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COMMONALITIES IN TIME AND AMBIGUITY AVERSION FOR LONG-TERM RISKS*

ABSTRACT. Optimal protective responses to long-term risks depend on rational perceptions of ambiguous risks and uncertain time horizons. Our study examined the joint influence of uncertain delay and risk in an original sample of business owners and managers. We found that many subjects disliked uncertainty in the timing of an outcome, a reaction we term "lottery timing risk aversion." Such aversion to uncertain timing was positively related to aversion to ambiguous probabilities for lotteries involving storm damage risks. This association suggests that uncertainty may be processed similarly in both the risk and time dimensions.

1. INTRODUCTION

Time and uncertainty complicate many choices we make. Numerous studies have suggested that there are forms of irrationality that arise in both the time and risk dimension and that people perceive future outcomes and uncertain outcomes in a cognitively similar manner.[1] That is, an agent's information processing in situations involving risk is closely related to the agent's processing of information regarding future outcomes. The existence of such parallels suggests that the same anomalies influencing how subjects process uncertain risks may determine the processing of uncertainty in the timing of an outcome. This paper examines the preferences that many people have for certainty in the timing of an outcome, a preference which we call "lottery timing risk aversion." Uncertainty regarding the timing of a payoff leads to behavior which would not likely be predicted by expected utility theory.[2] In addition to documenting this phenomenon, we specifically link aversion to uncertainty in the time dimension to the ambiguity aversion reflected in the Ellsberg Paradox for probabilities at a point in time.[3] More specifically,

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we test empirically whether responses to uncertainty in the timing of a lottery payoff are predictive of responses to uncertainty in outcome probability. We test for this relationship by examining within-subject data on the relation between lottery timing risk aversion and ambiguity aversion in the context of environmental risks.

The empirical focus of our study is on an original survey of coastal business owners and managers. While there are some notable exceptions of studies that focus on business decisions, for the most part the ambiguity literature has relied on student experiments and evidence outside of business decision contexts.[4] Our findings suggest a strong relationship between single period ambiguity aversion and lottery timing risk aversion. This association suggests that uncertainty may be processed similarly in both the risk and time dimensions.

This paper is organized as follows. Section 2 provides a brief description of the discounting anomaly hypothesis. Section 3 describes the survey design and the basic results. Section 4 examines the similarity in responses to uncertainty in outcome timing and to uncertainty in outcome probability. Section 5 concludes.

2. DISCOUNTED UTILITY MODEL

Under the traditional intertemporal utility function, an individual with wealth W solves:

$$v(W) = \max \sum_{0}^{T} \beta^t U(c_t), \tag{1}$$

where $\beta = 1/(1 + \rho)$ and ρ is the subject's discount rate, which is assumed to be time-invariant. [5] The utility associated with the consumption level c in year t is given by $u(c_t)$, and the present value of lifetime consumption cannot exceed W, which represents initial wealth plus the discounted value of future income.

Our hypothesized lottery timing risk aversion anomaly is based on the following situation. Suppose the agent is offered a gamble in which a fair coin is tossed to determine when the prize (X) is awarded. The money is awarded in $t - g$ years if the coin is heads

and in $t + g$ years if the coin lands tails. As an alternative to the timing gamble the agent is offered the option of receiving X in exactly t years, where t represents the midpoint of the time horizons offered in the gamble. If the utility of receiving X is $U(X)$, then under discounted expected utility maximization the agent will prefer the gamble if

$$0.5U(X)[\beta^{(t-g)} + \beta^{(t+g)}] > U(X)\beta^t \tag{2}$$

As shown in the appendix, as long as the discount rate is positive, nonzero, and constant, the expected discounted utility of the gamble is higher than the expected discounted utility of having X with certainty in t years.

Other factors besides aversion to uncertainty in the timing of the payoff might influence the choice between the timing gamble and the sure time payoff. For example, subjects whose discount rate is not constant (such as in the case of hyperbolic discounting), might have a preference for or against the sure time payoff as a result. It is also possible that risk aversion might influence a person's choice between the sure time payoff and the timing gamble.

2.1. *Risk aversion*

Another way to express the lottery timing decision would be to examine how the lottery might affect the person's wealth. If the timing gamble offers X in either $t - g$ years or in $t + g$ years, and the sure timing payoff offers X in year t, the subject will be indifferent if:

$$V(W + R^t X) = \frac{1}{2}V(W + R^{(t-g)}X) + \frac{1}{2}V(W + R^{(t+g)}X), \tag{3}$$

where $R = 1/(1 + r)$ and r is the discount rate at which the person can borrow or lend money. The first-order Taylor series approximation of this equation suggests the subject will be indifferent between the two choices if:

$$V(W) + V'(W)(R^t X) = V(W) + V'(W)\left(\frac{R^{(t-g)}X + R^{(t+g)}X}{2}\right), \tag{4}$$

TABLE I

Summary of sample characteristics

Variable	Mean (standard error)
Age	42.57
	(11.92)
Annual income ($)	47,850
	(22,752)
Income missing	0.18
(dummy variable)	(0.38)
Male	0.53
	(0.50)
Education	15.46
(years)	(2.93)
Married	0.71
	(0.46)
N	146

which after subtraction of $V(W)$ and division by $V'(W)$ and X yields:

$$R^t = \frac{R^{(t-g)}X + R^{(t+g)}}{2} \tag{5}$$

The first-order approximation suggests that risk aversion would not lead to aversion of the lottery timing gamble, because R^t is in fact less than the right-hand side of the above expression (see Appendix). However, this first-order approximation can not rule out any potential influence of risk aversion, as a second-order approximation would be needed to include diminishing marginal utility of wealth. Nonetheless, the influence of risk aversion will likely be small if the stakes involved are small relative to the person's income (see Arrow, 1971). For example, a subject with no initial wealth and a utility function $V(W) = \log(W)$ would be indifferent between the lottery timing gamble and the sure time payoff. With any other wealth, however, the subject with this utility function would have a strict preference for the lottery timing gamble.

The main hypothesis to be tested is whether subjects in fact do prefer the timing gamble or would rather have a payoff at the mid-point of the period. If discount rates are constant, the latter outcome might occur if people are averse to uncertainty in the timing of lottery payoffs, or possibly if extremely risk averse, or both.

3. SURVEY DESIGN AND MEAN RESULTS

3.1. *The survey design*

The research staff distributed surveys in person to 373 businesses in Carteret County, North Carolina, a county situated on the Atlantic coast.[6] The surveyor asked that the owner, manager, or some other employee complete the survey and return it by mail in the provided envelope.[7] Of this group, 266 businesses responded, for a response rate of 71.3%. [8] Of the 266 respondents, 146 were presented with the lottery timing gamble. Table I summarizes the sample characteristics of this 146-person sub-sample.

In the outcome timing gamble, the subjects faced a hypothetical monetary prize. The first option offered the prize to be awarded in t years. The second option offered a fair gamble in which the prize would be awarded in either $t-g$ years or $t+g$ years with equal probability. We used four different combinations of the timing gamble: 0–6 years, 1–5, 5–15, and 5–25. Table II provides an example of such a choice.

In addition to the outcome timing gamble, the subjects also responded to scenarios of ambiguous storm risks created by the uncertainties of climate change (Table II, Panel B). In the storm risk scenarios, the subjects were presented with a choice of two areas, one offering a more ambiguous risk (experts provided divergent storm risk estimates) of storm damage than the other (the experts agreed on the storm risk estimates). The coastal region selected for the study is a prime location at risk from potential effects of climate change, so that the survey dealt with potential risks that were pertinent to the business manager respondents.

TABLE II

Presentation of survey questions

Panel A: Lottery timing scenario

Imagine that you have won a prize of $1,000. You get to choose between
OPTION A and OPTION B to determine when you get the money.

OPTION A	You toss a coin.
	If it is heads, you get the
	money in 1 year.
	If it is tails, you get the
	money in 5 years.
OPTION B	You get the money in
	exactly 3 years.

Which option would you choose?
1. OPTION A
2. OPTION B

Panel B: Ambiguous storm risk scenario

In BEACH AREA ONE:	In BEACH AREA TWO:
the chance of heavy storm	the chance of heavy storm
damage (per decade) is:	damage (per decade) is:
Expert A says 20%	Both experts say 30%
Expert B says 40%	

If you had to locate your business in one of these
areas, which one would you choose?
1. BEACH AREA ONE
2. BEACH AREA TWO

3.2. *Controlling for subject consistency*

The general approach in the survey follows the methodology of Vis-
cusi et al. (1991) in that subjects make a pairwise comparison and
then provide a point of indifference. For example, in the outcome
timing gamble, the subject chose between the sure time payoff and

TABLE III

Basic survey results

	Full sample		Consistent sample only	
	Number of subjects	Percent of subjects	Number of subjects	Percent of subjects
Panel A: Subject preferences for lottery timing scenario				
Preferred the lottery timing gamble	98	69.0	78	78.0
Averse to the lottery timing gamble (Preferred the sure time)	44	31.0	22	22.0
Total	142	100	100	100
Panel B: Subject preferences for ambiguous storm risk scenario				
Preferred the ambiguous storm risk	73	56.2	50	56.2
Averse to ambiguous storm risk	57	43.8	39	43.8
Total	130	100	89	100

the timing gamble. After choosing between the two options, the subject was asked to provide a time horizon of indifference. Here, the subject stated how long he or she would be willing to wait for a certain outcome such that he or she would be indifferent between the sure time and the time gamble. The two tasks performed by each subject for each scenario provide a consistency check for the subject's comprehension of the survey question. For example, if the subject prefers the gamble, rather than taking the midpoint of the gamble's time span, then his or her time horizon of indifference should not be higher than the midpoint of the gamble's time span. The reverse holds true for subjects who prefer the sure thing. For example, suppose a subject prefers the fifty-fifty gamble of receiving the prize in either 1 or 5 years, rather than taking the prize for sure in exactly 3 years. This subject's time horizon of indifference should

not be higher than 3 years, otherwise the subject should have chosen the sure thing in the initial comparison.

In all, about 30% of the subjects responded with an indifference level that was inconsistent with the pairwise comparison in the first storm risk scenario and/or the lottery timing gamble. We refer to subjects who did not provide an inconsistent answer as the consistent sample.

3.3. *Aversion to uncertain outcome timing and ambiguous probabilities*

Roughly 31% of the subjects preferred the sure timing to the gamble in their initial pairwise comparison, as shown in Table III.[9] Among the consistent sample, 22% of the subjects preferred the sure timing. Although a substantial number of subjects preferred the sure timing, these rates of lottery timing risk aversion were not overwhelming. However, it is likely that further experimentation could find the specific time horizons that would dramatically increase the rates of lottery timing risk aversion.[10]

Roughly 44 percent of subjects preferred the unambiguous storm risk scenario (Table III, Panel B). Although many previous studies have detected higher rates of ambiguity aversion, the subjects in this sample were faced with relatively high ambiguous risks in the loss domain. Studies have suggested that persons facing such risks are less likely to be ambiguity averse than when facing low probability risks in the loss domain.[11] Furthermore, the choices presented were not between an ambiguous risk and a known risk, but rather between an ambiguous risk and a less ambiguous risk.

This evidence suggests that many subjects are averse to the introduction of uncertainty in the timing of an outcome, even when this uncertainty is to be resolved immediately. This aversion to uncertain time horizons may be analogous to the "Ellsberg Paradox" which arises from uncertain risk estimates. The following section explores the systematic relationship between these phenomena.

TABLE IV

Cross-tabulations of subject responses to lottery timing scenario and ambiguous storm risk scenario

	Number who were averse to ambiguous storm risks	Number who preferred ambiguous storm risk	Total
Panel A: Full sample[a]			
Number of subjects averse to the lottery timing gamble	23	18	41
Number of subjects who preferred the lottery timing gamble	31	54	85
Total	54	72	126
Panel B: Consistent sample[b]			
Number of subjects averse to the lottery timing gamble	14	6	20
Number of subjects who preferred the lottery timing gamble	22	43	65
Total	36	49	85

[a]Subjects averse to the lottery timing gamble were 1.5 times as likely to be averse to the ambiguous storm scenario than those who preferred the gamble ($p = 0.038$, based on Mantel–Haenszel chi-square of 4.32 calculated according to Dicker, 1996).

[b]Subjects averse to the lottery timing gamble were 2.1 times as likely to be averse to the ambiguous storm scenario than those who preferred the gamble ($p = 0.004$, based on Mantel–Heanszel chi-square of 8.09 calculated according to Dicker, 1996).

4. SIMILARITY IN RESPONSES TO UNCERTAINTY IN TIME AND PROBABILITY

4.1. *Cross-tabulations of within-subject responses*

Basic cross-tabulations of within-subject responses show that subjects who were averse to the outcome timing gamble were also averse to the presence of ambiguity in the storm risk estimates (Table IV, Panel A).[12] Subjects who preferred the known timing payoff

were 1.5 times as likely to prefer the less ambiguous storm risk estimates ($p = 0.038$), and this difference was more pronounced among the consistent sample (Table IV, Panel B).

4.2. *Regression analysis of the timing gamble decision*

To examine the systematic variations in subjects' behavior, we use a logistic regression to examine the driving forces behind aversion to uncertainty in the timing gamble scenario. We included demographic variables in the model, as well as dummy variables for the time horizons of the gamble. We included the variable "ambiguity averse" if the subject expressed a preference for the single storm risk estimate rather than the divergent expert estimates. Table V presents the logistic regression estimates to explore the effect of various sample characteristics on the probability of exhibiting lottery timing risk aversion. A positive coefficient estimate suggests the subjects were more likely to express aversion to the timing gamble. Education and wealth-related variables (income, income missing) were not significant. The only significant variables were "ambiguity averse" and "Scenario 1." Thus subjects who were averse to ambiguity in the storm risk were more likely to be averse to uncertainty in outcome timing, even after controlling for other characteristics. Those who were presented with the scenario which offered the lottery payoff in 3 years for sure (or in 1 or 5 years with the gamble) were more likely to express aversion to the timing gamble than those presented with other time horizons. When focusing on the consistent sample only, however, the "ambiguity averse" measure was the only significant variable.

5. CONCLUSION

This paper examined the joint influence of time and uncertainty. Roughly 30% of all subjects exhibited "lottery timing risk aversion" in their refusal to accept a fair gamble in the timing of a prize award. Persons who were averse to higher degrees of ambiguity in the storm risk scenario were more likely to be averse to uncertainty in outcome timing. This similarity held even though the storm risk scenario dealt with possible losses and the outcome timing gamble dealt with potential gains. Our findings suggest that subjects might process

TABLE V

Logistic regression estimates showing factors related to Aversion to outcome timing gamble

Variable	Coefficient (Standard error)	
	Full sample	Consistent sample only
Intercept	-1.598	-0.824
	(1.383)	(2.122)
Ambiguity averse	0.866*	1.527**
	(0.416)	(0.641)
Education	0.051	-0.044
	(0.075)	(0.115)
Business owner	0.342	1.234
	(0.476)	(0.765)
Age	-0.032	-0.041
	(0.021)	(0.029)
Income ($ thousands)	0.002	0.007
	(0.012)	(0.017)
Income missing	0.110	0.569
	(0.816)	(1.109)
Married	0.073	-0.435
	(0.541)	(0.824)
Smoker	0.183	0.663
	(0.478)	(0.730)
Scenario 1: Time horizon of gamble is 1 to 5 years	1.281*	0.781
	(0.580)	(0.827)
Scenario 2: Time horizon of gamble is 0 to 6 years	0.702	-0.685
	(0.627)	(1.208)
Scenario 3: Time horizon of gamble is 5 to 15 years	0.747	0.714
	(0.556)	(0.730)
N	124	83

$*p < 0.10$, $**p < 0.05$ (two-tailed test).

uncertainty in outcome timing in the same manner they process uncertainty in probabilities of outcomes. However, future research could help clarify this issue, as other possible factors (such as hyperbolic discounting or extreme risk aversion) might have influenced our findings.

This research and subsequent studies can have broad policy implications. Our survey component focused on ambiguity aversion dealt with the uncertainties posed by potential storm damage risks associated with climate change. Other long-term risks may pose similar cognitive difficulties.[13] The possible failure of these decisions to satisfy the normative guidelines of expected utility theory suggests that decentralized risk averting actions in response to long-term uncertainties may differ from what is warranted by the mean level of the risk. People may be doubly confused by the potential risks that are both ambiguous and deferred. This confusion arises not only from the ambiguity surrounding the imprecisely understood probabilities but also from the uncertain timing of potential outcomes. These twin influences may prevent individuals from choosing the optimal precautionary efforts to reduce long-term hazards.

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APPENDIX

In the absence of borrowing and lending, expected utility theory would predict a strict preference for the outcome timing gamble. To see this, note that

$$\beta^g(\beta^{t-g} - \beta^t) = \beta^t - \beta^{t+g}. \tag{6}$$

Since $\beta < 1$ and g is positive, it follows that $\beta^g < 1$. As both sides of the equation are positive, then the right hand side of the above equation must be less than the term in parenthesis on the left-hand side, which is written as

$$\beta^{t-g} - \beta^t > \beta^t - \beta^{t+g}. \tag{7}$$

Moving the negative terms to the other side of the inequality and multiplying each side by $0.5U(X)$ yields the inequality of (2), showing that under expected discounted utility the outcome timing gamble would be strictly preferred over the sure thing.

NOTES

1. Examples include Benzion et al. (1989), Rachlin et al. (1986), Rachlin et al. (1991), Leigh (1986), Mazur (1997), and Green et al. (1999).
2. Examples of studies of the importance of temporal aspects in decision making under uncertainty include Mossin (1969), Spence and Zeckhauser (1972), Drèze and Modigliani (1972), Ahlbrecht and Weber (1997), Arai (1997), and Lovallo and Kahneman (2000). Loewenstein and Thaler (1989), Loewenstein and Prelec (1992), and Roelofsma (1996) review anomalies in intertemporal choice.
3. See Ellsberg (1961). Camerer and Weber (1992) review the literature of decision-making under ambiguity for this more conventional form of ambiguity aversion at a given point in time.
4. Exceptions include Sarin and Weber (1993) and Sarin and Winkler (1992), among others.
5. See Samuelson (1937) and Loewenstein and Elster (1992). Our formulation assumes that inflation is at a constant rate and that it is subsumed into the discount rate.
6. The survey is described in more detail in Viscusi and Chesson (1999) and Chesson and Viscusi (2000).
7. Only 23 responses were returned by "other employees."
8. The initial response rate was almost 50%. The first follow-up raised the response rate to 60% and the second (final) follow-up brought the response rate above 70%. These three waves of responses were quite similar overall, suggesting that non-response bias was not a significant issue with this survey.
9. Sample sizes in Panel A and Panel B differ because Panel A results exclude subjects who did not provide a response to the lottery timing gamble question and Panel B results exclude subjects who did not provide a response to the storm risk scenario.
10. For example, lottery timing risk aversion was much more common in the 1–5 year timing gamble than for the 0–6 year gamble.
11. See Viscusi and Chesson (1999) for details of this phenomenon in this sample. Other examples include Kahn and Sarin (1988) and Einhorn and Hogarth (1986).
12. The sample sizes in Table IV differ from that of Table III because Table IV results exclude those who did not respond to the storm risk scenario or the lottery timing gamble, or both.

13. Gollier (2001) examines the difficulty in addressing risks when there is scientific uncertainty about the magnitude of these risks. Kunreuther el al. (1998) showed that people's willingness to pay for protections against future loss did not seem to be affected by the length of time these protections would be in place.

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