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The Aversion to the Sequential Resolution of Uncertainty

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Abstract

This paper sets forth and offers an explanation for preferences for the form of the timing of resolution of uncertainty; namely for uncertainty to be resolved all at one time rather than sequentially. The explanation is based on a weakening of the independence axiom, in particular on the notion of disappointment aversion developed in Gul's (1991) axiomatic model of preferences. Implications of this aversion are discussed for issues in finance, intertemporal decision making under uncertainty, high stakes risky situations and consumer self-regulation. The analysis encourages a formulation of preferences over all attributes of interest to the decision maker, including psychological satisfaction.

Key words: uncertainty resolution, sequential timing, anxiety, disappointment, expected utility axioms

JEL Classification: B49, D11, D81.

The study of decision making under uncertainty is a topic which is clearly basic to our own discipline and to many applications of the economic approach to human behavior in social sciences. This paper studies an aspect of dynamic choice theory that has been largely ignored in the literature. Its purpose is to set forth and clarify what may be an important aspect of the *timing* of the resolution of uncertainty. In the face of uncertain prospects, it is often observed that individuals have a preference for the *time* of the resolution of uncertainty, a feature which in fact arises naturally in a dynamic choice setting. This insight, as formalized by Kreps and Porteus (1978, 1979) and later expanded upon by others, has generated an important body of theoretical and empirical literature on the role and implications of preferences for the resolution of uncertainty. The implications of these preferences are wide. They range, for instance, from different areas in asset pricing finance, such as models of security prices and asset trading, to models of the demand for information (in terms of both quantity and quality), theories of price formation, the formation of preferences, models of information aggregation, investment, macroeconomics and consumption-based asset pricing, and several other types of individual and social choices under uncertainty.

The feature that distinguishes the analysis presented here from previous work is its focus not on the *timing* per se but on the *form of the timing* of the resolution of uncertainty. The analysis in particular discusses the "aversion" attached to the sequential resolution of uncertainty, that is, the aversion attached to sequentially learning about a lottery which is being sequentially resolved, as opposed to learning its complete resolution all at one time. This aversion reflects a common form of "anxiety" which is, however, different from the ones induced by the anticipation of future events and by the Kreps-Porteus preferences for the earlier (or later) resolution of uncertainty (Epstein and Zin, 1989, 1991; Chew and Ho, 1994). This paper is thus concerned with a related but different subject matter, namely, an individual's preference for the resolution of the uncertainty *all at one time* rather than *sequentially*.

Examples in which individuals experience anxiety and disutility by *having* partial information about the resolution of *one* lottery as it sequentially develops are not difficult to find. One example, which in part motivated this paper, is the following: On a given day in June 1994, in Los Angeles, the national soccer teams from Brazil and Italy played in the World Cup final. As most people in the world did, a well-known Brazilian professor of economics in the United States watched the game. After the regulation time the game was tied. After an extra thirty minutes the game remained tied. The soccer champion of the world for the next four years then had to be decided in a five-penalty-kick shoot-out. The professor then switched off his television set, as perhaps did many other people, especially Brazilians and Italians. (He also made sure he could not get any information about the sequential resolution of the penalty kicks from the radio or from other people). Why did he do it? Tautologically, because he preferred so. The formalization of this answer, however, is not trivial. Note that the expected utility model of preferences, which has been so successful in explaining much of the human behavior we observe, cannot explain this behavior: if the opportunity cost of time is zero, if no actions can be taken to affect the final outcome and, obviously, if there is no disutility attached to watching any one player kick a soccer ball, then the professor should be indifferent *ex ante* between watching the penalty shoot-out and not watching it. In other words, the process of the resolution of the uncertainty *itself* (the fact that partial information about the final outcome would be arriving sequentially) should not provide any disutility. In section 3 several important examples and economic settings are discussed where this does not appear to be the case.

A satisfactory solution of this paradox which will logically account for this behavior thus requires a modification or generalization of expected utility axioms. Over the last few decades, other paradoxes, criticisms and violations of expected utility theory have been documented.[1] These have generated a few extensions and generalizations of expected utility theory. Unfortunately, however, most of the models of preferences that have been offered as solutions to some of the paradoxes often violate even the most basic desiderata of choice under uncertainty (e.g., transitivity, stochastic dominance). Clearly, one would optimally like to find a solution which includes expected utility as a special case—as it explains much of the main human behavior we observe—satisfies fundamental desiderata of choice under uncertainty, and is consistent with other observed violations of the expected utility model. I will show here that an acceptable solution to this paradox can be found in Gul's (1991) theory of disappointment aversion.

Gul (1991) develops an axiomatic model of decision making under uncertainty that is consistent with the Allais paradox and other observed violations of expected utility theory, includes expected utility theory as a special case, and is the most restrictive possible model that satisfies these conditions. Furthermore, his axiomatic model of preferences is parsimonious, as it is only one parameter richer than the von Neumann-Morgenstern preferences. His generalization of expected utility theory is based on a weaker alternative independence axiom and retains as much of the insight offered by expected utility theory as possible. The notion of disappointment aversion he presents not only offers good intuition as to why the independence axiom is so often violated but also leads to a class of preferences with acceptable normative properties capable of accommodating many experimental results. The arguments in this paper thus point to a failure of the independence axiom and to its modification as suggested by Gul's model. It will be noted, however, that other similar types of formations of preferences where the independence axiom is weakened may also provide an explanation of the behavior discussed here.

The paper is organized as follows. In section 2, I first briefly review the essence of Gul's theory of disappointment aversion. I then prove, in the context of the example discussed above, but without loss of generality, that these preferences imply a preference for the resolution of uncertainty all at one time, and thus imply an aversion to the sequential resolution of uncertainty. A generalization of the result is also offered. This section concludes with some remarks about the fundamental insights of the suggested explanation and its advantages. Section 3 discusses several theoretical and empirical implications, examples and applications of these preferences. Section 4 concludes.

1. Disappointment and the resolution of uncertainty

1.1. A theory of disappointment aversion

Let me first briefly summarize the essence of Gul's theory of disappointment aversion. The preferences of a disappointment-averse individual can be represented by $[U(x), \beta]$, where $U(x)$ is a conventional utility function describing the utility of consuming good x, $U' > 0$, $U'' < 0$, and $\beta \geq 0$ is a parameter that measures the degree of disappointment aversion.[2] In the absence of risk the individual's utiliy level is simply $U(x)$. Let $V(\beta)$ denote the expected utility of a disappointment-averse individual whose disappointment rate is β. Suppose the individual faces risky prospects in n states of nature: $\{x_s : s = 1, \ldots, n\}$. Let μ denote the certain amount that yields the same utility level as the risky amount: $V(\beta) = U(\mu)$. The individual is thus indifferent between the prospect of a safe μ and risky amounts $\{x_s : s = 1, \ldots, n\}$. The individual reveals disappointment aversion if he attaches "extra" disutility to states in which the realized outcome is below μ. The usual way to define $V(\beta)$ is

$$V(\beta) = E(U(x)) - \beta E[U(\mu) - U(x) | \mu > x]$$

where E is the expectation operator and $E[U(\mu) - U(x) | \mu > x]$ is the expected value of $U(\mu) - U(x)$, conditional on the realized outcome being below the certainty equivalent amount. The term $E[U(\mu) - U(x) | \mu > x]$ thus measures the "expected disappointment," that is, the expected difference between the certainty equivalent utility and the actual utility in states of nature where the realization is below μ. The disappointment-averse expected utility thus equals the conventional expected utility, adjusted downwards by a measure of disappointment aversion (β) times the "expected disappointment." Consider now the simplest case: two states of nature. Assume that the individual will receive an amount x_s in state of nature s, $s = 1, 2$, where $x_1 > x_2$, with probabilities α and $1 - \alpha$ respectively. His disappointment-averse expected utility function is then

$$V(\beta) = \alpha U(x_1) + (1 - \alpha)U(x_2) - \beta(1 - \alpha)[V(\beta) - U(x_2)]$$

that is

$$V(\beta) = \frac{\alpha}{1 + \beta(1 - \alpha)} U(x_1) + \frac{(1 + \beta)(1 - \alpha)}{1 + \beta(1 - \alpha)} U(x_2)$$
$$= \alpha[1 - (1 - \alpha)\lambda]U(x_1) + (1 - \alpha)[1 + \alpha\lambda]U(x_2)$$

where $\lambda = \beta/(1 + (1 - \alpha)\beta)$. This individual thus attaches an extra weight $(1 - \alpha)\alpha\lambda$ to "bad" states of nature where he is disappointed (relative to the probability weight used in the conventional utility).

As Gul (1991, footnote 2) remarks, the term *disappointment* was first introduced by Bell (1985) and Loomes and Sugden (1986). While he borrows the word from them, his motivations and the class of preferences that he considers are different, as he develops an axiomatic model of preferences and decision making under uncertainty.[3]

1.2. Implications for the resolution of uncertainty

Consider now the case of the Brazilian professor watching the final of the 1994 World Cup between Brazil and Italy. After a 0-0 final score the World Champion had to be decided in a five-penalty shoot out. The rest of the paper will focus on this example, as it brings out in a clear way the intuition and the qualitative nature of the implications of these preferences for the sequential resolution of uncertainty. The results are not difficult to generalize.

Assume for simplicity, and without loss of generality, that Brazil and Italy have the same skills shooting penalties (something that most Brazilians and Italians will probably disagree on) and that they will score in a given penalty with a probability s. Assume also, without loss of generality, that instead of five penalty kicks there is only one penalty kick per team. Note that under these assumptions the probability of winning is $1/2$ for each team.[4] Let $U(w)$ denote the utility if Brazil wins and $U(l)$ the utility if Brazil looses. Then the following proposition can be proven:

Proposition. *A disappointment-averse individual strictly prefers the resolution of uncertainty all* at one time *rather than* sequentially.

Proof: Assume that Brazil shoots first. Let B denote the initial node at which Brazil shoots its penalty. With probability s it will score and we will arrive at node I_1. With probability $1 - s$ it will not score and we will arrive at node I_2. At nodes I_i, $i = 1, 2$, Italy shoots its penalty and will score with a probability s. If after Italy's penalty they are tied, 0-0 or 1-1, each team will shoot a second penalty. In the event of further ties, further additional penalties will be shot until a team wins. In order to compute the professor's utility at node B when going through the sequential process, $V_B(\beta)$, we need first to find out his utility at nodes I_1 and I_2, $V_{I_i}(\beta)$, $i = 1, 2$. Note that the utility of a tie is precisely $V_B(\beta)$, as each team will have to shoot another penalty. At node I_1 the utility will thus be

$$\begin{aligned} V_{I_1}(\beta) &= (1-s)U(w) + sV_B(\beta) - \beta s\left[V_{I_1}(\beta) - V_B(\beta)\right] \\ &= \frac{1-s}{1+\beta s}U(w) + \frac{s(1+\beta)}{1+\beta s}V_B(\beta) \end{aligned}$$

whereas at node I_2 his utility will be

$$\begin{aligned} V_{I_2}(\beta) &= (1-s)V_B(\beta) + sU(l) - \beta s\left[V_{I_2}(\beta) - U(l)\right] \\ &= \frac{1-s}{1+\beta s}V_B(\beta) + \frac{s(1+\beta)}{1+\beta s}U(l) \end{aligned}$$

Therefore, at node B his utility is

$$\begin{aligned} V_B(\beta) &= sV_{I_1}(\beta) + (1-s)V_{I_2}(\beta) - \beta(1-s)\left[V_B(\beta) - V_{I_2}(\beta)\right] \\ &= \frac{s}{1+\beta(1-s)}V_{I_1}(\beta) + \frac{(1-s)(1+\beta)}{1+\beta(1-s)}V_{I_2}(\beta) \end{aligned}$$

that is, substituting $V_{I_1}(\beta)$ and $V_{I_1}(\beta)$, we obtain:

$$V_B(\beta) = \frac{s(1-s)}{A}U(w) + \frac{s(1-s)(1+\beta)^2}{A}U(l)$$

where

$$A = [1 + \beta(1 - s)][1 + \beta s] - \left[s^2 + (1 - s)^2\right][1 + \beta]$$

The expected utility of knowing the final score *at one time* is

$$V(\beta) = \frac{\alpha}{1 + \beta(1 - \alpha)} U(w) + \frac{(1 + \beta)(1 - \alpha)}{1 + \beta(1 - \alpha)} U(l)$$
$$= \frac{1}{2 + \beta} U(w) + \frac{1 + \beta}{2 + \beta} U(l)$$

Note that both $V_B(\beta)$ and $V(\beta)$ are a convex combination of $U(w)$ and $U(l)$. Therefore, to prove that $V_B(\beta) < V(\beta)$ it is sufficient to show that $(s(1 - s))/A < 1/(2 + \beta)$. After simple algebra we obtain that this inequality implies

$$\beta s(1 + \beta)(1 - s) > 0$$

which is true since $\beta > 0$ and $0 < s < 1$. ■

The intuition for this result is simple: when taking a disappointment-averse individual *through* the sequential process of the resolution of uncertainty, final states of nature are weighted differently than if all of them were faced at one time. The reason is that when going through the process, *some* "components" of *some* final states that are *above* the certainty equivalent final outcome have, at some point in the process, been *below* the corresponding certainty equivalent (partial) outcome. As a result they end up being given "more weight" by a disappointment-averse individual than if he faced the resolution of the uncertainty all at one time with the corresponding disappointment-averse probabilities.[5] This is the reason why taking the professor *through the process* increases the number of times that *some* "disappointment" may occur and thus, in this sense, the process *itself* generates a loss of utility.

1.3. A generalization

The analysis above has referred to the sequential resolution of the uncertainty associated with a "final" lottery, where partial information about the resolution of the lottery is being developed in a sequential process. Consider now, along the lines of Samuelson (1963), a slightly different generalization of this result where the same "final" lottery is repeated *n* times. Samuelson (1963) asked a colleague whether he would be willing to accept a lottery in which there is a 50 percent chance to win \$200 and a 50 percent chance to lose \$100. His colleague turned down the lottery but said that he would accept 100 such bets. This response induced Samuelson into proving that his colleague's behavior was inconsistent with the axioms of expected utility theory: if one is unwilling to accept a single play of a bet then one should be unwilling to accept a number of repetitions of the bet. However, he did not provide an explanation that would reconcile expected utility theory with the behavior of his colleague. Some further discussion of this implication is provided in the next section.[6]

Define $V(n, \beta, p)$ and $V^s(n, \beta, p)$ as the expected utilities of a game that lasts for n stages, with $0 < p < 1$ probability of winning 1 unit of a good at any given stage, $1 - p$ probability of winning 0 units, for an individual with a coefficient of disappointment aversion β, when looking at the game "all at one time" and "sequentially" respectively. Let $U(m)$ denote the utility of m units, $m \in [0, n]$. Following the previous arguments we obtain that:

$$V(n, \beta, p) = \frac{1}{A}\left[\sum_{i=0}^{h-1}\binom{n}{n-i}p^{n-i}(1-p)^{i}U(n-i) + (1+\beta)\sum_{i=h}^{n}\binom{n}{n-i}p^{n-i}(1-p)^{i}U(n-i)\right]$$

where

$$A = 1 + \beta\left[\sum_{i=h}^{n}\binom{n}{n-i}p^{n-i}(1-p)^{i}\right].$$

It is important to note that h is a function of p, n, and $\beta : h = h(n, \beta, p)$, and $h \in [0, n-1]$. In other words, note that *the evaluation period* (n) *and the amount of risk that is taken are jointly and endogenously determined.* It is not difficult to calculate h. Define p_h, for given n and given β, as the p in which $V(n, \beta, p_h) = U(h)$. Then h is the only natural number in which the inequalities $p_h < p < p_{h+1}$ hold. The expected utility of being exposed to the sequential resolution of uncertainty is defined as:

$$V^s(n, \beta, p) = \sum_{i=0}^{n}\binom{n}{n-i}x^{n-i}z^{i}U(n-i)$$

where

$$x = \frac{p}{1+\beta(1-p)}, \quad z = \frac{(1+\beta)(1-p)}{1+\beta(1-p)}.$$

Define the amount

$$\Delta(n, \beta, p) = V(n, \beta, p) - V^s(n, \beta, p)$$

as the "sequential resolution premium." Then, it can be proven that $\Delta(n, \beta, p)$ is always greater or equal to zero,[7] that it increases at an increasing rate with n, that it is concave in p with:

$$\left.\frac{\partial \Delta(n, \beta, p)}{\partial p}\right|_{p<0.5} > 0, \left.\frac{\partial \Delta(n, \beta, p)}{\partial p}\right|_{p>0.5} < 0,$$

and

$$\left.\frac{\partial \Delta(n, \beta, p)}{\partial p}\right|_{p=0.5} = 0, \frac{\partial^2 \Delta(n, \beta, p)}{\partial p^2} < 0;$$

and that it is convex in β:

$$\frac{\partial \Delta(n, \beta, p)}{\partial \beta} > 0, \frac{\partial^2 \Delta(n, \beta, p)}{\partial \beta^2} > 0.$$

The concavity of $\Delta(n, \beta, p)$ in p, reaching its maximum at $p = 0.5$, implies that *ceteris paribus* the lower the skewness of the probability distribution, the greater the preference for uncertainty to be resolved all at one time. In other words, good or bad expected "news" (high and low p respectively) will be more likely to be developed sequentially (and therefore earlier), than "news" where the final outcome is more uncertain (the greatest uncertainty is at $p = 0.5$), which will more likely develop all at once.

1.4. Remarks

It is important to emphasize that a fundamental insight of this paper is that a weakening of the independence axiom will induce a preference for the way in which uncertainty gets resolved (the *form* of the timing of the resolution). This important aspect may often play an important role in reality but, surprisingly, it has been largely ignored in the literature on choice under uncertainty. Of course, there may be other similar types of formulations of preferences where the independence axiom is weakened that provide an alternative explanation of the behavioral property discussed here. For instance, Samuelson's (1963) observation has prompted some to offer an explanation of the preference for "aggregation" of lotteries in terms of Kahneman and Tversky's (1979) prospect theory.[8] The extent of the similarity between their explanation and the one provided here is thus, essentially, the extent to which Gul's (1991) theory of disappointment aversion is similar to prospect theory. Although I do not wish to discuss or summarize here the evidence and reasons that have been given in the literature to favor one theory over the other,[9] it appears that there are a few advantages of the former model of preferences over the latter, and over other models as well, especially in the context of the type of "anxiety" examined here:

(1) First, and most important, there is no simpler axiomation of preferences that, while explaining the aversion to the sequential resolution of uncertainty, retains as much as possible of expected utility theory (is only one parameter richer) and is consistent with the Allais paradox and several other behavioral anomalies.[10] Disappointment aversion, therefore, allows us to obtain a closed form solution of the "sequential resolution premium" using only one more parameter.

(2) Camerer and Ho (1994) recently found that disappointment aversion theory, which relaxes the independence axiom but still obeys the betweenness axiom, fits the data much better than expected utility (EU) and than other non-expected utility models of preferences.[11] The evidence they examined also showed that "when gambles were presented in compound form, violations of betweenness were somewhat fewer and much less systematic than when gambles were in reduced form." This may, at least partly, be explained by the aversion to the sequential resolution of uncertainty that, as we have seen, is induced by the theory of disappointment aversion.[12]

Lastly, on the basis of the important implications that an aversion to the sequential resolution of uncertainty may have (these are briefly discussed later in section 3), it appears that this is an important behavioral property which, surprisingly, has been largely ignored and whose analysis has remained unqualified in the literature. The behavioral property examined here is also useful:

(a) to provide empirical evidence in favor of theories that generalize expected utility (non-EU theories).

(b) to help discriminate among the non-EU theories which attempt to *describe* actual choices, to rank their empirical validity, to design better formal tests to evaluate such theories and to help guide further developments.

2. Discussion

If people prefer that uncertainty be resolved all at one time, why then, for instance, are they willing to pay for watching events in which uncertainty gets resolved sequentially, such as World Cup Finals, World Series Finals, and NBA Finals? Of course, the trivial explanation is that in these cases there is utility attached to the process itself in the sense of the behavior or "performance" it involves (e.g., *watching* players in action is a different good which provides more utility than *not watching* them and listening on the radio),[13] and this utility is greater than the utility losses induced by the sequential resolution of the uncertainty. More generally, and more importantly, in many (perhaps most) economically relevant cases, individuals can often take actions throughout the sequential process of the resolution of uncertainty and thus influence final outcomes. These two sources of utility mean that it will not be straightforward to empirically document the extent of this aversion. Of course, it would be of great interest to document and evaluate its empirical relevance in market and non-market behavior. The structural features of the way markets aggregate preferences to determine prices, or the fact that competition may alter the judgements people make, could reduce individual level violations of the expected utility model in a significant way and make the predictive validity of expected utility theory remain intact (Evans, 1997). Although a preference for uncertainty to be resolved all at one time may be an important determinant of choices, the option of taking actions throughout the process of the resolution of uncertainty as information gets developed may often offer a greater advantage. In principle, it would thus most clearly be observed when actions cannot be taken throughout the process and experiencing the process itself does not hold much positive or negative value for the individual.

The results of the previous section can easily be generalized to a greater number of states and different probability distributions over the states at different times, without affecting the qualitative nature of the analysis. Obviously, an aversion to the sequential resolution of uncertainty does not appear only in sports events. Moreover, it seems that it will rarely be observed in sports, unless the stakes are very high and there is not much performance left.[14] This type of aversion has important implications for all decision choices under uncertainty in temporal contexts, including all those where the implications of Kreps-Porteus preferences have been examined. Consequently, it has implications for the thickness and flow of information, as *ceteris paribus* information will be acquired or released less frequently and in larger chunks (more "stages" of information would be aggregated and resolved at one time) and thus its flow will be more discontinuous than with conventional expected utility. This in turn has implications, for instance, for models of information aggregation, theories of price formation, models of market making and information release, models of earnings management, models of trading activity and portfolio rebalancing, the strategic use of the flow of orders, and theories of price crashes.[15] Note also that with these preferences both the evaluation period of the uncertainty and the amount of risk that is taken are jointly and, if they are subject to a choice, *endogenously* determined: longer evaluation periods induce *more* risk-taking behavior and *vice versa*.[16] This aspect is relevant, for instance, for the risk-taking behavior and the evaluation period of health risks (e.g., frequency with which the status and evolution of different health risks such as cholesterol, fat, cancer, and AIDS are evaluated) and financial risks. In finance, it implies that the typical mean-variance analysis may need to be modified by taking into account the relationships between the moments of the probability distribution and the evaluation period. The reason is that the rules for ordering uncertain prospects, even with quadratic utility, are a function of the optimal evaluation period induced by the extent of disappointment aversion.[17]

Timing of lotteries. The importance of the temporal aspect of choice under uncertainty that is examined here is different from, but related to, the reflections in Markowitz (1959), Drèze and Modigliani (1966), Mossin (1972) and Spence and Zeckhauser (1972). These authors examined how choices among lotteries on wealth depended on the timing of the lotteries and on the timing of some decisions taken prior to the lotteries being conducted (earlier resolution improves planning and allocations). When some non-trivial commitment to a choice is forced prior to the resolution of a given lottery the certainty equivalent of that lottery declines. That is, the lottery is less attractive and the individual will appear to be more risk-averse. Furthermore, these authors discussed and showed how it is in general impossible to derive a von Neumann-Morgenstern utility function of wealth. The issue at hand in this paper is related to theirs, although it is clearly different. It may be thought of as its psychological counterpart, when psychological satisfaction, in addition to consumption satisfaction, is an appropriate objective to be included in decision analysis. The sequential resolution of uncertainty can be interpreted as requiring the individual to make some form of (psychological) "commitment" to certain paths, in the sense of the *knowledge* that other paths cannot be taken, whereas when the resolution takes place all at one time, all outcomes are available or possible until the very last moment.[18]

Endogenous timing of decisions and intertemporal consistency. The aspect of the timing of the resolution of uncertainty analyzed in this paper may also contribute to the literature on endogenous timing of actions and the differentiation between the clustering of decisions and herding. Under expected utility theory one would *certis paribus* be indifferent between the form of the timing of the resolution of uncertainty (all at one time or sequentially). Under Gul's axiomatic model, however, individuals prefer the resolution all at one time. This induces preferences over *when* to act. Actions will be taken later, after all uncertainty has been resolved and is known at once. As a result, information gets revealed later and actions get clustered together. This in turn provides a further motive for the clustering of decisions *without* involving an information cascade, two aspects whose relationship is important to clarify.[19] It also provides a novel explanation for the preference for delayed choices (or consumption) *without* assuming that the individual derives utility from anticipation. What may appear to be negative time preference may in fact be the consequence of preferences for the form of the resolution of the uncertainty induced by the features of the utility function (the aversion to disappointment). That is, such choices can be confused with negative time preference if one is required to wait to have all information at once.

These preferences over *when to act*, or *over when to know*, may perhaps be related to the literature on time inconsistent discounting. The reason is that these preferences may act in part as a "commitment mechanism," valuable when temporal discounting is not exponential, as there is a utility gain from postponing the knowledge of the (partial) resolution of uncertainty. These preferences induce a *more discrete* frequency of acquisition of knowledge, and thus possibly of decisions or choices as well. Note that this "commitment technology" for the current self is internalized in preferences, and thus is fully reliable. Consider a simple three period version of a model where an individual discounts the future with a non-exponential discounting structure. Following the working definition of Laibson (1997), consider the problem of a quasi-hyperbolic discounter who maximizes:

$$U(c_t) + \delta \sum_{i=1}^{2} \beta^i E_t U(c_{t+i})$$

with $0 < \beta < 1, U' > 0, U'' < 0, 0 < \delta < 1$, and where E_t is the expectation operator conditional on information available at time t, for deterministic consumption sequences beginning at time t, $\{c_{t+i} : i = 0, 1, 2\}$, and subject to an intertemporal budget constraint. At time t he will choose the consumption sequence that equates his marginal rates of substitution (MRS's) to one plus some rate of interest r which, without loss of generality, is considered to be constant:

$$\frac{U'(c_t)}{\delta\beta E_t U'(c_{t+1})} = \frac{E_t U'(c_{t+1})}{\beta E_t U'(c_{t+2})} = \cdots = 1 + r$$

However, at time $t + 1$, both because time has elapsed from t (the effect of δ) and because new information may arrive, the MRS between consumption at time $t + 1$ and time $t + 2$ changes: if seen from period t it is $E_t U'(c_{t+1})/\beta E_t U'(c_{t+2})$, whereas when seen from period $t + 1$ it is $E_{t+1} U'(c_{t+1})/\delta\beta E_{t+1} U'(c_{t+2})$. If no new information arrived at $t + 1$, c_{t+1} would be more urgent at $t + 1$ than t. This discounting structure would then induce greater consumption at time $t + 1$ (and thus smaller at time $t + 2$) than what it is optimal from the perspective of self t. In an uncertain environment, where uncertainty about a variable gets developed over times $t + 1$ and $t + 2$, if $U(\cdot)$ exhibits disappointment aversion, the individual would prefer to "sleep over" time $t + 1$, ignore the partial resolution of the uncertainty at $t + 1$, and observe all the resolution of the uncertainty at once at time $t + 2$. Insofar as changes in actions may be in part *contingent upon* or *associated with* the knowledge of new information (the partial resolution of uncertainty), disappointment aversion provides "some" incentive to commit not to change the allocation planned at t for $t + 1$ and arrive at $t + 2$ where all the uncertainty gets developed at once. For instance, self t, a Chicago Bulls fan, would like to study for a final exam instead of watching a Chicago Bulls game. However, he also knows that at time $t + 1$ self $t + 1$ would like to watch the game. If self t has disappointment aversion he has a *stronger* commitment not to watch how the game develops and to know the final score all at once. That is, disappointment aversion provides an additional incentive not to deviate from initially optimal allocations. The key is the association or link between the consumption of television watching and knowing about the partial resolution of the uncertainty of a lottery, which is also important to the individual. Under these circumstances, a hyperbolic discounter will have more incentives to commit not to deviate from initially optimal allocations.

Volume and gains of exchange, and the equity premium puzzle. One interesting aspect concerns the implications for the volume of exchanges and trades, as well as the value or gains involved in the exchanges. The valuation disparities between disappointment and non-disappointment outcomes implies fewer gains from trade, as the *status quo* is preferred to some gambles that would be accepted if the individual did not exhibit disappointment aversion. These valuation disparities, as well as the aversion they induce for less frequent evaluation periods, also imply fewer trades. These two implications are supported by recent experimental results (Burges and Knetsch, 1998).[20]

Disappointment aversion also implies that the equilibrium price of an asset at which individuals are indifferent between a long and a short position in the asset is smaller (and thus its return is higher) than under expected utility. This effect, in addition to the effects induced for the preference for the evaluation period, can contribute to explaining the equity premium puzzle. Recent research on the equity premium puzzle (e.g., Benartzi and Thaler (1995), Siegel and Thaler (1997), Thaler et al. (1997), Gneezy and Potters (1997)), in fact, examines the implications that prospect theory induces for the simultaneous determination of the evaluation period of uncertainty and the amount of risk that is taken in an individual's financial investment decisions, and thus the implications it has for explaining the equity premium puzzle. The results are promising. Similar experiments can obviously be performed assuming disappointment-averse preferences, as they essentially induce similar behavior to prospect theory, to explain the equity premium puzzle and other anomalies in portfolio choice and the purchase of information (Camerer, 1995).[21]

Empirical evidence from high stakes risks. Lastly, note that this aversion may also be observed more clearly when stakes are high (that is, when $U(w) \gg U(l)$, as absolute differences between $V(\cdot)$ and $V^s(\cdot)$ are larger and thus less likely to be dominated by the possible beneficial effects of having a sequential resolution) and/or when actions cannot be taken at any cost or are of little use to affect final outcomes. For example, an individual may prefer to remain ignorant of partial information sequentially being developed about the progress of the life-saving operation of a loved one, or about the current status of a certain serious infirmity he may have. [22] Health risks seem particularly important. Data regarding the frequency with which individuals test for HIV, breast cancer, cholesterol and fat, for example, could provide important support for the class of behavior analyzed in this paper, which implies that *more* risk is taken the *less* frequently the status of the infirmity is evaluated and vice versa. An empirical test of this relationship would require an accurate measurement of the riskiness of the potential infirmity and of the value of actions that could be taken to modify final outcomes (e.g., some cancers have greater incidence than others, and some are more difficult or expensive to cure than others). The explanation provided in this paper was in fact "suspected" by Philipson and Posner (1993) in their empirical analysis of the frequency of HIV testing and of the differences between mandatory and voluntary testing. They were puzzled when they observed a preference for uncertainty (ignorance) about one's health status (p. 106n, italics added):

> The preference for uncertainty about one's health may be related to the phenomenon that decision theorists *discuss* under the rubric of "intrinsic risk aversion" to distinguish it from the risk aversion that is a consequence from diminishing marginal utility. Taking a test to find out whether or not one is doomed is like a high-stakes gamble, which some people are *timid* about apart from the possible income consequences.

Interpersonal aspects. In addition to the implications discussed earlier, this aversion has implications for risk regulation, the distribution of information, and public and private responsibilities for risk (see Viscusi (1992)). The analysis may also be relevant for the pricing and management of environmental risks. The difference in the case of some environmental risks may have to do with the length of the evaluation period, as it may involve an intergenerational or interpersonal aspect which is not present in other cases. (All the scenarios of the possible applications discussed so far have been intragenerational and did not involve the relationship among individuals or generations.) To take an extreme case, consider that the optimal evaluation period of a given deteriorating aspect of the environment extends beyond the length of life of the individual who is making decisions. If the coefficient of altruism toward future generations is less than one, the evaluation period, and thus the choice of actions, may be suboptimal for future generations, whose coefficient of altruism toward themselves is one and who cannot "vote" or affect in any way the choice of actions toward the environment. The same would occur in scenarios that involve two or more individuals jointly producing a common good, such as in risky sexual relationships and the frequency of testing for HIV when altruism toward partners is less than one. While in this example transaction costs will tend to be low and markets complete, in certain cases of environmental risks, where voting is restricted to adults and which involve a great number of individuals, transaction costs will be high and markets possibly incomplete.

A generalization. This paper, in summary, contributes to the research on the timing of the resolution of uncertainty. The lack of support for the implications of the Kreps-Porteus preferences for the gradual and all-at-one-time resolution of uncertainty found in Ahlbrecht and Weber (1994) somewhat contrasts with the support found for these preferences in the macroeconomics and asset pricing studies of consumption, savings, and asset holding behavior (see Epstein and Zin (1991), Weil (1990)).[23] A formulation which encompasses both disappointment aversion and Kreps-Porteus preferences (these denoted as $U^{KP}(x,t)$) as

$$V(\beta,t) = E\left(U^{KP}(x,t)\right) - \beta E\left[U^{KP}(\mu,t) - U^{KP}(x,t) \mid \mu > x\right]$$

will likely be parsimonious enough and able to reconcile the evidence found both in experiments and in real situations, while still being derivable from axioms (see Gul (1991), Kreps and Porteus (1978, 1979), Epstein and Zin (1989), Chew and Epstein (1989)). The rich interactions between the timing and the form of the timing that may be derived from this formulation deserve further theoretical and empirical research.

Other applications. The issues examined in this paper can play a role in the analysis of consumer self-regulation in cases of payment-consumption interactions and mental accounting. The psychological "pain" of the ticking of a taxi meter or of the daily usage of internet access where individuals prefer to know the total volume of the expense all at once may indeed reflect an aversion to the sequential resolution of uncertainty.[24] A preference for flat-rate pricing schemes (such as unlimited internet access at a fixed monthly fee or a fixed taxi fare between zones within a city), even if it involves paying more for the same usage, can be a perfectly logical consequence of these preferences. (There are other explanations, of course). The reason is that a flat-rate pricing scheme per unit of time, given the amount of periods of time, resolves the uncertainty about the final outcome all at one time—in this case prior to the consumption of the good. Another important aspect of this model (and of other non-EU models as well), is that it may help us understand and formalize with extreme parsimony "unusual" preferences such as, for instance, "disappointment-seeking" or optimistic preferences (see footnote 2) and negative time preferences (discount rates greater than one).[25] Lastly, the issues examined in this paper seem to appear relevant for the literature on bundling of information goods, such as those increasingly available on the internet.[26] In our case, information goods are represented by the nodes in the tree of the sequential resolution. The novelty of the issue examined here is the intertemporal aspect of bundling information goods, not the cross-sectional aspect where different individuals have different valuations negatively correlated.

3. Concluding remarks

It is apparent that in the real world temporal prospects, not timeless ones, are the rule rather than the exception. The analysis in this paper has focused attention on a possibly important psychological determinant of risk-taking behavior, namely, the extent to which a decision maker explicitly trades off dollars to avoid a state of psychological dissatisfaction (anxiety or aversion to the sequential resolution of uncertainty). The explicit recognition that decision makers may be paying a premium to avoid potential disappointment provides an interpretation for some known behavioral paradoxes. It also provides an explanation for the type of anxiety examined in this paper in which decision makers are sensitive to the manner in which a lottery is resolved.

Psychological satisfaction, *in addition* to satisfaction derived from consumption, *may be* an appropriate objective that should be included in decision analysis. Its relevance to explain market and non-market behavior, of course, depends upon the type of situations and circumstances that are also involved. The analysis of health risks and financial risks, as well as both the macroeconomic and microeconomic data relevant to aspects of temporal discounting, seems to provide fertile ground for empirical study in both real and experimental situations.

The analysis allows us to appreciate the effects of "aggregation" (or "compounding") in mitigating disappointment risk. It clarifies why the betweenness axiom is less often violated when lotteries are "compounded." The preference for "compound" lotteries, or for uncertainty to be resolved all at one time, relaxing the independence axiom but still obeying betweenness, explains the superior fit of disappointment aversion theory, and corroborates the findings in Camerer and Ho (1994).

The theory is parsimonious (adds only one parameter to expected utility) and is precise enough to be useful in economic theorizing and empirics. Far from encouraging departure from traditional axioms of expected utility theory, this paper encourages a formulation of preferences over all attributes of interest to the decision maker (physical as well as psychological) in those cases in which they are relevant. The simple analysis in this paper has offered an explanation and clarified some of the discussion in recent developments in the literature on decision making under uncertainty. It has also discussed a variety of implications and applications that can be pursued in future research. The paper, I believe, is best taken as a glimpse of the promise of multidisciplinary inquiry and as one more effort to reconcile psychology and economics in the simplest possible manner (Rabin, 1998).

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Notes

1. See, for instance, Machina (1987), Camerer and Weber (1992), Camerer (1995), Harless and Camerer (1994), Kagel and Roth (1995) and other references therein.
2. Gul (1991) considered the more general case in which $\beta \geq -1$ and $U(x)$ increases in x but is either convex or concave. I focus here on the case where $\beta \geq 0$, as I restrict my attention to the case in which $U(\cdot)$ is concave. If $-1 \leq \beta < 0$ then the individual has a preference for the sequential resolution of uncertainty ("optimists" or disappointment lovers).
3. The emphasis in Bell (1985) and Loomes and Sugden (1986) is on *descriptive* aspects and on identifying functional forms consistent with empirical evidence. Unfortunately, their models do not

attempt to (and do not) *reconcile* the normative theory of choice under uncertainty with the existing empirical evidence. It is therefore not surprising to observe that they "often violate even the most basic desiderata of choice under uncertainty (transitivity, stochastic dominance, etc.)" (Gul, 1991, p. 669).

4. More generally, if Brazil has a chance $0 < s_B < 1$ of scoring and Italy $0 < s_I < 1$ then the probability that Brazil will win is $\alpha = s_B(1 - s_I)\Sigma_{t=0}^{\infty}[s_B s_I + (1 - s_B)(1 - s_I)]^t$. It is assumed that if they are still tied after each team shoots a penalty (both score or both miss), then they will each shoot a second one, and will continue to do so until a team wins.
5. In the context of the example, when looking at the game "all at one time," only one of the four possible final outcomes is below the certainty equivalent outcome (losing 0-1). However, when taking the individual through the process, a miss by Brazil in the first penalty is below the certainty equivalent outcome *at that node* (regardless of what happens later) and is thus given "extra" disappointment weight. In other words, regardless of whether Brazil ends up tied with Italy, 0-0 (which is above the certainty equivalent outcome at that node and, as a result, that component of *two* of the possible final outcomes is given an "extra" (disappointment) weight at that node. On the other hand, when looking at the four possible final outcomes "all at one time," a miss by Brazil in its penalty kick is only given "extra" weight by a disappointment-averse individual if the final score is 0-1 (which is below the certainty equivalent final outcome), that is, if Italy scores, but not if Italy misses and the final score is 0-0 (which is not below the certainty equivalent among the final outcomes). A similar discussion, of course, can be made from the perspective of an Italian fan.
6. See Rabin (1997) for a calibration theorem with regard to the relationship between risk aversion over modest stakes and over large stakes. He shows how under the axioms of expected utility theory even very little aversion over modest stakes implies implausible degrees of risk aversion over large stakes. For instance, an individual who turns down a 50-50 lose \$10/gain \$11 lottery should also turn down a 50-50 lose \$80/gain \$209 lottery and, most interestingly, a 50-50 lose \$100/gain \$$\infty$ lottery.
7. Trivially, it is zero when either there is no uncertainty, $p = \{0, 1\}$, or when there is no intertemporal dimension ($n = 1$), that is: $\Delta(n, \beta, 1) = \Delta(n, \beta, 0) = \Delta(1, \beta, p) = 0$.
8. See, for instance, Bernartzi and Thaler (1995), Siegel and Thaler (1997), Thaler, Tversky et al. (1997), and Gneezy and Potters (1997).
9. See, for instance, Gul (1991), Chew and Ho (1994), Harless and Camerer (1994), and Camerer and Ho (1994).
10. Disappointment aversion theory, however, cannot explain *all* known behavioral anomalies. See Harless and Camerer (1994). For instance, it cannot explain evidence of nonlinear probability weighting.
11. It fits better, for instance, than cumulative prospect theory. However, it does a little worse than prospect theory with separable probability weights.
12. Recent research by Myagkov and Plott (1997) finds that risk-seeking behavior when the individual faces loses, as predicted by prospect theory, diminishes with experience and evolves into either risk-neutral or risk-averse behavior. This recent empirical evidence renders support to Gul's axiomatic model over prospect theory in environments where the individual has had enough previous experience. It also suggests that repeated experience will induce less aversion to the sequential resolution of uncertainty. This provides important guidance for the research for empirical evidence. Two other, weaker advantages of disappointment aversion theory are that:

(a) Disappointment aversion theory is an axiomatic model, whereas prospect theory, and other non-EU as well, are essentially descriptive. A sketch of the axiomatic properties of prospect theory, however, can be found in Kahneman and Tversky's original paper and a more detailed analysis in Wakker and Tversky (1993).

(b) Disappointment outcomes make sense even when considering the *partial* resolution of *one* lottery, whereas the concept of gains and losses is more generally related only to a *final* lottery (over final states) or to a sequence of final lotteries, especially if they include losses. This is because the implicit concept of the reference point in Gul's disappointment aversion is the certainty equivalent outcome of the lottery, even if it is a lottery over partial outcomes which *per se* do not provide any utility and are not considered as gains and loses. (Tom Sargent brought to my attention the case of a colleague of his, a Chicago Bulls fan, who would first tape a game, and then find out whether the Chicago Bulls won or lost it—that is, uncertainty is resolved all at one time and partial scores are ignored. After learning the final score he would decide to watch the game only if they had won. Conditioned on a good outcome, the actual play becomes a "good," as opposed to a "bad" if the outcome had been a loss, which he decides to consume.) Analytically, of course, the treatment of partial and final lotteries is the same.

13. Likewise, this type of aversion must not be confused with the disutility attached to the process *itself* when the process is a bad (e.g., *seeing* one's son have a heart operation, or seeing him boxing or bullfighting is obviously a different good than *not seeing* it).
14. E.g., a die-hard Chicago Bulls fan (not) watching Michael Jordan shoot two free throws in the last second of the last game of the NBA finals with the Chicago Bulls down by one point.
15. An interesting example can be drawn from the recent paper by Degeorge et al. (1999), DPZ hereafter, on earnings management. The stock market typically reacts badly when firms report earnings losses relative to some thresholds or reference points (e.g., positive/negative profits, recent performance, analyst's expectations). It is thus not surprising to see that executives—who typically have considerable discretion and flexibility in determining earnings figures and whose compensation is often partly, directly or indirectly, indexed to such reference points—engage in managing the figures themselves, so that they end up above certain thresholds. These issues are examined in detail by the aforementioned authors. However, when the utility or reward function of executives or investors is kinked at some "reference" or "disappointment" point, the behavior of executives *ceteris paribus* should also exhibit an aversion to the sequential resolution of uncertainty. Although this aspect of earnings management is not examined in DPZ (1999), the evidence they present is consistent with the implications discussed in this paper and reflect the interaction between the direct management of earnings figures and the timing of earnings reports. For instance, generally executives meet or slightly exceed analysts' forecasts; however, sometimes they fall drastically short and "take the big bath" all at once. In their sample, the distribution of earnings relative to certain forecasts is statistically significant left-skewed, with a long left tail. Lastly, see for instance Madrigal and Scheinkman (1997) and other references therein.
16. More generally, longer evaluation periods may be associated not only with more risk-taking behavior, but also with more Knightian uncertainty-taking behavior or ambiguity-taking behavior (see, for instance, Camerer and Weber (1992)).
17. See the analysis in Hadar and Russell (1969).
18. Mossin (1969, p. 172, italics added) states: "When someone asks you which of a set of uncertain prospects you prefer you should answer: 'That depends upon *when* the outcomes will be known.' … The reason why the temporal aspect is important is not only that it will affect your choice, but, more fundamentally, because it has to do with the question of whether or not it is possible to represent such choices by means of a utility function. … If there are situations where choices among probability distributions cannot be represented by a utility function, then the rule for making those choices violates the consistency conditions of von Neumann and Morgenstern."
19. See, for instance, Gul and Lundholm (1995) and many references therein.
20. Burges and Knetsch (1998) focus on the analysis of prospect theory for the examination of the implications for the amount and volume of trades compared to the usual expected utility function.
21. There may be other situations where the implications of the analysis are relevant for the finance literature and the theories of the firm and organizations. Kahneman and Lovallo (1993), for instance, argue that "forces" where preferences for aggregation of lotteries may be observed (preference for ignorance) may even be stronger in the context of managerial decisions, in the management of information and risk taking in organizations, and in the organizational context in which many business decisions are made.

22. Several untenured colleagues have expressed to me a preference for knowing about their tenure decision all at one time rather than knowing the vote one by one of each member of the faculty committee that decides upon the tenure. The same may be true for a defendant facing the decision of a jury.
23. These preferences separate attitudes toward intertemporal substitution from risk aversion. Their favorable implications for the resolution of the equity premium puzzle are, however, still under dispute (Kocherlakotta, 1996).
24. See other examples in Prelec and Loewenstein (1998).
25. Loewenstein (1987) was one of the first authors in the modern literature to point out the influences of "savoring" and "dread" of future outcomes. An aversion to the sequential resolution of uncertainty, as we have seen, induces a preference to *wait* until the process of resolution of uncertainty is over and then know the final outcome all at once. This effect, which may induce temporal discount factors greater than one, may interact in rich ways with (but it is different from) recursive preferences in which individuals directly savor and dread future uncertain outcomes. (See Epstein and Zin (1989, 1991), Loewnstein (1987) and the discussion in the introduction.)
26. See Bakos and Brynjolfsson (1998) and many references therein.

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