A Dynamic Model of Optimism

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August 30, 2004

Abstract

In this paper we examine implications of two simple ideas: (1) that beliefs about the future are carriers of utility, and (2) that people have some ability to manipulate their own beliefs. We show that simple assumptions about how beliefs enter into utility, and about the ability of humans to directly manipulate their own beliefs, lead to a number of testable predictions concerning dynamic expectation formation. We then show that several of these predictions are, in fact, supported empirically.

1 Introduction

The idea that people derive utility from beliefs as well as from consumption is so straightforward that empirical verification would risk being viewed as a demonstration of the obvious. People derive pleasure and pain from thinking about the future (Loewenstein, 1987; Caplin and Leahy, 2000), their own worth (or lack thereof) (Koszegi, 1999; Bodner and Prelec, 2001), and from their view of the type of world they live in and the people who inhabit it (Lerner, 1978; 1981; Geanakoplos, Pearce and Stachetti 1989).

Despite the obviousness of the idea that beliefs confer utility, the implications of this observation have only recently begun to be addressed by economists. Recent analyses have shown that taking account of utility and disutility from beliefs about the future can help to explain a wide variety of otherwise anomalous phenomena: why people get unpleasant outcomes over with quickly (as if they have negative time preference), simultaneous gambling and insurance purchases (and more generally, intra-individual variability in risk-taking) and information avoidance (Caplin, 2003).

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Our focus in this paper is the motivation for self-manipulation of beliefs produced by the link between utility and beliefs. If beliefs enter into the utility function directly - i.e., apart from what they signal about future outcomes - then people will naturally have an incentive to manipulate their own beliefs.

There is, in fact, a large body of research in psychology that documents apparent self-manipulation of beliefs. For example, well over 50% of the population rank themselves as better than average on a wide range of traits and skills, from skill as a driver, to considerateness (Dunning and Hayes, 1996). Psychologists have also found that people tend to take disproportionate credit for good outcomes, which they attribute to their own skills and effort, but generally duck responsibility for bad outcomes, which are attributed to bad luck or to the actions of others (Weiner, 1982).

Despite the plethora of evidence for self-manipulation of beliefs, and the naturalness of the step from allowing beliefs to enter into utility to assuming that people manipulate their own beliefs, there has been very little work in economics on self-manipulation of beliefs. Akerlof and Dickens (1982) examined one type of belief-manipulation in their paper on the ”Economic Consequences of Cognitive Dissonance.” They modeled the situation faced by workers in a dangerous work environment who, lacking other employment options and needing to work, downplay the severity of the risks they face. Koszegi (1999) and Bodner and Prelec (2001) have also examined forms of belief manipulation in which people take actions to persuade themselves that they are a particular type of person (even when they are not). Benabou and Tirole (2000) propose a model of belief-distortion in which people exaggerate their own likelihood of succeeding at a task so as to counteract the inertia-inducing effects of hyperbolic time discounting.

Our focus in this paper is somewhat different. Whereas these earlier papers focused on the relationship between beliefs and actions – on beliefs manipulated to motivate actions or actions taken to alter beliefs – our focus is exclusively on beliefs. In the next subsection (section 2), drawing on both psychological research and intuition, we make some simple assumptions about how beliefs enter into the utility function. We then trace out the implications of those assumptions for optimism, deriving a number of predictions for dynamic patterns of expectation formation. In section 3, we then evaluate the accuracy of these predictions in light of empirical research on expectation formation, most of it conducted by psychologists. We conclude, in section 4, with a broader discussion of the role of information in economics.

2 A Model of Expectations

Assuming that beliefs about the future are carriers of utility, there are benefits of holding optimistic beliefs and/or having high expectations. First, it is emotionally pleasant to be optimistic about the future. People who hold an optimistic outlook of the future are happier, less depressed, and have a higher satisfaction with life (i.e., greater subjective well-being) than people who do not (Scheier, Carver, and Bridges, 2001). Hence, optimistic beliefs increase instant utility. Second, expecting to succeed may increase the chances of success. Quite simply, an individual may be more motivated to put effort into prospects if he or she expects them to succeed than if he or she expects them to fail. People who are optimistic have been found to adapt more successfully to stressful events such as beginning college (Scheier, *et al.*, 2001) and fare better both psychologically and physically after life-threatening events such as a heart attack (Petersen and Bossio, 2001).

However, optimistic beliefs also have drawbacks. Most importantly from the perspective of the current analysis, optimistic beliefs increase one's vulnerability to disappointment as a result of experiencing outcomes that fall short of expectations (Gul, 1991; Bell, 1988; Loomes and Sugden, 1986; Zeelenberg, *et al.*, 2000). Hence, part of what is gained in utility from holding optimistic beliefs may be lost as a result of the adverse effect of optimism on disappointment.

Optimistic beliefs reduce pleasure from experienced outcomes. Unexpected positive outcomes are perceived as more attractive than expected positive outcomes and unexpected negative outcomes are perceived as worse than expected negative outcomes (Feather, 1967; Shepperd & McNulty, 2002). For example, McGraw, Mellers and Ritov (in press) show that recreational basketball players experience successful shots as more pleasurable when they are unexpected than when they are expected, and failed shots as more painful when unexpected than when expected. Moreover, when the researchers reduced players' overconfidence with a debiasing procedure, the player's average pleasure was greater than without such debiasing.

In addition, unrealistic optimism, like any other form of judgmental bias, can distort decision making. In what is perhaps the paper most closely related to the current one, Brunnermeier and Parker (2003) propose a theoretical model of optimal expectations in which agents are assumed to trade off the direct utility benefits of holding optimistic beliefs against the negative effects that biased expectations have on the quality of decision-making. There are two important differences between their model and the model presented in this paper. First, whereas Brunnermeier and Parker focus on the trade off between optimism and distorted decision-making, we focus on the trade off between positive utility from optimism and negative utility from disappointment. Second, Brunnermeier and Parker assume that optimistic beliefs are static, while a main feature of our model is that the degree of optimism in beliefs varies dynamically over time.

In the following, we present a model of optimal beliefs that takes into account the direct benefits of optimistic beliefs and the direct costs of disappointment. We model the problem of dynamic intertemporal expectation formation in which a decision maker chooses her beliefs about a future uncertain outcome. The decision maker chooses only her beliefs – the realization of the future outcome is assumed to be beyond her control, so that no actions are included in our model; we are solely interested in what beliefs are optimal when the decision maker is interested only in the consumption of her beliefs and the possibility of unpleasant disappointment when the outcome is finally revealed to her.

Let X be a real-valued random variable, with realization $x \in [0, Y] \subset \mathbf{R}$ (assuming that $Y > 0$ and allowing for $Y = \infty$), distributed according to a continuously differentiable cumulative distribution function $F : \mathcal{B}(Y) \to [0, 1]$.[1] We denote the derivative of F by f. The model we analyze is continuous time and finite horizon, with the space of time under consideration being $[0, T + \tau]$, with both T and τ nonnegative and finite. The decision maker observes the realization of x at time T and the parameter $\tau \geq 0$ denotes the length of time after x is realized during which the decision maker receives a payoff based on x and the decision maker's beliefs about x held at $t = T$.

At time $t \in [0, T]$ (i.e., all times leading up to x's realization), the decision maker holds beliefs $p(t) \in Y$, which represents the decision maker's best guess about x. The decision maker receives payoffs as a function of both her beliefs about X and the realization, x. We assume that the utility of the decision maker prior to $t = T$ (i.e., before x is realized) is determined by a function,

$$A : Y \to \mathbf{R}.$$

Consistent with considerable evidence, as well as simple intuition, we assume that A is a continuous, strictly increasing function: that is, the decision maker is made happier by higher beliefs about the future outcome.[2]

The decision maker discounts future payoffs according to a discount factor $r \in [0, 1]$. Thus,

[1] We use the notation $\mathcal{B}(Y)$ to denote the Borel σ-algebra on Y.

[2] While beliefs play an explicitly hedonic role in our model, there are, of course, other roles that individuals' beliefs may play in their well-being. For example, there are studies demonstrating positive effects of optimism on psychological as well as physical health and well-being (reviewed above). Hence, from this perspective people may also derive indirect benefits from optimism.

the total payoff received by the decision maker from $t = 0$ to $t = T$ is

$$\bar{A}(p) = \int_0^T A(p(t))e^{-rt}dt,$$

where A denotes "anticipation."[3] Conditional upon the realization of x, the decision maker is assumed to receive utility as determined by a function

$$D : Y^2 \rightarrow \mathbf{R},$$

where D denotes "disappointment," which maps pairs of beliefs $p(\tau)$ and possible realizations of x into utility levels. We assume throughout that D is continuously differentiable, with $\partial D(p(T), x)/\partial x > 0$ and $\partial D(p, x)/\partial p < 0$, implying that the decision maker prefers high realizations of x and lower beliefs at $t = T$, *ceteris paribus*. This assumption is consistent with a substantial body of empirical evidence that disappointment is aversive (e.g., Zeelenberg at al., 2000) as well as with theoretical treatments of disappointment, such as Bell (1988), Loomes and Sugden (1986, 1987), and Gul (1991).

Of course, the inclusion of D and F into the model implies that an optimal decision maker needs to some extent to know their true chances of success (represented by F in our model) and at the same time potentially ignore this knowledge prior to the realization of the outcome. True self-deception has been argued to be logically impossible (see, e.g., Sartre 1953) , since it means to simultaneously know something and not know it (and perhaps, even more complicatedly, know that one both knows something and does not know it). But, this argument assumes that there is only one way to 'know' something. In fact, recent work by psychologists (e.g., Sloman, 1996; Epstein, 1992) suggest that people may hold beliefs at different levels. Thus, for example, when presented with two jars, one containing one blue and nine red beans, and the other containing ten blue and ninety red beans, most people state that the probability of drawing blue is the same with either jar; yet most people prefer to bet on the jar with the larger number of blue beans (and many are willing to pay a premium to do so). Other research shows that people's beliefs often lack precision – i.e., are "fuzzy" (Schneider, 2001) – which may provide some leeway for self-manipulation of expectations in relation to knowledge. Whether this should be labeled self-deception depends on one's definition of the term. What we are suggesting here is that there may be optimal ways to form these expectations to maximize the

[3]The term anticipation is chosen over the more specific phrase "expectation" because the second term carries a formal mathematical definition within our framework that is distinct from this function's role within our model.

utility that one extracts from beliefs.

The expected value of D, conditional upon p, is defined as

$$\begin{aligned}\bar{D}(p) &= \int_Y \int_T^{T+\tau} D(p,s)e^{-rt}dtF(ds), \\ &= \frac{e^{-rT}-e^{-r(T+\tau)}}{r}\int_Y D(p,s)F(ds), \\ &= \frac{e^{-rT}-e^{-r(T+\tau)}}{r}E_F[D(p,x)],\end{aligned}$$

where E_F denotes expectation with respect to the probability measure F.

In addition to anticipation and disappointment, the decision-maker may experience disutility from the act of belief revision itself. We capture this possibility in the form of a cost function, $C : \mathbf{R} \to \mathbf{R}$. This function associates the derivative of p (which represents the rate of belief revision) with its psychological cost. We assume that C is continuously differentiable and strictly convex. The cost of belief revision along a belief function p is then defined as

$$\bar{C}(p) = \int_0^T C(p'(t))e^{-rt}dt.$$

Finally, the decision-maker's expected payoff function for a belief function p is defined as

$$\pi(p) = \bar{A}(p) - \bar{C}(p) - \bar{D}(p). \quad (1)$$

Optimal Beliefs. We are now almost in a position to define optimal beliefs. For technical reasons, we must first restrict attention to belief functions that are (1) continuous, (2) continuously differentiable almost everywhere, and (3) map $[0,T]$ into Y. We denote the set of such functions by $\mathcal{P}$.[4] Given this restriction, optimal beliefs, in words, maximize the decision-maker's expected payoffs, as defined in Equation (1). This is stated formally below.

Definition 1 *An* optimal belief path *is any belief path* $\tilde{p}$ *such that*

$$\tilde{p} \in \arg\max_{p\in\mathcal{P}} \pi(p).$$

[4]Technically, $\mathcal{P}$ depends upon Y and T. However, since the dependence of $\mathcal{P}$ on these primitives is uninteresting and for reasons of exposition, we omit these from the notation.

2.1 Solution of an Example of the Model

The previous section provides a definition of optimal beliefs. This section examines the comparative statics of such beliefs with respect to the decision maker's discount rate, r, length of rumination, τ, and length of time spent anticipating the outcome, T. In order to derive these comparative statics, we make some assumptions about functional forms of the anticipation, cost, and disappintment functions. Specifically, we assume that

$$\begin{aligned} A(p(t)) &= \alpha p(t) && (2) \\ C(p'(t)) &= \kappa (p'(t))^2 \text{ and} && (3) \\ \bar{D}(p) &= -\frac{\delta}{2}(e^{-rT} - e^{-r(T+\tau)})(p(T))^2, && (4) \end{aligned}$$

with $\alpha, \kappa, \delta, r, \tau \geq 0$.[5] In addition, we assume that $Y = \infty$ in order to make the exposition clearer.[6] Using these assumptions, the optimal belief path is derived by solving the following optimization problem:

$$\max \int_0^T (A(p(t)) - C(p'(t)))e^{-rt}dt - \bar{D}(p(T))$$

subject to

$$p \in \mathcal{P}.$$

The solution of this problem consists of two steps; the derivation is contained in the appendix. The optimal belief path is

$$p(t) = \frac{\alpha T}{\delta(e^{-rT} - e^{-r(T+\tau)})} + \frac{\alpha T^2}{4\kappa} - \frac{\alpha t^2}{4\kappa},$$

with initial beliefs equal to

$$p(0) = \frac{\alpha T}{\delta(e^{-rT} - e^{-r(T+\tau)})} + \frac{\alpha T^2}{4\kappa},$$

[5]We have defined $\bar{D}$ directly, implicitly integrating according to some unspecified cumulative distribution function F. For expositional purposes, we have omitted the denominator value of r. This is unimportant, as we are only interested in the comparative statics of the solution up to the sign of first order differentiation with respect to $r \in [0, 1]$.

[6]Without this assumption, boundary solutions would need to be considered. Consideration of these is omitted because they are substantively uninteresting as well as offering no additional intuition.

final beliefs equal to

$$p(T) = \frac{\alpha T}{\delta(e^{-rT} - e^{-r(T+\tau)})},$$

and the absolute change in beliefs from beginning to end equal to

$$|p(0) - p(T)| = \frac{\alpha t^2}{4\kappa}.$$

Note that the degree to which beliefs change from the initial time until the time of revelation, $\frac{\alpha T^2}{4\kappa}$, is increasing in the marginal value of anticipation (α) and the time until revelation (T), while it is decreasing in the cost of belief revision (κ). The final level of beliefs, $\tilde{p}(T)$, is increasing in the marginal value of anticipation, α, and the length of time until revelation, T. The final level of beliefs is decreasing in the marginal cost of disappointment, represented by δ, r, and the length of time upon which disappointment will be ruminated over, τ.

Noting the *caveat* that our solution was generated with specific assumptions about functional forms, the model offers the following predictions about the dynamics of individual beliefs.

Prediction 1 *Holding all else constant, the initial level of optimism, $\tilde{p}(0)$, the final level of optimism, $\tilde{p}(T)$, and the degree to which beliefs change over time, $\tilde{p}(0) - \tilde{p}(T)$, are each increasing in the length of time until the result is revealed, T.*

Prediction 1 states that the decision maker's initial beliefs will be higher for outcomes that are revealed later. If the revelation is far enough in the future, the decision-maker will be "wholly optimistic" in the beginning, with $p(0) = \max Y$.

Prediction 2 *Holding all else constant, the decision maker's beliefs, $\tilde{p}$, decrease as time progresses and the revelation of the result draws nearer. Furthermore, the rate at which they decrease is increasing as the time of revelation approaches.*

According to Prediction 2, decision makers' beliefs will become less optimistic over time. While this generally implies that they become more realistic, this need not be the case if the decision maker derives enough satisfaction from "pleasant surprises," in which case her beliefs may become increasingly incorrect (too pessimistic) as time approaches. Regardless, the prediction is clear as to the direction of beliefs' movement: they become more pessimistic over time. The secondary prediction regarding the rate of belief revision is of interest as well. The optimal belief path will involve only moderate revision at first, with significant changes in beliefs occurring immediately prior to the revelation of the outcome.

Prediction 3 *Holding all else constant, the final level of beliefs, $\tilde{p}(T)$, is decreasing in the amount of time that the decision maker will ruminate upon the outcome after it is revealed, τ.*

Prediction 3 states that decision makers who ruminate longer over the surprise or disappointment following the outcome's revelation will be less optimistic before the outcome is realized. Another interpretation of this prediction is that as importance of not being overoptimistic increases, the final level of optimism decreases. This is particularly relevant if one wishes to place our model within a decision-making framework as examined (for example) by Brunnermeier and Parker (2003).

Prediction 4 *Holding all else constant, the final level of optimism, $\tilde{p}(T)$, is increasing in the rate at which the decision maker discounts the future, r.*

This prediction is strong – it implies that myopic decision makers will be more optimistic throughout the wait up until the result is revealed as well as at the time of revelation.[7]

2.2 Overview of the Baseline Model's Results and Predictions

We have characterized optimal beliefs in our framework. This section briefly frames the characteristics of such beliefs as predictions of regularities in empirical and experimental observations of individuals' beliefs.

Optimal beliefs will not become more optimistic as the realization of the outcome draws closer. It does not make one better off to hold initially pessimistic beliefs that grow increasingly optimistic. Similarly, once an individual begins to become less optimistic, she should continue to reduce her expectations up until the outcome is revealed.

Myopic individuals should be no less optimistic throughout the time leading up to the outcome's revelation. The potential disutility of disappointment is given less weight by a myopic individual. The effect of increased rumination is similar: decreasing rumination, which corresponds to decreasing τ in our model, decreases the effect of disappointment. Thus, decreased rumination increases the optimal level of optimism prior to the outcome's realization.

[7]This prediction is dependent upon our assumption that the decision maker discounts the future exponentially. It would be interesting, but beyond the scope of this paper, to extend the model to include other forms of intertemporal preferences.

3 Evidence for the Dynamic Model of Optimism

There is ample evidence supporting Prediction 1 – that people should hold unrealistic optimistic beliefs about future outcomes and risks (Weinstein, 1980, 1984, 1987). People tend to believe that good things, such as getting a desirable first job, are more likely to happen to them than to others (Weinstein, 1980) and that they are more likely than others to do well on future tasks (Crandall, Solomon, and Kelleway, 1955). Conversely, on average people believe that they are less likely than others to fall prey to negative events, for instance to be a victim of crime or illness (Perloff and Fetzer, 1986). It has been hypothesized that overly optimistic beliefs are due to "a desire for personal control, egocentric thinking, downward social comparison, or from the fact that optimistic predictions are gratifying" (Shepperd el al., 1996, p. 844). Our model implicates the last of these incentives – that is, that people gain direct pleasure or utility from holding optimistic beliefs about themselves and about future events.

Consistent with Prediction 2, there is substantial evidence that people tend to become more pessimistic when approaching the "moment of truth." In an early study by Nisan (1972), subjects who were told that they would take a test four weeks from the time of the experiment expected to do better on the test than did those who were told that they would take a test on the same day. Similarly, Manger and Teigen (1988) reported a large reduction in undergraduates' prediction of their grades from eight months before to two months before final exam. Although overly optimistic in their predictions on both occasions (as our model predicts), this optimism decreases as the exam becomes imminent.

In a series of four experiments, Gilovich, Kerr, and Medvec (1993) present further evidence for the loss of confidence in success as the time for revelation of outcomes draws nearer. In the first of these experiments, the researchers compared expected success on a midterm exam on the first day of the course and on the day of the exam and observed a decline in optimism over this period. The authors acknowledge the methodological shortcomings of this experimental design, specifically that students learn more about the course as time went on, which could have accounted for the reduction in optimism. However, in subsequent studies they avoided this problem by studying tasks which did not benefit from preparation, such as a memory task, anagram task, and persuasion task. Loewenstein (1985) likewise reports a decline in expectations of scores on a test that could not be explained in terms of information acquisition because, in his study, expectations were first elicited immediately *after* the test was taken, then again just before the results were revealed.

Shepperd, Ouelette, and Fernandez (1996) compared sophomore, junior, and senior undergraduates in their expectation of salary after graduation both at the beginning (Time 1) and end of a semester (Time 2). They found that only seniors gave significantly lower expectations at the later occasion. Furthermore, while sophomores and juniors expected to get salaries that were higher than the actual average salaries reported for graduated students at Time 1 as well as at Time 2, the seniors' expectations only exceeded the actual average salaries at Time 1.

In a second study, Shepperd et al. (1996) found that undergraduates' expectations of their results on a exam dropped dramatically from one month before the exam to just before they received the results. A third experiment, however, observed such a drop only in students who were low in self-esteem. Finally, Taylor and Sheppard (1998) investigated expectations regarding medical tests, and found that more pessimistic expectations were held by people who expected to receive test results immediately, and that this effect was greater for more severe medical conditions. Taken together, there seems to be substantial evidence for the prediction that people qualify their optimism as they get closer to the revelation of a self-relevant outcome or performance.[8]

Neither Prediction 3 - that people who think more about the possible surprise or disappointment of an outcome tend to decrease their optimism more over time than those who do not - nor Prediction 4 - that we should observe a positive relationship between time discounting and optimism - have been tested directly. Nevertheless, both predictions are in principle easily testable.

4 Conclusions

In this paper we propose a very simple model of expectation formation that incorporates relatively noncontroversial assumptions about how expectations affect utility and about the constraints on dynamic shifts of expectations. The model generates several testable predictions, the two most important of which appear to be consistent with the data. The final two predictions have not been tested as of yet.

We should note, however, that the model is extremely incomplete. For example, it assumes that the only variable under the individual's control is expectations. In fact, according to Zeelenberg et al. (2000) self-manipulation of expectations is only one of many strategies that people can adopt to protect themselves from disappointment. For instance, people may avoid

[8] A note of caution is necessary when considering the interplay of Predictions 1 and 2. Prediction 1 implies that examining final levels of optimism across settings with periods of uncertainty of different lengths is not appropriate way to test Prediction 2. That is, Prediction 2 can be rejected or verified only *within* a period of uncertainty.

making decisions, postpone decisions, avoid risks, intensify effort to live up to expectations, downgrade the importance of outcomes or set less specific expectations. Lowering expectations does, however, seem to be one strategy that is commonly employed. According to a survey in which participants reported strategies to reduce disappointment, lowering expectations was by far the most mentioned strategy (van Dijk, 1999).

Another important means for manipulating beliefs that has been recognized in psychology (Festinger, 1964), as well as in economics (e.g., Caplin, 2003), is to avoid information that runs counter to beliefs that people hold or want to hold. Caplin (2003) assumes that people have some ability to choose how much to attend to information. He develops a model in which people respond to health warnings either by adopting behaviors justified by the warnings or, if the warnings are too threatening, by, in effect, 'putting their head in the sand'. Karlsson, Loewenstein, and Seppi (2004) examine how people selectively expose themselves to positive, and avoid negative, information about their financial investments. Specifically, they find that people who hold risky portfolios of assets are more inclined to check on their value at times when they have reason to suspect that the performance has been positive than at times when they have reason to suspect it has been negative.

Furthermore, the dynamics of optimism that we suggest are not likely to be valid for expectations of all types. First, people are less optimistic for situations that are perceived to be outside of their control (Armor and Taylor, 1998). For instance, people have been found to believe that they are at a lower risk than others to be involved in car accidents as the driver, while they do not show this optimism bias for being involved in a car accident as the passenger (Kos and Clarke, 2001). Second, when performance or outcomes may be easily measured, people tend to have more realistic expectation about their abilities and prospects (Armor and Taylor, 1998).

One direction in which the model could be extended would be the inclusion of a more sophisticated treatment of the costs of belief revision. The current model penalizes decision-makers for revising their beliefs, but a more comprehensive model might penalize them for holding beliefs that are unrealistic. Realism in such a model might be measured by the distance between the decision maker's beliefs at time t and either his or her final beliefs, $\tilde{p}(T)$, or some exogenously defined "true" beliefs.

An important issue is the degree to which the dynamics of optimism that we predict, and find evidence for in the literature, actually affects decision making. Beside the effects of optimistic beliefs on motivation and effort (see, e.g., Benabou & Tirole, 2002), we can think of at least three reasons why such dynamic shifts in beliefs are, in fact, likely to influence behavior.

First, as highlighted by the vast body of research on cognitive dissonance, there are limits to people's ability to behave in ways that conflict with their beliefs (or to hold beliefs that conflict with one another). Second, similar issues are likely to come into play when such beliefs are expressed to others, as they are likely to be. Thus, for example, one might feel sheepish about publicly stating that one isn't expecting to get tenure while at the same time making an offer on a house. Third, even if people don't act upon their beliefs themselves, if they express those beliefs to others, the beliefs may influence other people's actions. So, for instance, other people's investment behavior may well be affected by hearing an optimistic estimate of long-term investment and their vacation plans may be affected by hearing how cheap or wonderful a summer vacation in Italy is likely to be.

Our analysis can be seen as part of a general trend in economics toward taking a more realistic view of information. Stigler's (1961) seminal paper on the economics of information initiated an extraordinarily productive line of research on the 'new economics of information,' which has encompassed phenomena such as signaling, adverse selection, asymmetric information in bargaining and "herd behavior." We hope that the work presented here will become part of a new new economics of information that draws on psychological research to revise some of the less realistic assumptions that economists make about information.

Some of this new research calls into question conventional assumptions about information processing, such as the idea that information can be freely disposed of or that people update probabilities in a fashion consistent with Bayes' rule (Koehler, 1996). For example, people exhibit a "hindsight bias" (Fischhoff, 1975); they overestimate their own ability to have predicted events which they know have taken place. They have a difficult time reverting back to their original beliefs after evidence on the basis of which they updated those beliefs is discredited (e.g., Hubbard, 1975).

Another line of research challenges the assumption that people process information in an impartial fashion. For example, research on the self-serving bias shows that people unconsciously and without deliberate intent interpret information in a fashion that is favorable to themselves (Babcock and Loewenstein, 1997). Research on the "confirmatory bias" shows that people behave in a 'super-Bayesian' fashion, dismissing evidence that contradicts their preexisting beliefs and overweighting evidence that confirms them (e.g., Lord, Lepper and Ross, 1979; Rabin and Schrag, 1999).

By supporting the twin ideas that people derive utility directly from beliefs and have some capacity to manipulate those beliefs, the current paper provides yet more evidence of the complexities of the ways in which people deal with information.

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A Solution of the Example in Section 2.1.

First, suppose that $\tilde{p}$ is a solution and let $\tilde{p}(0) = p_0$ and $\tilde{p}(T) = p_T$. Holding these endpoints fixed, a necessary condition for optimization is satisfaction of the following Euler equation:

$$A'(p(t)) = \partial C'(p'(t))/\partial t. \tag{5}$$

(Note that the discounting factor, e^{-rt}, will not enter into Equation 5. This term will affect only the optimal final level of beliefs, $\tilde{p}(T)$, derived below, as it represents the marginal cost of current optimism in terms of the cost of future disappointment after the realization of X.)

To solve Equation 5 we substitute our assumed functional forms for A and C. Equation 5 then reduces to

$$\alpha = -2\kappa p''(t),$$

or

$$p''(t) = -\frac{\alpha}{2\kappa}.$$

Therefore, an optimal belief path in this setting must have a constant second derivative. Integrating twice with respect to t, this implies that the optimal belief path is a function of the form

$$p(t) = \beta_1 + \beta_2 t - \frac{\alpha}{4\kappa}t^2,$$

where β_1 and β_2 are constants of integration that are derived from p_0 and p_T.

In order to find the values of $\tilde{p}(0)$ and $\tilde{p}(T)$, note that the optimization problem is a relatively simple constrained optimization problem once Equation 5 has been solved. In particular, the decision-maker's payoff is now a function only of p_0 and p_T. Given p_0 and p_T, the function $\tilde{p}$ is derived as follows:

$$p_0 = \beta_1$$

and

$$p_T = \beta_1 + \beta_2 T - \frac{\alpha}{4\kappa}T^2,$$

which jointly imply

$$\begin{aligned}
\beta_1 &= p_0 \\
p_T &= p_0 + \beta_2 T - \frac{\alpha}{4\kappa}T^2 \\
\beta_2 T &= p_T - p_0 + \frac{\alpha}{4\kappa}T^2 \\
\beta_2 &= \frac{p_T - p_0}{T} + \frac{\alpha}{4\kappa}T.
\end{aligned}$$

Thus, given p_0 and p_T,

$$\tilde{p}(t|p_0, p_T) = p_0 + \frac{(p_T - p_0)t}{T} + \frac{\alpha}{4\kappa}(T-t)t.$$

The last step is to use this function to derive optimal values of p_0 and p_T. Recall that we have assumed that $\bar{D}(p(T)) = -\frac{\delta}{2}(e^{-rT} - e^{-r(T+\tau)})p(T)^2$.[9] Then, the optimization problem in

[9]This functional form implies that the decision maker prefers to be surprised by a higher value of the realized

terms of p_0 and p_T is as follows:

$$\max_{p_0,p_T} \gamma(p_0,p_T) = \int_0^T \alpha\tilde{p}(t|p_0,p_T) - \kappa\left(\frac{p_T-p_0}{T} + \frac{\alpha}{4\kappa}T - \frac{\alpha}{2\kappa}t\right)^2 dt - \frac{\delta}{2}(e^{-rT} - e^{-r(T+\tau)})p_T^2. \tag{6}$$

Differentiating Equation 6 with respect to p_T, we obtain

$$\frac{\partial\gamma(p_0,p_T)}{\partial p_T} = \int_0^T \alpha\frac{\partial\tilde{p}(t|p_0,p_T)}{\partial p_T} - \frac{2\kappa}{T}\left(\frac{p_T-p_0}{T} + \frac{\alpha}{4\kappa}T - \frac{\alpha}{2\kappa}t\right) dt - \delta(e^{-rT} - e^{-r(T+\tau)})p_T,$$

which reduces to

$$\begin{aligned}\frac{\partial\gamma(p_0,p_T)}{\partial p_T} &= \int_0^T \alpha\frac{t}{T} - \frac{2\kappa}{T}\left(\frac{p_T-p_0}{T} + \frac{\alpha}{4\kappa}T - \frac{\alpha}{2\kappa}t\right) dt - \delta(e^{-rT} - e^{-r(T+\tau)})p_T \\ &= \frac{1}{T}\int_0^T \alpha t - 2\kappa\left(\frac{p_T-p_0}{T} + \frac{\alpha}{4\kappa}T - \frac{\alpha}{2\kappa}t\right) dt - \delta(e^{-rT} - e^{-r(T+\tau)})p_T,\end{aligned}$$

leading (after integration and some algebra) to

$$p_T = \frac{\alpha T^2 + 4\kappa p_0}{4\kappa + 2\delta(e^{-rT} - e^{-r(T+\tau)})T}. \tag{7}$$

Differentiating Equation 6 with respect to p_0, we obtain

$$\frac{\partial\gamma(p_0,p_T)}{\partial p_0} = \int_0^T \alpha\frac{\partial\tilde{p}(t|p_0,p_T)}{\partial p_0} + \frac{2\kappa}{T}\left(\frac{p_T-p_0}{T} + \frac{\alpha}{4\kappa}T - \frac{\alpha}{2\kappa}t\right) dt,$$

value at time T than his or her beliefs. Alternatively, we could instead assume that the decision maker has a desire for accurate beliefs at time T by assuming that $\bar{D}$ is a form of a loss function around the true expected value of X. Derivation of such a model is straightforward and, given the immediately preceding discussion, leads to results that are substantively identical to those presented here.

which reduces to

$$\begin{aligned}
\frac{\partial \gamma(p_0, p_T)}{\partial p_T} &= \int_0^T \alpha \left(1 - \frac{t}{T}\right) + \frac{2\kappa}{T} \left(\frac{p_T - p_0}{T} + \frac{\alpha}{4\kappa}T - \frac{\alpha}{2\kappa}t\right) dt, \\
&= \int_0^T \alpha \left(\frac{3}{2} - \frac{2t}{T}\right) + \frac{2\kappa(p_T - p_0)}{T^2} dt, \\
&= \left. \frac{3\alpha}{2}t - \frac{\alpha}{T}t^2 + \frac{2\kappa(p_T - p_0)t}{T^2} \right]_{t=0}^{t=T} \\
&= \frac{3\alpha}{2}T - \alpha T + \frac{2\kappa(p_T - p_0)}{T} \\
&= \frac{\alpha T}{2} + \frac{2\kappa(p_T - p_0)}{T},
\end{aligned}$$

which implies that

$$p_T = p_0 - \frac{\alpha T^2}{4\kappa}. \tag{8}$$

Working through the algebra resulting from substituting Equation 7 into Equation 8, the following endpoints for the optimal belief function are obtained:

$$\tilde{p}(0) = \frac{\alpha T}{\delta\big(e^{-rT} - e^{-r(T+\tau)}\big)} + \frac{\alpha T^2}{4\kappa} \text{ and} \tag{9}$$

$$\tilde{p}(T) = \frac{\alpha T}{\delta\big(e^{-rT} - e^{-r(T+\tau)}\big)}. \tag{10}$$