Journal of Behavioral Decision Making
J. Behav. Dec. Making, **13**: 251–258 (2000)

The Heterogeneity of Time–risk Tradeoffs

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ABSTRACT

This paper uses an original sample of 146 business managers to examine the rationality of choices with respect to deferred lotteries. Using a new empirical methodology, it explicitly estimates implicit rates of time preference with respect to these deferred gambles. The estimated discount rate decreases with the time horizon of the gamble, which is consistent with violations observed in discounted utility contexts. Cigarette smokers exhibit lower estimated discount rates in this context, which is contrary to many popular hypotheses about the economic causes of smoking behavior. Copyright © 2000 John Wiley & Sons, Ltd.

KEY WORDS intertemporal choice; discounting risk; smoking

Intertemporal choices often violate standard discounted expected utility theory models, which typically assume that an individual's discount rate is constant over a series of decisions. Well-documented violations of discounted utility theory suggest that intertemporal choices are not entirely reflective of an underlying rate of time preference (Loewenstein and Thaler, 1989; Loewenstein and Prelec, 1992; Loewenstein and Elster, 1992). The presence of risk and uncertainty with respect to payoffs at a point in time also have led to a wide variety of anomalies and irrational behaviors. This paper explores the particular kinds of irrationalities that arise when the complicating influences of both time and uncertainty are present. The fact that irrationalities might arise in this instance is not entirely surprising, but what will be of interest is the nature of these systematic violations and the variations of the types of violations with individual characteristics.

Under usual discounted utility theory models a subject's discount rate is time-invariant and is reflected by the subject's choices involving delayed consumption. We analyze these decisions using original survey data in which our survey subjects chose between a hypothetical monetary prize to be awarded with a known delay and a gamble which either speeds up or delays (with equal probability) the waiting period for the prize. The two matters of interest that we will explore are the rationality of these choices and their variation with different personal characteristics. One personal characteristic of policy interest is smoking status. Individual discount rates with respect to future risks are clearly an essential element of the smoking decision. Do smokers display higher discount rates than nonsmokers, thus placing a greater weight on more immediate rewards? Similarly, does the discount rate vary with age in

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a manner that suggests that the young might display temporal myopia with respect to longer-term rewards? Other variations that we will explore include the effect of income status, education level, and the time horizon for the gamble on the estimated discount rate.

The discount rates implied by these choices are quite plausible for the survey sample as a whole, but the differences in discount rates across specific subgroups often were surprising and, in some cases, clearly irrational. For example, the implied discount rate of smokers was significantly lower that of nonsmokers, and the subjects with post-graduate educations exhibited a higher discount rate than those subjects without the advanced educational attainment. These unexpected implied discount rates may suggest that the combined tasks of discounting and probability assessment exceed the cognitive capabilities of many survey subjects.

The substantive focus of the survey is of policy interest as well. Many private decisions with long-term consequences are the subject of government regulation — whether it be smoking restrictions or mandatory minimum education requirements — and it is instructive to know the extent to which people are thinking about these decisions sensibly. Similarly, responses to the threat of global warming depend on attitudes toward uncertain future outcomes. A better understanding of the joint effects of time and uncertainty would help to improve risk communication for the many important health and environmental risks we face today.

DISCOUNTED UTILITY THEORY

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

$$U(W) = \max \sum_{t=1}^{n} \beta^t u(c_t) \tag{1}$$

where $\beta = 1/(1+\rho)$, ρ is the subject's discount rate, $u(c_t)$ is the utility associated with the consumption level c in year t, and there is the usual budget constraint requiring that the present value of lifetime consumption not exceed W, which for simplicity equals initial wealth plus the discounted value of future income. The utility function need not be linear with respect to the level of consumption; risk aversion or risk seeking are both possible.

Our survey offered subjects gambles so that what is relevant is the expected utility in each period rather than a non-stochastic utility level. Subjects considered a hypothetical lottery in which a prize P is awarded in w years if the subject wins a coin toss and in l years if the subject loses a coin toss, where $l > w$. As a risk-free alternative to the lottery, the subject is offered prize P in $(l+w)/2$ years, the midpoint of the range of the timing gamble. After choosing between the gamble and the 'known time payoff', the subject provides his or her time level of indifference i, the amount of delay under the 'known time payoff' for which they would be indifferent between the gamble and the known time i. In the absence of borrowing and lending, and if the subject's annual income is constant over the period of the outcome timing gamble, the subject's time horizon of indifference provides information about his or her discount rate according to the equation:

$$\beta^i = \frac{\beta^l + \beta^w}{2}. \tag{2}$$

For example, consider a subject who is indifferent between receiving the payoff in 2.72 years and accepting the timing gamble which offers the payoff in either 1 or 5 years with equal probability. Under the assumptions stated above, this subject is behaving as if his or her discount rate were 15%. Note that as the values of i increases, the subject's implied discount rate ρ decreases. However, this equation ignores the possibility of borrowing and lending. Without this restriction the subject's time horizon of indifference depends on both the discount rate and the lifetime utility function for income, ($U(W)$). A subject who is risk-averse would have a diminishing marginal utility of income, a factor which is not captured in equation (2). However, as shown in the Appendix, equation (2) represents a first-order Taylor series approximation of equation (1) (without any restrictions on borrowing or lending). This approximation should be quite accurate as the lotteries considered involve only small changes in income relative to the subject's lifetime wealth. Still, the estimated discount rates will be biased downward because risk aversion is ignored, but this bias will likely be small, especially if the stakes involved are small relative to the person's income (see Arrow, 1971).

DISCOUNT RATES AND INTERTEMPORAL CHOICE: THE RESEARCH CONTEXT

Loewenstein and Prelec (1992) provide an extensive review of examples of anomalies in discounting from the existing literature on intertemporal choice. The main classes of these violations include: higher discount rates for gains over losses, lower discount rates for longer time intervals, magnitude effects (subjects have a lower discount rate for larger amounts of money), and a delay–speedup asymmetry (subjects exhibit a discount rate which varies depending on whether the delay of a prize is reduced or lengthened). Thaler (1981) and others have suggested other violations of discounted utility, such as subjects being unwilling to pay to have a loss postponed.

While there are numerous established violations associated with discounted expected utility theory, these violations arise from discontinuity in the discount rate. Our paper examines the role of the discount rate in choice under intertemporal uncertainty. We offer subjects an outcome timing gamble which offers the chance to speed up or delay (with equal probability) the timing of the awarding of a monetary prize. Several investigations have detected aversion to uncertainty in the timing of the resolution of uncertainty (Mossin, 1969; Spence and Zeckhauser, 1972; Drèze and Modigliani, 1972). This paper, however, examines uncertainty in the timing of an outcome rather than uncertainty in the resolution of an outcome. Subjects face uncertainty in the timing of receiving a prize, but this uncertainty is resolved immediately by a coin toss after the subject chooses between timing lotteries. Subjects choose between lotteries which vary in the timing of the payoff of a monetary prize. Under discounted expected utility theory, the agent's choice in this outcome timing gamble depends in part upon his or her discount rate. This paper examines these implied discount rates and the differences in discount rates across different populations.

SURVEY DESIGN AND SAMPLE CHARACTERISTICS

One of the authors distributed surveys in person to 373 businesses in Carteret County, a coastal county approximately midway along North Carolina's Atlantic coast border. Of this group selected, 266 participated (by completing the survey and returning it by mail), bringing the response rate above 70%. Of the 266 subjects, 146 responded to a scenario involving uncertain outcome timing. On average the sample was 42 years old, roughly evenly divided between men and women, with three years of college education. One fourth of the sample was currently a smoker, which is quite similar to the average smoking rate for the adult population nationally.

The survey presented a choice between two payoff options, one which offered a known payoff time and one which offered a gamble in the timing of the award. Exhibit 1 provides an example of this pairwise comparison. After making the pairwise comparison the subjects provided the time horizon for

Exhibit 1. Presentation of timing lottery question, Task One

Imagine that you have won a prize of \$1000. 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

the known payoff which would make them indifferent between the two options (Viscusi, Magat, and Huber, 1991, and Viscusi and Magat, 1992).

DISCOUNT RATES AND UNCERTAIN TIME HORIZONS

Responses regarding the time horizons of indifference make it possible to estimate the person's discount rate. Equation (2) can be written as:

$$i = \frac{\ln(0.5\,\beta^{l} + 0.5\,\beta^{h})}{\ln \beta}. \tag{3}$$

Using this formulation, it is possible to estimate the discount rate by nonlinear least squares. The estimated discount rate for the entire sample is 10.6%, with the asymptotic 95% confidence interval ranging from 7.6% to 13.7%. Our primary focus is on the heterogeneity of the discount rate across sample groups. For a more descriptive estimate of the discount rate, we obtain different estimates for different subgroups of the survey samples. More specifically, we vary ρ by demographic group by expressing the β term in equation (5) as:

$$\beta = \frac{1}{(1 + \rho + \gamma\rho)} \tag{4}$$

where γ is a dummy variable which can reflect, for example, smoking status. Attempts to estimate γ as a vector of demographic variables in this equation did not converge. Thus we estimate this equation separately for each demographic factor we wish to examine.

Exhibit 2 contains the estimates of the discount rates based on this equation for five different binary breakdowns of the population.[1] We considered smokers, low-income subjects (income $< \$20,000$), age (those above mean age), education (those with post-graduate attendance or degree), and long time horizon (those subjects presented with a risk gamble whose expected payoff was more than 10 years in the future). Variations by gender were not statistically significant. This result suggests that factors other than discounting account for gender differences in risky behaviors (Hersch, 1996). In each case

[1] For simplicity, the standard error of the discount rate for each demographic group is calculated from the standard error of the discount rate for the population and the standard error of the dummy variable, assuming these two variances are independent. This approximation is not critical, as the statistical significance of the difference in discount rates is based on the significance of the dummy variable.

Exhibit 2. Estimates of implied discount rates, $n = 138$

	Estimate	Standard Error
General sample	0.139	0.022
Smokers	0.034[a]	0.036
General sample	0.116	0.017
Low income	0.023[b]	0.044
General sample	0.078	0.017
Older	0.157[b]	0.041
General sample	0.089	0.015
Post-graduate	0.235[c]	0.087
General sample	0.235	0.075
Long time horizon	0.095[c]	0.108

Discount rates for general sample are significant at the 0.01 level in all five regressions.
The discount rate for the group listed below the general sample is significant at the [a]0.01 level, two-tailed test, [b]0.05 level, two-tailed test, [c]0.10 level, two-tailed test.

we present the discount rate for the base population group and an estimate of how the discount rate changes for the particular group in question.

Smokers exhibited a discount rate of 3.4%, 10.5 percentage points less than for the rest of the sample, whose discount rate is estimated at 13.9%. The lower estimated discount rate for smokers runs contrary to what one might expect given many popular beliefs concerning smokers. One might have hypothesized that smokers would have higher discount rates that reflected a greater weight on current utility derived from smoking as opposed to future expected health losses. The opposite result is the case for this gamble. While our model did not incorporate the effects of risk aversion, it is important to note that risk aversion would lead to a higher stated level of indifference for the value of i, which in our model would imply a lower discount rate. As smokers in general would be expected to be more risk-seeing than nonsmokers, it is unlikely that risk aversion is the driving force behind the lower estimated discount rates for smokers. If rates of time preference for money are the same as rates for health status, this result suggests that differences in preferences and risk perceptions rather than differences in discount rates are likely contributors to these individuals' smoking status. Discount rates for health and money may, however, differ (Chapman, 1996).

Those with a lower income exhibited a much lower discount rate than the rest of the population. The older half of the population showed a higher discount rate than the younger half. The role of age would be in line with expectations to the extent that older respondents are more concerned with obtaining the lottery payoff within their lifetimes than are younger respondents. Those with at least some post-graduate schooling responded in a manner consistent with much higher discount rates than those with a college degree or less. The fact that the better educated display higher discount rates than those who are less educated is not consistent with the economic hypothesis one might have, which is that lower discount rates lead individuals to seek post-graduate schooling. However, it should also be noted that this effect is sensitive to the specification of the breakdowns of the educational groups analyzed.[2] Subjects who faced the long time horizon gamble (which offered payoff in either 5 years or 25 years) exhibited a much lower discount rate than those subjects facing shorter time horizons. The time

[2] The 'low income', the 'long time horizon', and the 'post-graduate' findings are significant only when the dummy variable is coded to represent the extremes of the possible responses. For example, grouping those with 4-year degrees together with those with post-graduate educations did not yield a significant difference from the rest of the population.

horizon effect parallels a well-known result in the literature. In our sample, individuals facing gambles with a long time horizon (i.e. a time horizon of 5–25 years) had lower implicit rates of discount than those facing gambles with shorter-term horizons. An analogous result is well established with respect to discounted utility models, as is indicated in the critical survey by Loewenstein and Prelec (1992). The novelty of our contribution is that we indicated that the same character of effect also generalizes the situation in which the time horizon differences pertain to the timing of lotteries rather than payoffs that are provided with certainty.

CONCLUSION

The methodology introduced in this paper allows the estimation of the discount rate and to ascertain differences in the implicit rates of time preference across different sample groups. The results suggest that a subject's decision when facing uncertainty in the timing of an outcome depends upon more than just the subject's degree of risk aversion and rate of time preference. Clearly, the choices involving elements of both time and risk create substantial difficulties for rational decision making.

The heterogeneity of the responses to the outcome timing gamble across sample groups yielded several intriguing results. Some patterns represented generalizations of influences that have been documented in narrower contexts. For example, the respondents displayed a lower rate of time preference as the time horizon for the lotteries was extended. This result for lotteries across time parallels the findings in the discounted utility literature for certain payoffs at different times. In each case, the pattern reflects a violation of discounted utility theory.

Another interesting discount rate difference pertains to the rate of time preference of smokers. Contrary to expectations based on popular belief, smokers exhibited a significantly lower rate of time preference than did nonsmokers. Since cigarette smoking also involves substantial deferred risks, this result suggests that a difference in financial discount rates alone does not appear to account for an individual's decision to smoke. Other factors, such as risk perceptions and differences in tastes, may be more influential in this decision.

APPENDIX

The timing lottery offers prize P in either w years or in l years, and the subject provides the time horizon i at which he or she is indifferent between the gamble and the sure thing, as expressed by:

$$U(W + \beta^i P) = \frac{1}{2}U(W + \beta^w P) + \frac{1}{2}U(W + \beta^l P). \qquad (A1)$$

This equation can be approximated with a first-order Taylor series approximation of the U function about the point W:

$$U(W) + U'(W)(\beta^i P) \approx U(W) + U'(W)\left(\frac{\beta^l P + \beta^w P}{2}\right) \qquad (A2)$$

which through manipulation can be written as:

$$\beta^i \approx \frac{\beta^l + \beta^w}{2}. \qquad (A3)$$

A strict equality in equation (A3) (as in equation (2)) holds if people do not borrow or lend across time, and if the subject's incomes are constant over the period of the timing gamble. This analysis is only needed to address the influence of intertemporal resource allocation, for which some approximation is needed. A subject who is risk-averse would have a diminishing marginal utility of income, a factor which is not captured in the first-order approximation. Using a second-order Taylor's series to approximate the function U about the point W yields:

$$U(W) + U'(W)(\beta^i P) + \frac{U''(W)}{2}(\beta^{2i}P^2) \approx U(W) + U'(W)\left(\frac{\beta^l P + \beta^w P}{2}\right) + \frac{U''(W)}{2}\left(\frac{\beta^{2l}P^2 + \beta^{2w}P^2}{2}\right) \quad (A4)$$

which can be written as:

$$\beta^i \approx \frac{\beta^w + \beta^l}{2} + \left(\frac{U''(W)}{U'(W)}\right)\left(\frac{P}{2}\right)\left(\frac{\beta^{2l} + \beta^{2w}}{2} - \beta^{2i}\right) \quad (A5)$$

It is not unreasonable to expect risk aversion to diminish with wealth (see Arrow, 1971). For example, setting $U(W) = A + B\ln(W)$ results in the following approximation:

$$\beta^i \approx \frac{\beta^w + \beta^l}{2} - \frac{P}{2W}\left(\frac{\beta^{2l} + \beta^{2w}}{2} - \beta^{2i}\right) \quad (A6)$$

As the dollar value of the prize is trivial (most subjects were offered a hypothetical payoff of \$1000 to \$10,000) when compared to lifetime wealth (especially for our sample, most of whom owned their own business), the $P/2W$ term approaches zero and equation (A6) would thus be quite similar to equation (A3). Further, there was no significant effect of the magnitude of the prize on the risk level of indifference provided.

Consistency checks

Subjects who preferred the sure time outcome and were willing to wait longer than the mean time of the gamble behave as if they have a negative discount rate, or, more likely, that they are quite risk averse. When these subjects are excluded from the sample the results are similar to those in Exhibit 2, with the main difference being that the magnitudes and significance of some of the findings has changed.

The survey responses must be considered in light of the survey design, which forced the subjects to provide a time horizon of indifference in one year intervals, without rounding off by months. For example, in the scenario presented in Exhibit 1, the subject might have responded with an indifference period of 3 years when the true indifference period was two and a half years. We used the rounded-off time period provided by the subjects. As a robustness check, we recorded the responses to reflect the minimum waiting period (i.e. 2.5 years for a response of 3 years) and the maximum waiting suggested by the response.

The two tasks associated with this timing lottery question provides a check of consistency for the responses. For example, a subject who prefers the timing lottery in the pairwise comparison yet expresses a time horizon of indifference which is longer than that offered by the sure thing is answering inconsistently, just as a subject who prefers the sure thing yet expresses a time horizon of indifference which is shorter than that originally offered by the sure thing. Just under 20% of the subjects responded in an inconsistent manner on the outcome timing scenario. Complete details of the survey are available upon request from the authors (Chesson, 1996).

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