of the number of observations that they have taken into account as bearing on those propositions and where earlier observations make more of an impact, modulo some local deviation. Of course, it is not assumed that the subjects will *know* that the respective  $p_i$  are whichever of  $p$  or  $\neg p$  are true for each  $i$  among the  $n$  propositions of interest prior to inquiry. Insofar as the focus cases are common,

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at an appropriate later time. Even holding something in working memory takes up processing resources (Barrouillet et al., 2004, 2007), so we should expect that holding it in working memory to commit it to long-term memory will be costly too.

the model provides valuable insight into the general effects of adopting the information-response policies under investigation. However, we have to keep in mind the restriction when thinking about cases of theoretical, or scientific, inquiry where data is scarce and substantial data scarcer still. For all the more precise argument says, obstinacy may not be a better policy over this domain.

For specificity, we make the assumption that a subject's *expected* credence in  $p_i$  after taking into account  $j$  observations bearing on  $p_i$  follows the logistic function:

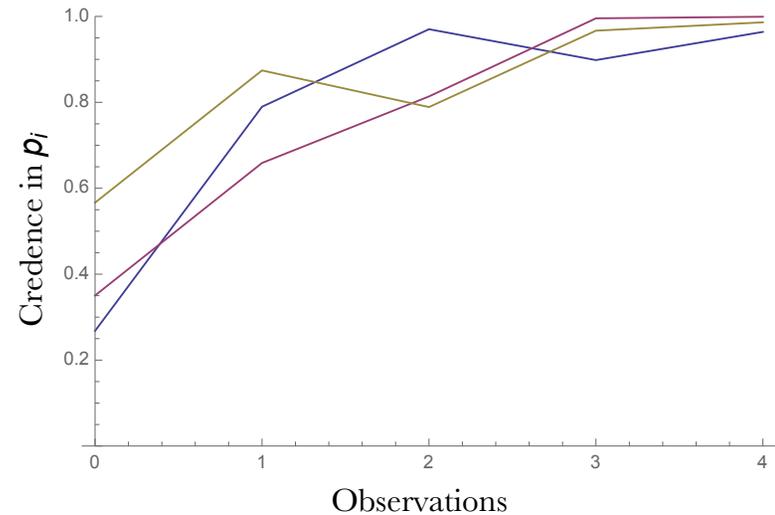
$$\mathbb{E} [\mathbb{P} [p_i | j \text{ pieces of information relevant to } p_i]] = \frac{1}{1 + e^{-j}}.$$

The function ignores local deviation in the quality of the information on the grounds that as long as it is as likely to push one's confidences towards the truth as away from the truth, that deviation will be washed out from the point of view of *expected* accuracy. Thus, a logistic function that incorporates deviation, like the one in Figure 2, will produce the same results.<sup>16</sup>

This logistic function is a modest approximation in the context. It encodes the typical characteristics of the impact of observations on credence, like being in general increasing and being subject to diminishing returns. For this particular function, the diminishing returns it encodes become pronounced after three or four observations. This seems plausible for hypotheses about everyday objects — the peanut butter sandwich example motivated convergence after one or two observations. By expanding the range of cases covered by the original ar-

16. The depicted progressions increase on average according to a logistic growth rate function centering the reasoner's initial confidence on .5 — i.e.  $\frac{1}{1+e^{-j}}$ , where  $j$  is the number of pieces of information that have been taken into account by the subject as bearing on the specified proposition. The fact that the data can be misleading, especially initially, is then accommodated by including some stochastic variation as follows:  $\frac{1}{1+e^{-j}} + \Delta$ , where  $\Delta$  is some distribution with mean 0 that tracks deviations from the logistic tendency. In the figure, the three progressions were generated pseudo-randomly, taking  $\Delta$  to be a uniform distribution over  $[-.5, .5]$  scaled by  $(1 + e^x)$ .

Figure 2: Possible credence progressions in the truth on successive updating.



gument, this function errs on the side of underestimating the rational impact of initial observation on confidence assignments to the propositions of interest. In any case, not much hangs on this choice since the effects of interest in the model are robust under plausible choices of impact functions for everyday inquiry.<sup>17</sup>

A second choice point concerns the time at which information in working memory should affect one's confidences in the model. One possibility would be to adjust a subject's confidences only *after* that information has been fully processed as it is removed from the queue. However, since the pieces of information placed in working memory

17. What particular choices of impact functions *do* tend to affect is the required number of observations relevant to a proposition needed until the effects of further evidence become negligible. The logistic function is modest in this regard.

need not be processed serially for ordinary reasoners, or even on a piece-by-piece basis, this stipulation would underestimate the information processed by a subject at a time by a small amount. Another option is to treat information as fully processed once it is placed in working memory. This stipulation would overestimate the information processed by a subject at a time, again by a small amount. The correct confidence distribution for a subject will lie somewhere between these options at a time.

Since it is questionable whether any precise trade-off between these two possible modeling choices will be meaningful, the results will be close under either choice, and the latter has the benefit of at least corresponding to the subject's state once all information obtained at the time has been fully processed, I use the latter in what follows. Our reasoner's credences will be adjusted by an observation in the model at the time that it gets put into the queue instead of when that specific piece of information is removed from the queue. An added benefit of this approach is that this allows us to simplify the bookkeeping in what follows by disregarding the order in which the pieces of information have been put into the working memory queue.

Our reasoners' cognitive states will be assessed from the point of view of their *accuracy*. Letting 1 represent the truth value of a true proposition, 0 the truth value of a false proposition, and credences range over the unit interval  $[0, 1]$ , we follow the prevalent tradition in formal epistemology that judges a credence in  $p$  as being more accurate as the distance between that credence and the truth value of  $p$  decreases.<sup>18</sup>

Again to fix discussion, we will assume a version of the popular quadratic measure of accuracy for a total credal state  $S$  with respect to each proposition  $p_i$  in  $\{p_1, \dots, p_n\}$ :  $D(S) = \sum_i - (1 - \mathbb{P}_t [p_i])^2$ , with  $\mathbb{P}_t$  the subject's credence function at  $t$ . Here the rule is appropriate since the truth value of each  $p_i$  is known to be 1 and it will be assumed that

18. See (Joyce, 1998; Greaves and Wallace, 2006; Easwaran, 2013) for a representative sample of works in this tradition.

our subject's credences obey the complementation principle — i.e. for any proposition  $p_i$  among the  $n$ ,  $\mathbb{P} [p_i] = 1 - \mathbb{P} [\neg p_i]$ .<sup>19</sup>

Finally, in order to assess the obstinate and naïve policies, the distributions of the waiting times between observations  $\mathcal{D}_i$  for  $i$  in  $\{1, \dots, n\}$ , the distribution of the time it takes to process an observation  $\mathcal{D}_\mu$ , and the amount of working memory  $m$  possessed by a given subject must be specified. Here we restrict  $\mathcal{D}_i$  and  $\mathcal{D}_\mu$  to a class of distributions commonly used to model wait times for natural events. We will focus on situations in which any relevant event is as likely to occur within any time interval of equal length, and whether or not an interval in question was recently preceded by another incident. This amounts to assuming that the following are pairwise independent: (i) the waiting times for previous pieces of information relevant to a proposition, (ii) the variable waiting time for the next piece of information relevant to a proposition at a time, (iii) the variable waiting times between pieces of information pertaining to different propositions, and (iv) the variable processing times of pieces of information past, present, and future.<sup>20</sup>

Though these assumptions are simplifications, they are not unnatural or unmotivated as an approximation. Constraints like the above make sense for processes like the number of people arriving at a bus stop during a work day or the wait times between rider arrivals, but not for either the number of buses which arrive throughout that interval or the wait times between buses — since they are scheduled. We

19. A perfectly general account would allow an epistemic subject to choose any reasonable accuracy measure. This isn't feasible in the present case, because of the numerical nature of the results — though the results are also robust under other popular accuracy measures, including the spherical and logarithmic measures. See fn. 23 for details.

20. In this context, this is equivalent to the assumption that the number of pieces of information presented which are relevant to a proposition of interest and the number of pieces of information processed are independently Poisson distributed or, equivalently, that the waiting times are exponentially distributed. This entailment is well known, see (Billingsley, 1995, p. 190). Another effect of this choice is that our system becomes, using Kendall's queuing-theory notation, a  $E/M/1/(m-1)$  queue. The *transient* — as opposed to long-run — behavior of this type of queue is not particularly well studied; thus the discussion might also be of some statistical interest.

are thus restricting our attention to cases in which information arrives more like people arrive at a bus stop than buses to that stop. In practice, these assumptions are used in modeling a wide range of systems, like the number of photons that reach a telescope, the number of mutations in a given segment of DNA, and the number of phone calls arriving at a call center in a specified period. That said, the model can be applied to other (less tractable) choices of variables for the  $X_i$  and  $Y_\mu$  too.

Under these assumptions, we can assess the two policies for responding to presented information for a wide range of values of the working memory  $m$  we possess, the number of propositions of interest  $n$ , the average rate at which evidence for a given proposition of interest presents itself  $\lambda$ , and the average rate at which our observers fully process a given piece of information  $\lambda_\mu$ . What range of values make sense? Setting  $m$  aside for the moment, it is not so much the values of  $n$ ,  $\lambda$ , and  $\lambda_\mu$  that are important from the point of view of the model, but rather the relationship between the average rate of information arrival for *any* question in the designated time period,  $n\lambda$ , and the average rate at which information is processed in that period,  $\lambda_\mu$ . Consequently, I have fixed  $n$  at a manageable 3 and manipulated the relationship between the parameters by varying the choices of  $\lambda$  and  $\lambda_\mu$  given that  $n = 3$ . A robust range of conditions from cases in which information is on average processed much quicker than on average it arrives —  $10\lambda_\mu = n\lambda$  — to cases in which much more information presents itself on average than can on average be processed —  $\lambda_\mu = 10n\lambda$  — was examined.

The appropriate value for the total amount of working memory  $m$  available to a subject at a time will depend on the limitations of the subject, or subjects, of interest. The psychological literature (and perhaps introspection) suggests that we can consciously assess the evidential impact of very few pieces of information at a time, with current research suggesting that on average 3 or 4 “chunks” of information can be handled at a time but other studies suggesting up to an average of

7.<sup>21</sup> However, since a clear conception of what values of  $m$  are appropriate depends on subtle and substantive philosophical and psychological theorizing, I examined choices of  $m$  ranging from 1 up to a value of 8.

Call any event in which an observation is processed or a piece of information becomes available to our reasoner an “epistemic event”. For this range of values, and over the short to medium term of thirty epistemic events, the obstinate policy of ignoring information does better from the point of view of expected credal accuracy than the naïve policy of taking information into account as it arrives whenever the average rate of information processing is less than the average rate at which it arrives.<sup>22</sup> In many cases, the effect is even more pronounced. For instance, with smaller working memories of  $m = 1$ ,  $m = 2$ , or  $m = 3$ , the obstinate policy is preferable up to, and beyond, the boundary case of thirty epistemic events when information is processed on average *ten times faster* than it arrives. For a working memory of  $m = 4$ , the obstinate policy is preferable over the first thirty epistemic events up to and including the case where information is processed four times faster than it, on average, arrives. For a working memory of  $m = 5$ , the obstinate policy is preferable over the first thirty epistemic events up to and including the case where information is processed twice as fast as it arrives.<sup>23</sup>

These results give us a good idea of when the obstinate policy will be preferable to the naïve one. Whenever the amount of available infor-

21. See (Cowan, 2001, 2005) and (Brady et al., 2011, pp. 1–5) for summaries of the research on the limits of visual working memory.

22. Details of the proofs for the quadratic score can be found in the technical appendix §7.

23. The results are at least as favorable under the spherical scoring rule  $\sum_i \frac{p_i}{[p_i^2 + (1 - p_i)^2]^{\frac{1}{2}}}$ . More observations are needed in the case of the logarithmic score,  $\sum_i \log(p_i)$ , to yield the same results, since it punishes inaccuracy

more severely. Consequently the results obtain for the logarithmic score just in case we firm up our confidences in a proposition after processing correspondingly more information on that issue, in this case after processing 7 relevant pieces of information.

mation exceeds our processing power, and the distributional assumptions are approximately correct, the obstinate policy will be preferable.<sup>24</sup> One interesting effect that the model illustrates is that even if *on average* we process information more quickly (and sometimes much more quickly) than it arrives, the obstinate policy will be preferable to the naïve one. Sometimes a lot of information just happens by chance to come in all at once or by chance we process less information than average. Whenever either or both of these occur to a sufficient extent, it results in an information bottleneck. This effect makes prioritizing high-impact information important even in cases where information is fairly scarce and a subject processes incoming information with relative ease.

As a consequence, the model suggests that the obstinate policy might be beneficial even if we implement certain other strategies for overcoming our limitations.<sup>25</sup> In particular, it might be beneficial if in response to overabundant information we implement a strategy that involves increasing the speed at which we process information at the cost of a higher variance in the results, or even at a slight cost in accuracy. Heuristic reasoning of this kind may increase the rate at which information is processed relative to the amount arriving, but the previous observation shows that obstinance is still a better policy than the naïve one under modest increases in processing speed. Obstinance is compatible with, and may be a good supplement to, an array of strategies to overcome our limitations.

24. Of course, adopting the obstinate policy is *guaranteed* to do worse in the long term since, in the long term, the policy leads to indiscriminately ignoring all information with probability 1. From the current perspective, it is important that our reasoner, like us, epistemically operates in the present and near future rather than in the long run.

25. Here, as always, ‘implementing a strategy’ need not imply anything *deliberate* and is meant to be compatible with us *automatically* acting in accordance with a strategy below the level of awareness.

## 5. Applications

Some authors (correctly) hold that facts about our cognitive limitations should structure theorizing about our world-directed cognitive states like outright belief and credence. In this section, I argue that the above framework and results help to clarify some of this theorizing and explain why some of our cognitive behavior which seems deleterious might be beneficial. §5.1 presents some influential work in psychology documenting obstinance effects in our responses to information. While these are often presented as “cognitive biases” to be overcome, the results above explain how they are useful in a wide range of cases. §5.2 shows how the results fill in some much-needed details for accounts of belief as a kind of epistemic plan. In §5.3, I argue that the results concerning the obstinate policy undercut certain “demandingness” objections to the possibility that we are credal reasoners.

### 5.1 *Obstinance effects in psychology*

Work in empirical psychology has revealed a few ways in which we resemble obstinate reasoners. So-called “primacy effects” provide one example. In Cameron Peterson and Wesley DuCharme’s influential (1967) study on the phenomenon, subjects were told the distribution of colored chips in two urns. They were then presented with a series of data that they were told corresponded to draws from exactly one of the urns, with replacement. After each datum was presented, the subjects recorded their confidence in the hypothesis that the draws were from the first urn. The information presented to subjects favored the hypothesis that the draws were from the first urn rather than the second for the first 30 observations then, symmetrically, the next 30 “draws” favored the second. The last forty “draws” also favored the hypothesis that the draws were from the second urn.

If the subjects were acting as perfect Bayesian reasoners — who, upon receiving information, set their confidence that a draw was from an urn to their prior confidence in that proposition conditional on any new information — they would have had a confidence of .5 or less in

the hypothesis that the data resulted from draws from the first urn after their initial sixty observations. In fact, for most subjects, high confidence in the first hypothesis persisted well beyond sixty observations — over half of the subjects failed to reduce their confidence in the first urn hypothesis below .5 over the total 100 observations, by which point a Bayesian updater would have had a confidence below .05. Information provided later in the experiment had much less of an impact on their confidences than it would have had if the reasoners took it into account by updating in an ideal Bayesian way. Other experiments reveal a similar tendency.<sup>26</sup>

Documented belief “persistence effects” constitute another way in which we resemble obstinate reasoners. The experiments that best illustrate belief persistence are ones in which subjects retain an elevated confidence in a proposition after support for that proposition is undercut (as opposed to merely being outweighed as in the Peterson and DuCharme case). In one experiment, Lee Ross et al. presented subjects with pairs of purported suicide notes, told them that each pair contained one real and one fabricated note, and asked them to say which one they thought it was (1975). After each response was elicited, subjects were told whether or not they were correct — the response was in fact predetermined by the researchers and independent of their performance. One test group received mostly positive responses, and another negative.

After the test, the subjects were debriefed and told that the information that they had received was predetermined and independent of their actual choices. Nevertheless, those that received mostly positive responses still thought that they did much better at the task and would be better at it in the future than those who were told that their choices were mostly wrong. The effect was also present when an outside party, after watching the experiment and being similarly debriefed, was asked to rate the participant on how well they performed

and how they might be expected to perform in the future. In their discussion of the result, Ross et al. conclude that “the relevance, reliability, and validity of dubiously relevant, reliable, or valid information is resolved as a function of its consistency with the attributor’s [sic.] initial impression” (1975, p. 889). Impressions, they take it, can be sustained by the evidence-filtering effects that accompany them.

Both primacy and persistence effects are usually presented as epistemically deleterious cognitive biases. Those conclusions are warranted when the evidence does not diminish in marginal value, like in the presented experiments. The evidence there was *locally misleading* in the sense that it unexpectedly pointed towards the wrong conclusion for a sustained period. However, courses of evidence that are systematically misleading like those of the experiment are atypical. In cases where evidence instead diminishes in marginal value, the above arguments and model suggest that subjects who exhibit these “biases” might have a more accurate picture of the world as a result.

### 5.2 *Clarifying the belief-as-plan view*

According to the belief-as-plan view, belief is best thought of by analogy to Michael Bratman’s notion of intention (Bratman, 1987).<sup>27</sup> Just as intention is, on this view, a kind of *practical* coordination point or a stable point that constrains future action, belief is a kind of *epistemic* coordination point or a stable point that shapes our representation of the world, guiding theoretical deliberation and inquiry. By forming a belief in a proposition, we become disposed to treat that proposition as true in reasoning.

One of the central mechanisms by which belief plays this role, on this view, is by being disposed to *resist reconsideration*. The thought parallels the rough argument for obstinacy presented above. It is cognitively costly to remain responsive to every epistemic contingency. After

26. (Baron, 2007) contains a good summary of “primacy” results like the one described.

27. A defense of the belief-as-plan view can be found at (Holton, 2013). We follow the details of his presentation here. A similar position is suggested by Ross and Schroeder (2014).

weighty enough evidence for a proposition is taken into account, proponents of the belief-as-plan view argue, we usually expect that further information for that proposition will be largely epistemically inconsequential. There is little to gain by responding to further information regarding that proposition. Thus, instead of being disposed to respond to such information, it would be better to be disposed to disregard it in order to make up gains on other issues — to resist reconsideration on well-established propositions by being blind to information that bears on it.

According to the belief-as-plan view, that is what believing does. Believing a proposition firms up one's epistemic stance towards the believed proposition. It trades off the epistemic flexibility of being able to constantly fine-tune one's epistemic stance towards a proposition in order to make up epistemic gains on other issues. This should sound familiar. The obstinate policy, remember, recommends disregarding available information as bearing on a proposition when substantial information for that proposition has been gathered. The motivation for the belief-as-plan view parallels the rough defense of the obstinate policy over the naïve one and stands to be clarified along the same lines as the model clarified the rough argument for obstnacy.

It should be noted that, in this application, it is important that a believer's stance towards future evidence more closely resembles blindness than deliberate ignorance. This is for two reasons. First, deliberately ignoring information is often (or perhaps always) irrational. If one is blind to information, then, arguably, that is not (or at least less obviously) epistemically pernicious. In this way, the proposal takes a policy for responding to information to be more like a *filter* on what information is processed than a willful stance towards it. Moreover, the disposition to resist reconsideration that accompanies outright belief on this view must typically be overridden by high-impact information. A subject who believes that it will not rain might get along just fine by being blind to the relevance of a few dark clouds on the horizon, but that subject would be deeply defective if she were blind to the rain-drops falling on her head as she leaves for the picnic.

The second reason that obstnacy should be treated as analogous to information blindness rather than to a state of deliberately ignoring information is that if the resistance to reconsideration were a deliberate matter, the proposal would be self-undermining. Deliberately considering how further information bears on a proposition already incurs the cost of reconsideration. Thus, in order for the obstinate policy to help explain how belief might offload the costs of reconsideration for a gain in accuracy, the resistance to reconsideration that it suggests cannot be deliberate.

With this in mind, the model and case study can be used to unpack the belief-as-plan view if either (i) credence and outright belief "march in step",<sup>28</sup> in the sense that belief is always accompanied by high confidence, or (ii) outright belief reduces to credence.

If outright belief reduces to credence, then the application is direct. Belief's resistance to reconsideration can be understood as a generalized version of credal obstnacy, and the obstinate policy shows how forming beliefs on the belief-as-plan view is cognitively valuable in the range of focus cases considered, since obstinate credences are expected to be more accurate than those formed using a naïve policy in those cases. The more common the focus cases are, the more support the model gives the belief-as-plan view.

The model can also be used to unpack the details of our mental lives on the belief-as-plan picture if credence and belief merely "march in step". If beliefs resist reconsideration according to the belief-as-plan view, then the high credences that accompany those beliefs will have to likewise "march in step" and resist reconsideration in the same cases. But then, whatever one's account of how one gets into a belief-as-plan state, one will need an account of how credence gets into a state of resisting reconsideration too. The generalizations of the obstinate policy presented work equally well here. If one updates in accordance

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28. This locution, and observation, is due to Scott Sturgeon (2008). The thought is implicit in any account of belief that reduces belief to a variety of high confidence.

with a generalization of the obstinate policy while outright belief and credence “march in step”, then the obstinate policy provides a partial explanation of why forming plan-like beliefs promotes overall representational accuracy at the level of outright belief.

By following the obstinate policy at the credal level, a subject increases the chances that the available information will propel more of her credences towards the truth than if she were to update naïvely in our focus cases — that is the effect driving the results in the case study. But, given the “march in step” phenomenon, one consequence of this is that following an obstinate policy will make it possible to form more outright beliefs in truths than if one updated naïvely in those circumstances. So, obstinate policies promote being in a credal state that is more fertile for forming accurate outright beliefs than the naïve policy insofar as those circumstances are common. The hypothesis that credences adhere to an obstinate policy, together with the “march in step” claim, supports the idea that forming belief-as-plan states is good for overall representational accuracy.

In sum, many find the view that outright belief reduces to confidence plausible. But, even if it is false, it is plausible that belief and credence “march in step”. It is difficult to imagine what it could be like to believe a proposition without being more confident than not that that proposition obtains. In either case, the queue-theoretic model and case study provide a plausible way to unpack the cognitive states at issue in the belief-as-plan view, and show how entering into such states can be cognitively beneficial.

### 5.3 *Demandingness worries*

The possibility of information-response policies like the obstinate policy helps to alleviate, if not eliminate, certain “demandingness” objections to views that take us to be credal reasoners. In this vein, Gilbert Harman (1986, ch. 3), and more recently Richard Holton (2013, pp. 2–3, 10–12), have argued that we are not the kinds of creatures that explicitly reason with credences because doing so would outstrip our mental

capacities — reasoning with credences is *too cognitively costly* for creatures like us.

In particular, they both begin by assuming that credences are the kinds of states that are responsive to *any* non-trivial evidence. But, we are not the kinds of creatures that are capable of readily responding to all of the available information. Consequently, the line of thought continues, the amount of cognitive processing that being a credal reasoner would require makes it implausible that we are credal reasoners — in order to be good credal reasoners we would have to be willing to take unrealistically many things into epistemic account.<sup>29</sup>

However, the assumption upon which this general argument relies — that credences are the kind of states that are responsive to any non-trivial information — is implausible. It marks another place that the theory of ideal reasoning, in this case Bayesian updating, is being misinterpreted as a description of attentive deliberation. If we take our cognitive limitations seriously in the way that both Harman and Holton suppose that we should, then, contrary to what Bayesian models of ideal credal reasoning might suggest, credal states should not be expected to be responsive to absolutely any non-trivial information. Some credences might resist reconsideration in the same way that Holton takes belief states to fail to respond to some pieces of information as a matter of brute disposition. The obstinate policy serves as a simple proof of concept of how this might be so, while the policy comparison illus-

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29. Holton and Harman give different reasons for why we cannot readily respond to all of the available information. Harman worries that doing so would require credal reasoners to have implausibly many conditional confidences waiting in the wing. Holton worries that doing so would make our mental lives unmanageably unstable, in that we would have to be constantly recalculating our credences in established propositions. I am here focusing on the general features shared by each author’s objection rather than the specifics over which they differ. There are further worries for the specifics — many of which are clearly articulated in Julia Staffel’s (2013) criticisms of Harman’s (1986) version of the objection. Both Harman and Holton also have additional arguments for the conclusion that we are not credal reasoners. It is less clear that the above discussion can help with those arguments, so, while I don’t find them compelling, I do not take them up in what follows.

trates one way that we stand to profit by instantiating a credal policy of disregarding information on issues for which we have processed substantial information. The objection is no more persuasive when leveled against accounts of reasoning with credences than when it is leveled against accounts of reasoning with belief.

## 6. Summing up

For limited creatures like us, properly responding to information comes at a cognitive cost. In this paper, I laid out a queue-theoretic framework for precisely assessing how different policies for responding to information interact with some of our limitations to influence the cognitive value of our total credal state. Two simple policies for responding to information, “the naïve policy” and “the obstinate policy”, were assessed within this framework under modest assumptions about our cognitive limitations, in a range of common cases, and under defensible simplifying assumptions. Under these conditions it is provable that, from the point of view of expected credal accuracy, it is better for epistemic subjects like us *not to update* on available information that bears on propositions for which substantial evidence has been gathered than it is to update on information as it presents itself.

The conditions assumed in the model are most appropriate when the propositions under investigation concern the familiar properties of ordinary mid-sized dry goods. Given the central role that hypotheses of this kind play in everyday inquiry, the model helps to explain why some of our non-ideal techniques for responding to evidence are nonetheless useful. By pointing out that credences might be formed in accordance with the obstinate policy, the above picture undercuts a “demandingness” objection to the possibility that we are credal reasoners and helps to give substance to the view that takes belief to be a kind of plan.

## 7. Technical Appendix

This section provides the details of the result documented in §4. In order to derive the results, it was assumed that the waiting times be-

tween observations relevant to the truth of a proposition  $p_i$ ,  $X_i$  for  $i \in \{1, \dots, n\}$ , are identically but independently exponentially distributed with rate of arrival  $\lambda$ . Likewise, the waiting time for a proposition in the queue to be processed,  $Y_\mu$ , is independently exponentially distributed at a (possibly distinct) rate of  $\lambda_\mu$  pieces of information per time period. That is, the  $X_i$  and  $Y_\mu$  have the following probability density function:

$$f(x) = \begin{cases} \theta e^{-\theta x} & \text{if } x \geq 0 \\ 0 & \text{if } x < 0 \end{cases}$$

where  $\theta$  is the average rate at which pieces of information arrive for the given  $p_i$  or are processed, respectively.

Now, let  $t_1, t_2, \dots$  be the sequence of times at which an *epistemic event* occurs, that is, either a piece of information relevant to a proposition is presented according to an  $X_i$  or a piece of information is processed from the queue according to  $Y_\mu$ . Let  $S_{p_1, p_2, p_3, \dots, q}$ , with  $p_k, q \in \mathbb{N}$  and  $q \leq m$  be the state in which our reasoner has made  $p_1$  observations relevant concerning the truth of the first proposition of interest,  $p_2$  observations relevant to the second proposition of interest,  $\dots$ , and for which  $q$  of  $m$  states of working memory are currently being expended to process observations. A proposition and two corollaries follow from these definitions and observations:

**Proposition 1.** The probability, at time  $t$ , that a given  $\mathcal{V}$  chosen from  $\{X_1, \dots, X_n, Y_\mu\}$  will occur next,  $\mathbb{P}_t[\mathcal{V} = \min\{X_1, \dots, X_n, Y_\mu\}]$ , is  $\frac{\lambda_\mathcal{V}}{\lambda_\mu + n\lambda}$ , where  $\frac{1}{\lambda_\mathcal{V}}$  is the mean of  $\mathcal{V}$ . By the no-memory property of  $X_1, \dots, X_n, Y_\mu$ , this is so no matter which events have occurred before  $t$ .<sup>30</sup>

30. See (Ross, 2007, p. 294) for a standard proof of the result. It is worth noting that the assumptions support the more general proposition in which the means of the distributions of observations are not assumed to be equal. In that case,  $\mathbb{P}_t[\mathcal{V} = \min\{X_1, \dots, X_n, Y_\mu\}] = \frac{\lambda_\mathcal{V}}{\sum \lambda}$ , where  $\lambda$  ranges over the mean rates of arrival for  $X_1, \dots, X_n$  and  $Y_\mu$ .

This, in turn, yields the following probabilities for transitioning between states when the naïve policy for responding to presented information is operative:

**Corollary 2** (Naïve transition probabilities). Where ‘ $S_i \rightarrow_{\mathbb{P}} S_j$ ’ is the probability of transitioning from state  $S_i$  to  $S_j$ , and  $p_k, q \in \mathbb{N}$ :

1.  $S_i \rightarrow_{\mathbb{P}} S_j = \frac{\lambda}{\lambda_{\mu} + n\lambda}$  if  $q < m$  and  $S_i = S_{\dots, p_k, \dots, q}$  while  $S_j = S_{\dots, p_k+1, \dots, q+1}$ ;
2.  $S_i \rightarrow_{\mathbb{P}} S_j = \frac{\lambda_{\mu}}{\lambda_{\mu} + n\lambda}$  if  $S_i = S_{\dots, q}$  while  $S_j = S_{\dots, q-1}$ ;
3.  $S_i \rightarrow_{\mathbb{P}} S_j = \frac{n\lambda}{\lambda_{\mu} + n\lambda}$  if  $S_i = S_j = S_{\dots, q}$  with  $q = m$ ;
4.  $S_i \rightarrow_{\mathbb{P}} S_j = 0$ , otherwise.

Moreover, the state-transition probabilities under the obstinate policy are given by the following:

**Corollary 3** (Obstinate transition probabilities). Where ‘ $S_i \rightarrow_{\mathbb{P}} S_j$ ’ is the probability of transitioning from state  $S_i$  to  $S_j$ , information for a proposition of interest is ignored after  $\omega$  observations, and  $p_k, q \in \mathbb{N}$ :

1.  $S_i \rightarrow_{\mathbb{P}} S_j = \frac{\lambda}{\lambda_{\mu} + n\lambda}$  if either
  - (a)  $q < m$ ,  $p_k < \omega$  and  $S_i = S_{\dots, p_k, \dots, q}$  while  $S_j = S_{\dots, p_k+1, \dots, q+1}$ ; or
  - (b)  $q < m$ ,  $p_k = \omega$ , and  $S_i = S_j$ .
2.  $S_i \rightarrow_{\mathbb{P}} S_j = \frac{\lambda_{\mu}}{\lambda_{\mu} + n\lambda}$  if  $S_i = S_{\dots, q}$  while  $S_j = S_{\dots, q-1}$ ;
3.  $S_i \rightarrow_{\mathbb{P}} S_j = \frac{n\lambda}{\lambda_{\mu} + n\lambda}$  if  $S_i = S_j = S_{\dots, q}$  with  $q = m$ ;
4. Otherwise,  $S_i \rightarrow_{\mathbb{P}} S_j = 0$ .

The above observations allow us to compute the probability that an individual is in a given state after a specified number  $E$  of epistemic events for either of the discussed information-response policies. The result follows by application of a version of the Chapman-Kolmogorov Equations. In particular, letting ‘ $S_i \rightarrow_{\mathbb{P}, E} S_j$ ’ be the probability that beginning in state  $S_i$  one arrives at  $S_j$  after  $E$  epistemic events, the probabilities follow by looking at each possible way that one can end up in a state  $S_j$  from  $S_i$

$$S_i \rightarrow_{\mathbb{P}, a+b=E} S_j = \sum_{k=0}^{\infty} (S_i \rightarrow_{\mathbb{P}, a} S_k) \cdot (S_k \rightarrow_{\mathbb{P}, b} S_j).$$

Specifying the starting state yields a distribution of probabilities for the possible states one might be in after  $E$  epistemic events according to the relevant method of responding to available information.

With these details in place, fixing  $m, n, \lambda, \lambda_{\mu}$ , and the epistemic subject’s starting state allows the subject to calculate the expected accuracy of their credal state  $S$  after  $E$  epistemic events. Recall that for a total credal state  $S$  in propositions  $p_1, \dots, p_n$ , the total accuracy  $D(S)$  of that state given by a version of the quadratic scoring rule is  $\sum_i - (1 - \mathbb{P}_E [p_i])^2$  with  $\mathbb{P}_E$  the subject’s credence function after  $E$  epistemic events.<sup>31</sup>

Now, letting  $S_1, S_2, \dots$  be the possible states describing the pieces of information taken into account as above, the length of the queue after  $E$  epistemic events,  $o_i(S)$  be the number of propositions with  $i$  observations specified in the subject’s total credal state  $S$ , and  $\mathbb{P}$  — without index — be our reasoner’s credence function before inquiry, the expected accuracy of our reasoner’s credal state after  $E$  epistemic events is  $\mathbb{E} [D(S)] = \mathbb{E} [\mathbb{E} [D(S) | S_i]]$ , by the Law of Total Expectation. Which is equal to:

$$\mathbb{E} \left[ \sum_j -o_j(S_i) \left(1 - \frac{1}{1+e^j}\right)^2 \right] = \sum_i \mathbb{P} [S_i] \sum_j -o_j(S_i) \left(1 - \frac{1}{1+e^j}\right)^2.$$

Filling in the state transition probabilities for either policy yields the expected accuracy of that policy at a time at which any specified number of epistemic events has occurred, as desired.<sup>32, 33</sup>

31. The proof is parallel for the spherical and logarithmic scoring rules.

32. A Mathematica notebook for calculating the expected value of epistemic states for particular choices of model parameters and scoring rules is available at [jdallmann.org/research](http://jdallmann.org/research).

33. This paper has benefited from the comments of Kenny Easwaran, Matthew Lutz, Jacob Ross, Hannah Rubin, Ralph Wedgwood, Jonathan Weisberg, audiences at the 2015 Formal Epistemology Workshop, Jane Friedman’s Norms of Inquiry Workshop at New York University, the 2014 Inductive Logic and Confirmation in Science Workshop, and the University of Manitoba. I also thank

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