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Belief updating and the demand for information

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ABSTRACT

How do individuals value noisy information that guides economic decisions? In our laboratory experiment, we find that individuals underreact to increasing the informativeness of a signal, thus undervalue high-quality information, and that they disproportionately prefer information that may yield certainty. Both biases appear to be mainly due to non-standard belief updating. We find that individuals differ consistently in their *responsiveness to information* – the extent that their beliefs move upon observing signals. Individual parameters of responsiveness to information have explanatory power in two distinct choice environments and are unrelated to proxies for mathematical aptitude.

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1. Introduction

Modern economies increasingly trade not just in physical goods, but in information. Economic agents consider whether to purchase medical tests, consulting expertise, or financial forecasts. Entire industries are premised on the sale of useful but noisy information.

In this paper we use a laboratory experiment to investigate whether, and why, the demand for information systematically deviates from the predictions of the standard rational agent model. In contrast to the existing literature on the demand for information, information in our setting is instrumentally useful but concerns a state that is of no intrinsic relevance to subjects, and strategic considerations play no role.

The purchase of information is commonly conceptualized as the decision to partake in a two-stage lottery. In the first stage, the agent updates her beliefs upon observing the realization of an informative signal. In the second stage, she chooses an action, upon which the state of the world is revealed and payoffs are realized.[1] A standard rational agent will update beliefs according to Bayes' rule, and make choices according to expected utility theory. For any agent who correctly anticipates his own belief updating, this suggests two mechanisms through which empirical behavior could deviate from the predictions of the standard model.

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[1] This conceptualization of the demand for information has been chosen by a wide range of theoretical papers, including, for instance, Azrieli and Lehrer (2008), Athey and Levin (2001), Cabrales et al. (2013a), and Cabrales et al. (2013b).

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First, the demand for information may be affected by systematic deviations from expected utility theory in compound lotteries. These have been documented and modeled, for instance, by Bernasconi and Loomes (1992), Ergin and Gul (2009), Halevy (2007), Halevy and Feltkamp (2005), Segal (1987), Seo (2009), and Yates and Zukowski (1976). Second, the demand for information may be influenced by biases in belief updating (reviewed in Camerer, 1995). Our design allows us to estimate the effect of the latter channel on the demand for information, and to identify three biases in belief updating and the demand for information.[2]

In our experiment, subjects reveal how valuable they think it is to first observe an informative signal about a binary state of the world and then make a guess about it. At the very end of the experiment, a correct guess may be rewarded with a prize. Since our elicitation is in terms of probability units of winning the prize, our results are independent of the shape of subjects' utility function for money. Discriminating between channels is possible as a second stage asks subjects to reveal posterior beliefs for each of these signals. A third stage presents subjects with a conditionally i.i.d. sequence of signal realizations that depends on the state of the world. It measures how much information subjects require until they first prefer betting on the state of the world to an outside option.

We identify two biases in the demand for information that depend on the properties of *information structures*. Subjects value signals of varying informativeness as though they were more alike, compared to the predictions of the standard model (the *compression effect*). Additionally, subjects disproportionately prefer information structures that may perfectly reveal the state of the world (the *certainty effect*). We also test how valuations change if we increase the precision of the signal in one state of the world and decreasing it in another, such that the utility of a standard rational agent is unchanged. A class of theories of non-standard risk preferences predict that this will make an information structure less attractive to subjects (Segal, 1987; Seo, 2009). Our data do not support this hypothesis.

We identify a third bias that is *individual-specific*. Subjects in our experiment are heterogeneous in *responsiveness to information*, the extent to which their beliefs move upon observing information. Importantly, this heterogeneity is *consistent* within individuals. We measure this individual tendency in one task, and find that it is significantly correlated with subjects' behavior in two additional tasks. Moreover, while it is related to cognitive style, it is uncorrelated with proxies for mathematical aptitude. In particular, neither the direction nor the absolute size of this bias is correlated with whether a subject knows Bayes' law, has taken a statistics class, or has a STEM major.

Following Grether (1980) and Holt and Smith (2009), we propose a one-parameter model of responsiveness to information and estimate each subjects' parameter using data only from the latter part of our experiment. This procedure collapses all the data about each subject's belief updating to a single parameter, yet it explains 80% of the individual variation in the demand for information that can be explained with a model that uses each individual's beliefs data in a maximally flexible way. Our individual-level estimates of responsiveness to information are also significantly related to subjects' behavior in our environment that gradually uncovers information and reveals how quickly subjects' beliefs about the state of the world cross a given threshold.[3]

Conditional on the estimated parameters, the responsiveness model also generates the compression effect and the certainty effect. This is perhaps surprising, since the model is set up to capture a single individual-specific bias, while these two effects pertain to properties of the information structures. Both of these are consequences of the fact that our average subject is less responsive to information than a Bayesian, but correctly interprets perfectly informative and perfectly uninformative signal realizations. Formally, the model of responsiveness to information is equivalent to applying a prospect theory probability-weighting function to the Bayesian posterior. The information structure-specific effects we observe are implications of the inverse S-shape of that function.

Many of our results could in principle be due to either non-Bayesian belief updating, or due to non-standard risk preferences. We argue that the latter are unlikely to explain the entirety of our data, for three reasons. First, by design, our results cannot be due to the shape of subjects' utility function for money. Each choice in our experiment elicits, for some event X, the value of k such that the subject is indifferent between *receiving \$35 with probability k and \$0 otherwise*, and *receiving \$35 if event X occurs and \$0 otherwise*.[4] For any expected utility maximizer, the value of k that leaves such an agent indifferent does not depend on his degree of risk aversion (Roth and Malouf, 1979).

Second, also by design, they cannot be due ambiguity aversion, at least if interpreted in the standard fashion. In our experiment, all probabilities are objectively given. Subjects have induced priors about the state space, and all information structures are explicitly given, so that the probability of any payoff-relevant event can be calculated, via a simple application of Bayes' rule. In contrast, ambiguity aversion models are usually interpreted to apply under Knightian uncertainty, where objective probabilities are not applicable (Knight, 1921; Ellsberg, 1961; Baillon and Bleichrodt, 2015).

[2] This exercise, however, does not decompose behavior into beliefs and *preferences*. In the subjective expected utility framework, preferences are basic, and beliefs are just part of the representation (Savage, 1954). To be scrupulous, when we say that a subject deviates from Bayesian belief updating, we mean "in the representation that rationalizes this choice, the beliefs differ from the objective Bayes posteriors."

[3] We emphasize that heterogeneous responsiveness to information is not observationally equivalent to heterogeneous risk aversion. To see this, consider an agent who chooses between a safe option and a risky option, and who purchases information that might affect the optimal decision. If, in the absence of information, the agent would choose the risky option, then his willingness to pay for information is *increasing* in risk aversion. If, in the absence of information, the agent would choose the safe option, then his willingness to pay for information is *decreasing* in risk aversion. By contrast, his willingness to pay for information is *increasing* in responsiveness in both of these cases. (Appendix C formalizes this argument.)

[4] This mechanism was suggested in Allen (1987), Grether (1992), and Karni (2009), Schlag and van der Weele (2013), and has been used, amongst others, by Hoelzl and Rustichini (2005) and Moebius et al. (2013).

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