Discounting Environmental Goods: An Experimental Analysis

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Abstract

Environmental policy decisions have impacts that are inherently long-lived. Subjecting policy options to cost-benefit analysis, therefore, involves discounting future costs and benefits at an appropriate rate of interest. The usual assumption is that future values are discounted at a constant, exponential rate, but there is some evidence from the lab suggesting that discount functions are more appropriately quasi-hyperbolic. If this is indeed the case, then the policy implications are dramatic: Some even suggest applying a zero discount rate for values that accrue far into the future. Understanding the structure of time preference for environmental amenities is imperative for sound policy decisions. We compare estimates of subjects' rate of inter-temporal time preference for financial rewards and environmental goods using multiple price-list (MPL) and a new matrix multiple price list (MMPL) approaches. We find that financial discount functions are not hyperbolic, but those for environmental goods are. Discount rates for environmental goods are approximately 50% lower than for financial rewards, but are still well above zero. Discounting according to hyperbolic discount functions as a matter of public policy, however, is unadvisable due to the time-inconsistent nature of the results, so using very low discount rates for long-lived environmental investments is the natural implication of our findings.

Keywords: experimental economics, hyperbolic discounting, incentive compatibility

JEL Codes: D03, D90, Q28, Q51

Introduction

Implementing environmental policy necessarily involves long-term investments. Assumptions made regarding the rate at which future costs and benefits are discounted to the present, therefore, can have dramatic impacts on which decision is taken, if any at all. Typically, future costs and benefits are discounted at a constant, exponential rate. Evidence from the lab, however, is mixed: Some suggest that discount rates are rather hyperbolic, or more specifically, quasi-hyperbolic (Loewenstein and Prelec 2002) while others find that exponential discounting is more likely to be the case when other factors are appropriately taken into account (Andersen et al. 2008; Benhabib, Bisin and Schotter 2010; Andreoni and Sprenger 2012). Quasi-hyperbolic rates of time preference are problematic from a policy perspective because they imply that decisions will be time-inconsistent. That is, a decision made at the present time, and thought to be optimal for all future periods will be changed once a future period arrives.[1] For environmental goods, such as global warming or the preservation of recreation areas, this is particularly important because the implications of a single decision impact millions of individuals, and even future generations (Karp 2005). There is little empirical evidence, however, as to whether discount rates for environmental goods reflect the hyperbolic pattern some observe in the lab for purely monetary rewards. In this study, we provide evidence regarding the nature of environmental discount rates, and test whether environmental discounting can be explained by individual attributes and behaviors.

Why should discount rates for environmental goods differ from those applied to purely monetary rewards? Some believe that environmental goods are likely to be discounted more heavily than monetary rewards because environmental damages involve high degrees of uncertainty, the damages occur long into the future, affect other places due to their migratory nature and involve other people (e.g., air pollution). This realization prompts Gattig and Hendrickx (2007) to state that human decision making is generally biased to recognize goods

[1] As Cropper and Laibson (1999) and Karp (2005) explain, observed consumption paths of individuals with hyperbolic preferences can be explained by allowing them to play games with each of their "intertemporal selves." The resulting consumption path for a finite-lived individual can be shown to be a unique, sub-game perfect equilibrium of these games and is observationally equivalent to the consumption path for an individual with exponential time preferences (Cropper and Laibson 1999).

that have "... risks with negative outcomes that occur for sure, now, here, and to us" (p. 22). The empirical evidence, however, suggests the opposite. Studying discount rates applied to the negative effects of various forms of environmental damage, a number of studies find a plurality of subjects do not discount at all -- an observation that is consistent with hyperbolic discounting, but not exponential (Svenson and Karlson 1989 (radioactive waste); Nicolaij and Hendrickx, 2003 (greenhouse gases), Hendrickx and Nicolaij 2004 (soil and water pollution); and Bohm and Pfister 2005 (water pollution)). Arrow et al. (1996) draw a sharp distinction between positive and normative judgments over the appropriate rate of discount for environmental goods such as climate change (or a lack thereof) and argue for a relatively low rate of discount on the grounds of intergenerational equity and that many environmental goods have few good substitutes. Nordhaus (1994), on the other hand, points toward a higher discount rate as he argues that it must be equivalent to the return on displaced investments in order to make best use of society's resources over the long run. We add an empirical dimension to this debate by applying experimental methods to study whether discount rates for environmental goods do indeed differ from discount rates for monetary rewards.

A number of methods have been employed to elicit both monetary and real discount rates, or discount rates for real goods. Harrison et al. (2002, 2005) and Andersen et al. (2008) use a multiple price list (MPL) instrument to separate pure time preference from risk aversion or the front-end delay effect in purely financial rewards. Subjects in an MPL experiment are presented a series of binary choices that differ only in price (future reward in the present case). By varying the price or reward incrementally as the subject moves through the series of choices, the MPL method is able to identify relatively clearly points of indifference between the two choices. The experimenter can then choose one choice from the series at random and nominate it to be the one that is used to determine the subject's payment. Because the subject does not know which choice will be binding a priori, he or she has an incentive to respond truthfully to each. Andersen et al. (2006) describe the advantages of the MPL method as transparency to subjects and it provides "...simple incentives for truthful revelation." Simplicity, however, is also the source of a disadvantage: While most choices consist of multiple attributes (cost, delay and green space improvement in the current example), the MPL method only allows the experimenter to vary one. Consequently, it is necessary to ask a large number of MPL questions to gather data on responses to changes in multiple attributes.

Viscusi, Huber and Bell (2008) adopt a choice-based conjoint (CBC) framework as a means of addressing the single-attribute problem of the MPL. CBC has been widely used in marketing and economic research to elicit willingness-to-pay for new products. Though questions used in a CBC analysis are more complex than an MPL analysis, a carefully crafted CBC study will illicit incentive compatible responses (Miller et al. 2011, and Lusk and Schroeder 2004). Viscusi, Huber and Bell (2008) allow the choice attributes of proposed water-quality improvement projects to include the cost, the extent of the improvement, and the delay in initiating the project. By estimating the implied choice parameters for water quality improvement at different delay horizons using a random utility approach, they are able to recover discount rates for different delay horizons. However, choice-based approaches are only able to include a few attribute-levels before overwhelming subjects with choice combinations. To overcome these limitations, we develop a matrix multiple price list (MMPL) design in which we present subjects with several price lists, each with a different cost. With the MMPL approach, we vary the improvement and delay row-by-row and column-by-column. Our MMPL method combines the simplicity of the MPL method with the flexibility of a CBC design.

We find that there is indeed a significant difference between discount rates for environmental goods and purely financial rewards. In fact, controlling for both a front-end-delay and curvature in the utility function (the uncertainty hypothesis of Andersen et al. 2008 and Andreoni and Sprenger 2012), financial discount rates do not appear to be hyperbolic at all. Environmental discount rates, however, are found to be hyperbolic. Moreover, discount rates for financial rewards are approximately 50% higher than for environmental goods. Those who engage in some risky behaviors, such as drinking and overeating, appear to discount at higher rates than others, while those who contribute to environmental organizations tend to discount environmental goods at lower rates. Comparing discount rates across methods, we find no significant difference for environmental discount rates gathered with MPL and MMPL techniques. Given the relative efficiency of the MMPL approach, this method appears to be a promising new tool for time-value elicitation for complex future rewards.

We contribute to both the substantive literature on discounting for environmental goods, and the methodological literature on time-value elicitation. There are few estimates in the literature of discount rates, obtaining using incentive-compatible experimental methods, for environmental goods relative to financial rewards, despite the clear policy importance of this type of information. We also contribute to the literature on public choice more generally as the structure of time preference is fundamental to many problems beyond environmental goods: retirement planning, healthcare choices, and behavioral choices such as overeating, smoking and drinking that have proven to be empirical conundrums in the health economics literature. Third, we develop a new experimental approach to time value elicitation -- the MMPL method -- that may prove valuable in future research regarding time-preferences for real rewards.

We begin by providing a brief discussion of previous research on discounting for non-financial rewards. We then describe the experimental procedures used in three complementary time-value elicitation studies, and explain how we parameterize subjects' discount functions in each. A fourth section summarizes the experimental data and discusses the results obtained from estimating discount rates econometrically. A final section concludes and draws a number of implications for both environmental policy and the analysis of long-lived relative to long-horizon decisions in general.

Background on Hyperbolic Discounting of Non-Financial Rewards

The investment horizon for some environmental policies can be dozens or even hundreds of years in the future. Consider greenhouse gas emission (GHG) or nuclear waste disposal as but two examples. Evaluated using exponential discount functions, even low discount rates will produce near-zero net present values for any policy with net benefits that are generations into the future. Yet, some countries have adopted very strict regulations on GHG emissions, and strongly supported the initial Kyoto Accord and any successor that would seek to sharply limit values for most policies. Others have relatively uncontroversial nuclear waste disposal programs. Why the difference?

If discount schedules are hyperbolic, or quasi-hyperbolic, then net benefits from limiting GHG in the short-run (if they exist) are heavily discounted, while those occurring further out may not be discounted at all. This pattern of discounting has been shown to be a relatively common artifact of human behavior with respect to nearly any decision with long-term consequences. Weitzman (1998) constructs a model of the "distant future" with which he argues that the discount rate applied to benefits and costs that occur far in the future (three or four centuries) should be very near zero, or at least as low as possible. Given the degree of uncertainty regarding future discount rates, let alone the costs and benefits themselves, any certainty-equivalent discount rate should be very low by definition.

More generally, empirical research suggests that there is a strong behavioral component to discounting at an individual-level, so arguments for using a constant exponential rate on social projects may lack empirical support. Thaler (1981) argues that gains are discounted more heavily than losses (valence, or the "sign effect"), discount small values more than large ones (the "magnitude effect") and discount effects that are expected to occur to others at a greater rate than to themselves (Hardisty and Weber 2009). These behavioral postulates may explain the empirical observation that discount rates depend on the "domain" in which the costs and benefits are to be incurred -- domain referring to whether the future cost or benefit refers to environmental goods, healthcare or financial gains (Chapman 1996a,b; Bohm and Pfister 2005; Gattig and Hendrickx 2007; Hardisty and Weber 2009). Finding low empirical discount rates for environmental policies may simply reflect the sign and magnitude effects. Because most policies are designed to mitigate environmental losses, individuals may simply be reluctant to discount damages that they would otherwise impose on their children or grandchildren. Similarly, the scope of losses some associate with global warming -- the loss of whole cities or the ability to produce food in entire regions -- means that the magnitude effect is likely to drive empirical discount rates very near to zero. Low discount rates for environmental projects may also reflect the fact that environmental damages tend to be fugitive resources, impacting someone else in a different region or even in a different country. For these reasons, our primary hypothesis is that discount rates for environmental rewards are lower than for financial benefits.

Environmental goods, however, are not all alike. While Viscusi, Huber and Bell (2008) find evidence of hyperbolic discounting for environmental improvements that occur immediately, have significant use-value and last indefinitely, there are many types of environmental policies with rewards that do not flow to users for several decades, if not longer. The types of risks described by Bohm and Pfister (2005) and Gattig and Hendrickx (2007) are examples of the latter. All investments in environmental goods are assumed to be long-lived, so discounting is likely to be relevant to each, but the time-frame of benefits is likely to differ. We differentiate between "short-horizon" (SH) investments in the environment, or investments that are made now, pay-off in the current period, and last for many years, and "long-horizon" (LH) environmental rewards, or those with payoffs that do not start until many years into the future, possibly to future generations. We include improvements in green space and storm-water control as examples of short-horizon environmental goods, and investments in greenhouse gas (GHG) abatement as an example of a long-horizon environmental good. We expect that discount rates for long-horizon environmental goods will be significantly lower than for long-lived investments. If discount schedules are indeed hyperbolic, then projects with immediate payoffs will be discounted heavily at first and much lower in later years. However, projects with only distant payoffs will only be discounted at low rates, if at all.

We also differentiate between goods with private-benefit (PB) and those with public benefit (BB). Private-benefit environment goods, or those with use-value, are those that provide subjects with a plausible and tangible benefit. In our experiment, storm-water control and improvements in green space have significant private benefit. Public-benefit goods, however, are more nearly pure public goods as subjects cannot plausibly derive a tangible immediate benefit and any utility gain comes from the knowledge that they are benefiting future generations. We use a GHG abatement project as an example of investments in BB environmental goods. Given the less tangible nature of public-benefit environmental goods, we expect discount rates to be lower for BB relative to PB goods. We test each these hypotheses using the experiment described in the next section.

Experimental Procedures

We conduct a time-value elicitation experiment using 300 undergraduate and graduate students from the Albers School of Business at Seattle University. Our intent is to answer substantive questions of whether environmental and financial discount rates differ, whether environmental discount rates differ by the type of good involved, and a methodological question regarding the difference in discount rates that may be revealed by the type of experimental procedure. To do so, subjects are randomly selected into one of two experimental procedures to determine their environmental discount rates (MPL and MMPL) and one of three treatments (short-horizon, private-benefit (SH-PB), short-horizon, public-benefit (SH-BB), and long-horizon, public-benefit (LH-BB)). All subjects complete a series of financial discounting questions using an MPL procedure in order to establish a control set of discount rates for each individual. The first treatment examines whether rewards from environmental goods that promise benefits in the short term, and contain a higher degree of tangible, personal benefit are discounted at a different rate than purely financial returns, while the second generates data on how returns to similar short-horizon environmental rewards without private benefit are discounted. The third treatment is intended to elicit discount rates for environmental investments that are plausibly expected to "pay off" only in the distant future, and to society in general rather than the subject taking the experiment.

In the financial MPL procedure, subjects in the control treatment are asked to make a binary choice between accepting an amount in one month ($20) and a higher amount some number of months later (1 month, 6 months, 12 months and 24 months). Choosing each delay as an amount of time after 1 month is intended to control for the front-end-delay effect (Andersen et al. 2008). Accounting for a front-end-delay is important, because payments promised after only very short delays (one day, for example) may be preferred simply because the subject does not trust the experimenter to remit payment at a future date. [2] Table 1 provides an example of one screen in the MPL procedure and shows the interest rates implicit in each row.[3] With an MPL approach, the implicit assumption is that the experimenter will be able to identify a specific value over the base amount ($20) at which the subject will be indifferent between the $20 now and higher amount with delay. This indifference-choice defines the discount rate for that choice set. We then choose one choice, or row, in the MPL table to be binding and pay subjects either now or in the appropriate future period depending upon their choice. We explain carefully to the subjects beforehand that this design is incentive compatible, or that it is in their best interests to answer exactly as they would if they were making decisions with their own money.[4] We offer the same financial MPL to all treatment-groups.

[table 1 in here]

For each of the environmental treatments the amounts to be received are in real (i.e., not monetary) terms. We anchor subjects' beliefs regarding the financial implications of their contribution by varying the cost of each project from $20 to $30 and $40 within treatment groups. Allowing cost to vary also tests for the magnitude effect (Thaler 1981) that is often found to be important in a lab setting. In other words, all respondents are members of a specific treatment and answer all questions within that treatment at three different cost levels.

We minimize the interval problem typical of MPL studies (Andersen, Harrison, Lau and Rutstrom 2006; Andersen, Harrison, Lau and Rutstrom 2008) by pilot-testing the survey a number of times and choosing a large number of increments (20) and a maximum and minimum choice-value that are within the bounds suggested by the pilot-survey data. Carefully piloting the survey also allowed us to minimize the framing problem as we narrowed our minimum and maximum WTP values to lie within the range generated by the pre-test procedure. Because the

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[2] Previous research shows that 24 months is sufficient to identify the hypothesized curvature in the discount function. Benhabib, Bisin and Schotter (2010), for example, use a maximum horizon of 6 months. Any longer than 24 months and the incentive-compatibility of our experimental design would no longer be credible.

[3] Note that these interest rate calculations were not shown to subjects on their choice screen, but are revealed in table 1 to show the exact discount rates implied by each choice.

[4] Ideally, or maximum delay would be longer than 24 months to identify truly long-term discount rates. However, decisions regarding rewards more than two-years out are no longer plausibly incentive compatible as subjects are not likely to expect payment after a two-year delay.

range of responses offered lies within the pre-test range, we expect none of the sample subjects to want to make a choice out of the sample range. We choose the specific amount of improvement or investment associated with each environmental good to represent approximately equal cost of improvement, and the same percentage improvement from one row to the next. The values for each are taken from public sources and represent realistic values of green space, storm-water control and GHG abatement.

In the MMPL procedure, subjects choose which project they prefer from among 4 delay levels (1 month, 6 months, 12 months, 24 months), 3 cost levels ($20, $30 and $40) and 10 levels of environmental improvement (2%, 5%, 10%, 15%, 25%, 35%, 45%, 65%, 75%, and 100%). The MMPL method differs from the MPL method in that each row consists of four delay levels, each with more greenspace, storm water improvement or GHG abatement, while holding the cost level constant. Each row increments the level of improvement for each delay level by a fixed amount. Therefore, respondents should move down the MMPL as in the MPL exercise, and transition from shorter to longer delays as the amount of improvement rises. Subjects fill out one MMPL matrix for each of the three costs levels, so we collect a total of 30 observations for each individual. MMPL represents a synthesis of the MPL method used by Andersen et al. (2008) for purely financial rewards and the CBC approach of Viscusi, Huber and Bell (2008) for environmental rewards. However, the choice set is much richer in the MMPL relative to the MPL method, and completing the MMPL is relatively fast and the incentives more clear than in the CBC. As in the MPL approach, SH-PB, SH-BB and LH-BB treatments are offered to separate sample groups, with two replications each in order to control for any session-specific variation in responses.

[table 2 in here]

Incentive compatibility among environmental choices is more difficult to achieve than in the baseline, financial experiment. Carson and Groves (2007) explain that if the subject regards his or her choice regarding a public good as "consequential" then he or she will respond as if they have a vested self-interest in the outcome. Consequentiality, in turn, requires that "...[F]irst, the agent answering a preference survey question must view their responses as potentially influencing the agency's actions. Second, the agent needs to care about what the outcomes of those actions might be" (Carson and Groves 2007). Consequentiality, however, is only a sufficient condition for incentive compatibility in discrete choice experiments (DCE), whereas our experiment consists of multinomial choices. Therefore, we maintain incentive compatibility in our public good experiments in the following way: For each procedure (MMPL and MPL) and treatment (SH-PB, SH-BB, LH-BB), we explain that one of the combinations (choices) will be chosen at random, and we will make a donation to a charitable organization created to make each type of investment in the subject's name. We control for variation in individual subjects' willingness to contribute to such organizations by asking questions in another part of the survey that are designed to characterize the subject as either willing or unwilling to contribute. Conditional on this "free rider" variable, the revealed contributions will reflect each subjects' inherent valuation of future benefits from each type of environmental good. We carefully explain why this procedure is incentive compatible to all subjects in the experiment instructions.

Discount rates are estimated from the experimental data using the econometric model described in the next section. Econometric estimation is necessary because discounting may be confounded with either contribution or risk-aversion effects if the latter are not properly conditioned out of the estimation procedure.

Empirical Model of Discounting

The empirical discount function, $D(y, t)$, nests quasi-hyperbolic and exponential discounting models. The most general form of the model also allows for the inclusion of a variable-cost component, a fixed-cost component, demographic effects and attitudes toward environmental and government policy. With data on the reward-time pairs and demographic attributes of each respondent, we identify all of these effects using a two-stage estimation procedure in which we estimate the curvature of the discount function in the first stage, and the parameters of the discount function in a second.[5] Because individual-level discount functions are

[5] Benhabib, Bisin and Schotter (2010) specify and estimate perhaps the most general empirical model, but find that their nesting parameter is estimated imprecisely in nearly all specifications with individual-level models. It is not clear from their data how their data are able to identify the separate fixed- and variable-cost effects that they report.

likely to contain a large amount of both observed and unobserved heterogeneity, we use a random-parameters specification that allows the discount rate to depend on a set of demographic and behavioral variables, as well as a purely random effect. In this way, we test whether observed individual-level attributes and behaviors are associated with different discount rates.

To nest both exponential and hyperbolic discounting, an empirical discount function must be able to capture declining discount rates over time. Prelec (2004) develops a general model of discounting in which the basic postulate is decreasing impatience (DI), meaning that the model should exhibit declining discount rates as the length of delay increases. His most general specification, however, is empirically intractable. Nonetheless, he suggests another for its ability to fit time-value data, its simplicity and parsimony, but does not investigate its properties. We extend his model to allow for fixed and variable costs of discounting and constant relative risk aversion (CRRA) as in Andersen, et al. (2008), and estimate the final model using panel-data methods. In its most general form, the econometric model is written as:

(1) $$x_h^r = y_h^r D(y, z_h, t; \delta_h, \alpha, \beta, \tau) = y_h^r \tau \left(\exp\left(-\delta_h t^{\alpha}\right) - \beta / y_h^r\right) \phi(\varepsilon_h)$$

where x_h is the promised payment for the particular question for subject *h*, y_h is the subject's indifference amount or their bid, *r* is a risk aversion (CRRA) parameter, *D* is the discount function, *t* is the number of days over which the subject is being asked to discount (defined as a proportion of a year), z_h is a vector of subject attributes, δ_h is the discount rate, α measures the departure of discounting from exponential, τ is a variable-cost component that determines whether the discount function is quasi-hyperbolic ($\tau < 1$), β is a fixed-cost component that Benhabib, Bisin and Schotter (2010) find to be an important contributor to the present-bias evident in their data.[6] One can think of τ as shifting the discount function up or down and α as changing the slope of the discount function. Among the random components, the discount rate is assumed to reflect both observed and unobserved heterogeneity such that $\delta_h \sim N\left(z_h' \delta_h, \sigma_\delta\right)$ while ε is an unobserved random effect ($\varepsilon \sim N\left(\mu_{\varepsilon h}, \sigma_{\varepsilon h}\right)$). If $\alpha = 1$, the discount function is exponential and as α rises above 1.0, the function assumes more of a hyperbolic shape (Prelec 2004;

[6] This factor is also akin to the "...additive constant..." of Becker and Mulligan (1997).

Andersen, et al. 2008). Specifically, at low levels of *t* the present value function is steep, indicating a high rate of discount. As t increases the function flattens out and asymptotes to zero. Because of this property, the function in (1) is ideally suited to testing the pattern of discounting for environmental goods described in the theoretical, and previous empirical literatures.

Present bias will arise with this specification, therefore, with higher values of α, higher values of β, or, of course, higher values of the underlying discount rate, δ. We also allow the agent-specific error term, ϕ, to include a log-normally distributed error term, ε. This panel estimator is unlike Benhabib, Bisin and Schotter (2010), who estimate separate models for each individual, so index all three parameters by h.

We test for systematic differences among individuals' time preference rates that may reflect more fundamental, behavioral determinants of an individual's discount rate. Therefore, we assume all parameters are constant across individuals, except for the rate of time preference. If an individual exhibits present bias in financial decision making, then our hypothesis is that he or she is also likely to engage in risky behaviors that may shorten his or her lifespan (smoking, drinking, overeating). Moreover, subjects who discount environmental goods heavily are not likely to engage in other practices that reflect future-oriented thinking with respect to environmental goods. Recycling, belonging to environmental organizations, or even believing that polluting goods should be priced higher than others are all examples. Our survey includes a number of questions designed to elicit information on these types of behaviors.

We measure drinking as the number of alcoholic beverages consumed per week, smoking as the number of cigarettes per week and obesity by body-mass-index (BMI). In general, we expect discount rates to be higher if the subject is a heavy drinker (as opposed to a moderate drinker, Ashley et al. 2000), a heavy smoker and is obese. Although this expectation is intuitive, it may be the case that the youthful nature of our sample and the long-term nature of damage from smoking mean that adverse health effects are not yet tangible for our subjects. Moreover, if individuals have an inherent tendency toward obesity or drinking, they may believe, at least implicitly, that they are pre-destined to a relatively short lifetime and thus make decisions that reveal higher discount rates (Cutler and Glaeser 2005). Smokers, on the other hand, smoke from a behavioral preference and clearly do not believe that doing so will shorten their lifespan, and make decisions as if their discount rates are correspondingly lower.

We estimate the various forms of (1) using simulated maximum likelihood (SML), which is necessary given the random-parameters assumption described above. With this specification, however, it was not possible to estimate the curvature parameter in the same SML routine as the other parameters. Consequently, we adopt a two-stage procedure in which the curvature parameter α is estimated using non-linear least squares in the first stage and the remaining parameters estimated with SML in the second stage, conditional on the estimated value of α. We also found that the SML estimates of β were not robust to different model specifications so do not report estimates of the fixed-cost parameter in the final model. For the SML routine, we use a Halton draw technique in order to speed convergence and find that no gains in performance were obtained for draw numbers greater than 75 (Train 2003).

Results and Discussion

In this section, we first summarize our experimental findings, and then report estimation results for both financial and environmental discount rates, and environmental discount rates obtained using MMPL and MPL elicitation methods. Within each of the models, we compare estimates obtained using a random-parameter specification to estimates obtained under an assumption that all subjects have the same discount function. In this way, we highlight the importance of unobserved heterogeneity and a more fundamental pattern of behavior that underlies discounting.

Based on the demographic profile of our sample shown in table 3, we clearly draw a typical student-sample. Respondents are generally young, with below-average income and consist of a majority of white females. Incomes tend to be relatively low compared to the general population, and the number of cigarettes smoked even lower. Among other behavioral measures, our sample tends to drink only moderately, and is below average in terms of obesity, at least as measured by BMI.

[table 3 in here]

In our sample, nearly 86% of respondents believe products that pollute should be priced significantly higher than those who do not (table 4). Nonetheless, some 68% do not make sacrifices to avoid polluting -- evidence that individuals tend to separate what is right for society from what is right for themselves. Further, nearly everyone recycles, but few belong to an environmental organization, suggesting that environmental concerns influence daily practices, but do not cause subjects to commit time and resources to influence others. This lack of passion for environmental causes is also reflected in the relatively low level of volunteerism and donations to environmental organizations. Nonetheless, subjects in this age cohort (and region of the country) are willing to spend sometimes large amounts enjoying recreational amenities afforded by their environment.

[table 4 in here]

We also asked subjects a series of questions designed to assess their attitudes toward government intervention in various aspects of the economy, seeking to describe the boundaries of what role the government may have in regulating public goods other than the environment. Based on the results in table 5, the areas perceived as most deserving of government involvement (defined as areas that earned either a "yes" or "absolutely" response to the question whether governments should commit resources to...) are the environment (93.99%), unemployment (86.34%) and climate (82.51%). Therefore, among all the issues that face regulators, problems related to the environment rank highly among more general economic, social and political concerns. Based on these summary findings, we expect to find discount rate estimates that favor investments in solutions to long term problems: Much lower than discount rates for financial rewards and critically dependent upon the nature of the problem.

[table 5 in here]

Imputing discount rates from the experimental data, however, requires econometric estimation. Table 6 presents the parameter estimates of the discount function for purely financial rewards. Each of the parameter estimates in the top part of the table, the second-stage estimates, are conditional on the curvature parameter (α) estimated in the first stage.[7] The estimate of 0.686 suggests that the discount function for financial rewards is in fact not hyperbolic but rather less convex than the maintained exponential discount function. This finding is consistent with others in the recent literature (Andersen et al. 2008; Benhabib, Bisin and Schotter 2010; Andreoni and Sprenger 2012). These studies, also using experimental data, control for other potential reasons why discount functions may appear to be hyperbolic. Although this finding is itself of particular interest, our primary purpose in controlling for the curvature of the discount function is in obtaining unbiased estimates of the second-stage function in which we control for a number of other factors.

[table 6 in here]

Discount rates vary considerably among respondents, both systematically with observable attributes, and randomly with attributes that we cannot observe. Based on a likelihood ratio test (LR) comparing the fixed and random coefficient specifications, we see that the fixed coefficient version is easily rejected in favor of the random parameter model. Consistent with previous literature on experimental discount rates, we find that, once we include a front-end delay, discount rates for financial rewards are very high, with a mean estimate of some 18.0% per year. Without further modification, or other arguments in the discount function, therefore, this high discount-rate estimate would explain a considerable amount of present-bias. Our discount function is more complex than this, however.

Quasi-hyperbolic discounting involves discounting values in future periods at higher rates as if there were a "variable cost" of discounting -- independent of the rate of intertemporal time preference (δ) the total discount associated with future rewards rises with the amount of the reward in a log-linear way (Benhabib, Bisin and Schotter 2010). The estimates in table 6 show that the variable cost parameter (τ) is significantly different from zero. Because some of the observed discounting behavior may be ascribed to a variable cost of discounting, it is perhaps not

[7] The first-stage function, estimated with non-linear least squares, also consists of a constant term and discount-rate estimate. These parameters, each of which are statistically significant, are available upon request.

surprising that the estimate of δ is considerably higher than market rates of interest. Therefore, although the curvature parameter α suggests that our financial discount functions are not hyperbolic, per se, they are instead quasi-hyperbolic. Imposing a zero variable cost of discounting, as is usual in this literature, creates a bias toward finding a hyperbolic discount function.

We also relax the assumption of risk neutrality, an assumption that is often blamed for confounding time preference for risk aversion. Andersen at al. (2008) find that controlling for risk aversion causes estimated discount rates to fall slightly, explaining some of the apparent present bias found in previous studies. We find that subjects are indeed risk averse with respect to financial rewards (r = 0.711), which is consistent with Andersen et al. (2008) and Andreoni and Sprenger (2012).

Unobserved heterogeneity is also important as the standard deviation of the individual parameter estimates is significantly different from zero. Allowing the mean discount rate to vary with observable attributes, we find that discount rates are lower (a positive parameter estimate as the discount rate is negative in this specification) for older men, smokers and for obese people.

The relationships between smoking, drinking, obesity -- all behaviors that may be described as risky in the sense that they may lead to early death -- and time preference are of particular interest in forming discount-rate policy for public projects in general. With respect to financial discount rates, subjects who smoke or are obese have lower discount rates than others. The drinking effect is not significant. Previous research provides no definitive priors with respect to the effect of smoking on discount rates, but our finding can be explained by the fact that our sample is predominantly students and relatively young. Obese people also discount at lower rates. Because 50% of BMI is thought to be due to genetic factors (Shell 2002), and thereby out of an individual's control, many obese individuals may in fact be more concerned about the future than others as they "fight with their weight" and are thus continually reminded of the future implications of current behaviors.

Estimates from the same discount function, but applied to the experimental data on improvements to park space, storm water control and GHG abatement are shown in table 7. Due to the fundamental differences between environmental and purely financial benefits described above, it is perhaps not surprising that we find a number of important differences between financial and environmental discounting. First, the curvature parameter α is now significantly greater than 1.0. Discount rates for environmental rewards are, therefore, hyperbolic in shape even after allowing for a considerable front-end delay period and allowing for the risk-averse nature of our subjects (r = 0.930). Regardless of the rate at which subjects discount environmental benefits, this is an important result in itself because it suggests environmental decisions, if they are made in a way that is consistent with agents' intertemporal time preferences, will exhibit present-bias and will be time-inconsistent. Although we show estimation results pooled over all three types of environmental goods in table 7, this finding holds when we allow α to vary by the type of environmental reward. Subjects in our experiment show a present bias for investments that have immediate use-value, have no apparent use-value at all, and have value only over a relatively long horizon.

[table 7 in here]

Second, we find that mean discount rates are significantly lower for environmental rewards than for purely financial benefits: At 12.4%, the mean discount rate is 31.4% lower than for financial rewards. While this finding is consistent with the empirical literature on environmental discounting (Nicolaij and Hendrickx 2003; Bohm and Pfister 2005), the estimated discount rate is by no means "low" in the sense of Arrow et al. (2006) as a 12% discount rate is still far above prevailing market rates at the time of the experiment. Moreover, interpreting a single discount rate estimate in a hyperbolic discount function is somewhat misleading as the actual rate of discount is far higher for near-term benefits and far lower for rewards expected in the outer years.

Third, discount rates vary significantly by the type of environmental reward. Accounting for differences by allowing the random discount rate parameter to vary by type of reward, we find that agents discount both storm-water control improvements and carbon abatement at significantly lower rates than in the base-case (park improvements). Although statistically significant, these differences are, however, relatively small in an economic sense as storm-water improvements are still discounted at a 15.1% rate, on average, while carbon-abatement investments are discounted at a 23.0% rate. Why the difference? Park improvements, the base-case, provide immediate use-value once completed. Storm-water control and carbon-abatement, on the other hand, are more characteristic of pure public goods as they are both non-exclusive in use and non-rival in consumption. Therefore, while the differences in estimated discount rates are small, our results suggest that environmental goods that provide use-value will be discounted at rates more akin to private investments and public environmental goods will be discounted at rates consistent with social investments.

Variable-costs of discounting are also important for environmental rewards. The estimate of τ reported in table 7 is significantly different from zero, and much lower than in the financial discount function. Again following the interpretation of Benhabib, Bisin and Schotter (2010), this finding implies that subjects discount larger values at more-distant time periods at much lower rates than smaller values received at less-distant time periods. Environmental discount functions appear to be both hyperbolic in the traditional sense of the term, and quasi-hyperbolic once variable costs of discounting and risk aversion are properly accounted for. Relative to the financial-rewards case, however, the coefficient of risk aversion is closer to 1.0 (risk neutrality) at 0.93, which may indicate that agents perceive financial and environmental risks in fundamentally different ways.

Heterogeneity is also important for environmental discount rates. Unlike the financial discounting case, we find that older men discount environmental rewards at higher rates than others, perhaps indicating less concern with broader social issues and more concern for immediate, personal financial issues. Further, we find that smokers again discount environmental rewards at lower rates than others, but drinkers discount them at higher rates and the obesity effect is now not statistically significant. This result is consistent with Cutler and Glaeser (2005) in that drinkers may be expected to discount public goods at higher rates than others if they perceive a lower probability of benefiting from them in the more distant future.

Controlling for differences in behaviors toward environmental amenities, we also find several statistically-significant results. First, as in the financial discounting case, subjects who recycle discount environmental investments at a higher rate than other subjects. Second, unlike the financial discounting results, members of environmental organizations also discount at higher rates. The similarity between the findings with respect to subjects who recycle and those who belong to environmental organizations is notable because they reflect the passive versus active support for environmental causes: While recycling is part of the daily routine of most members of our sample, it is only a committed few who belong to environmental organizations. With respect to financial decisions, organization members tend to take a longer-term perspective while they exhibit more of a present-bias with respect to the environment, likely reflecting a fundamental impatience for action on all manner of environmental issues. Third, subjects who both volunteer their time and donate money to environmental organizations tend to discount at lower rates. The difference between these results and for organizational membership may reflect the extent of the commitment measured by the latter two variables. Membership may be an active decision, but it does not carry with it the same cost in terms of time and resources as volunteering or donating. Each of these results has important implications for both managers of the environmental organizations themselves and those engaged in the public policy process, intending to target those engaged in forming environmental policy.

Our results have many implications. Most importantly, if decisions regarding investments in environmental goods are to be made using traditional net present value criteria, and reflect discount rates typical of the relevant population, finding that environmental discount rates are hyperbolic implies that decisions will be made with a strong present-bias and may be time inconsistent. Second, finding environmental discount rates are many times higher than market interest rates means that few projects will be found to be viable on a cost-benefit basis, particularly those with benefits that are difficult to quantify or are highly uncertain. Third, beyond the specific subject matter considered in our experiment, our results may explain many of the public policy decisions regarding environmental goods evident from actual practice. While few in management positions charged with making such investments would conceivably discount future benefits using hyperbolic discount functions, favoring projects that have high use-values, more immediate benefit-flows, or those with more tangible benefits to constituents represents "as if" behaviors consistent with our findings. Finally, our results corroborate other studies from the medical or real-estate literatures that find evidence of present-bias in other types of non-financial decisions: Finding both high discount rates and hyperbolic discount functions easily explains apparent myopia in many types of personal and public policy decisions.

Conclusions

Evaluating investments in any type of environmental amenity, from local green space to storm water control and carbon abatement, necessarily involves discounting a future flow of benefits and costs. However, there appears to be a fundamental inconsistency between discount rates used in practice, and those found in the lab. Namely, environmental projects are typically evaluated using exponential discount functions with market-based discount rates, while existing evidence suggests that discount functions are instead hyperbolic, and have relatively high discount rates. In this study, we investigate the nature of discounting for environmental goods using experimental methods. We introduce a new method of time-value elicitation for multi-attribute goods called matrix multiple price list (MMPL), which combines features of both choice-based conjoint (CBC) and multiple price list (MPL) methods. From a practical perspective, our intent that is that our findings are able to both explain current public policy regarding environmental goods and to provide decision makers for a framework to use in evaluating long-term investments in a variety of environmental projects.

We find that discount functions for financial rewards, once we appropriately account for a one-month front-end-delay in receiving the earliest reward, and for risk aversion, are not hyperbolic as is often found in the lab, but rather something less convex than exponential. Discount rates, however, are nonetheless very high (18%). Discount functions for environmental goods, on the other hand, are indeed hyperbolic and the implied discount rates some 31% lower than for financial rewards. By estimating the discount function using panel-data methods, we are able to determine the impact of personal attributes, practices and attitudes on revealed discounting behavior. While subjects who engage in risky behaviors (smoking, drinking and overeating) do not tend to discount at higher rates as we expected, those who are particularly committed to environmental causes (as evidenced by volunteering or contributing to environmental organizations) do indeed discount environmental goods at lower rates than others.

We also find that the MMPL method provides an efficient and flexible method of time-value elicitation that does not introduce bias relative to an MPL benchmark. Researchers interested in finding discount rates for other relatively complex goods -- those with multiple attributes -- may find the MMPL of value.

If environmental projects are to be discounted in a way that reflects individual agents' intertemporal time preference, then the natural implication of our findings is that projects with near-term benefits should be evaluated using relatively high discount rates, while those with longer horizons should be assessed with much lower rates. Doing so, however, will simply institutionalize the present-bias evident in many individual-level decisions. Rather, a prudent interpretation of hyperbolic discount functions for environmental goods suggests that costs and benefits that are expected to occur far in the future should be discounted at very low discount rates, far lower than those for purely financial values. This interpretation is not only intuitive, but consistent with other empirical literature on this topic that uses different methods, in different contexts and with different subject-samples.

Future research in this area should consider a few limitations of our experimental approach. First, although student-samples are well-accepted in the experimental literature, a sample of the general population may serve as a better guide for broader environmental policy. Second, our selection of time-frames was limited by the need to ensure that the experimental data remained incentive-compatible. Payment horizons beyond two years are simply not credible. Future research may consider the extent of hypothetical-bias inherent in experiments with longer time frames than that considered here. Finally, investigations into any potential difference between our MMPL method and an alternative multi-attribute approach such as the CBC would be valuable additions to the methodological literature on environmental time-value elicitation.

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Table1: Multiple Price List Example: 3 Month Delay

Choice A 1 Month	Choice B 3 Months	% Return Per Ann.
20	20.00	0%
20	20.10	2%
20	20.48	10%
20	20.71	15%
20	20.93	20%
20	21.15	25%
20	21.56	35%
20	21.95	45%
20	22.32	55%
20	22.84	70%
20	23.33	85%
20	23.78	100%

Table 2: Matrix Multiple Price List Example: Park Improvement

Choice A 1 Month	Choice B 3 Months	Choice C 6 Months	Choice D 12 Months	Choice E 24 months
33.0 sq.ft.	33.2 sq.ft.	33.3 sq.ft.	33.7 sq.ft.	34.3 sq.ft.
33.0 sq.ft.	33.4 sq.ft.	33.8 sq.ft.	34.7 sq.ft.	36.4 sq.ft.
33.0 sq.ft.	33.8 sq.ft.	34.6 sq.ft.	36.3 sq.ft.	39.9 sq.ft.
33.0 sq.ft.	34.2 sq.ft.	35.4 sq.ft.	38.0 sq.ft.	43.6 sq.ft.
33.0 sq.ft.	34.9 sq.ft.	36.9 sq.ft.	41.3 sq.ft.	51.6 sq.ft.
33.0 sq.ft.	35.6 sq.ft.	38.3 sq.ft.	44.6 sq.ft.	60.1 sq.ft.
33.0 sq.ft.	36.2 sq ft.	39.7 sq.ft.	47.9 sq.ft.	69.4 sq.ft.
33.0 sq.ft.	37.1 sq.ft.	41.7 sq.ft.	52.8 sq.ft.	84.5 sq.ft.
33.0 sq.ft.	38.0 sq.ft.	43.7 sq.ft.	57.8 sq.ft.	101.1 sq.ft.
33.0 sq.ft.	39.2 sq.ft.	46.7 sq.ft.	66.0 sq.ft.	132.0 sq.ft.

Table 3: Summary of Demographic and Behavioral Responses

Variable	Units	Mean	Std.Dev.	Min.	Max.
Age	Years	23.995	6.231	18.000	60.000
Gender (1 = Male)	%	0.432	0.495	0.000	1.000
White	%	0.634	0.482	0.000	1.000
African-American	%	0.016	0.127	0.000	1.000
African	%	0.153	0.360	0.000	1.000
Asian-American	%	0.087	0.282	0.000	1.000
Asian	%	0.016	0.127	0.000	1.000
Hispanic-American	%	0.022	0.146	0.000	1.000
Hispanic	%	0.055	0.227	0.000	1.000
Mixed Race	%	0.016	0.127	0.000	1.000
Household Size	#	1.880	1.425	0.000	7.000
Income	$ '000	38.511	36.045	7.500	125.000
Number Smoke	#	0.039	0.243	0.000	3.000
Number Drink	#	2.273	1.311	1.000	7.000
BMI	Index	23.872	4.189	16.909	39.237

Table 4: Summary of Environmental Attitudes and Behaviors

Question	Strongly Agree	Agree	Disagree	Strongly Disagree
Polluting goods should cost more?	33.88%	51.91%	11.48%	2.73%
	No	If Convenient	Usually	Always
Sacrifices to avoid polluting?	1.64%	31.15%	59.56%	7.65%
Do you recycle?		0.00%	9.84%	38.80%
	Mean	Std. Dev.	Min.	Max.
Environmental organization?	11.42%	31.80%	0.00%	100.00%
Dollars spent outdoors?	$491.15	$1,181.07	$0.00	$12,500.00
Dollars donated to enviro. organizations?	$28.93	$114.54	$0.00	$1,250.00
Volunteer for an enviro. organizations?	1.38	4.70	0.00	35.00

Table 5: Summary of Attitudes Toward Policy Issues

Issue	No	Little	Yes	Absolutely
Unemployment	1.64%	12.02%	43.72%	42.62%
Debt	1.09%	18.58%	44.81%	35.52%
Immigration	14.21%	33.33%	35.52%	16.94%
Climate	2.73%	14.75%	39.34%	43.17%
Nuclear	2.19%	20.22%	40.44%	37.16%
Disease	5.46%	27.32%	38.80%	28.42%
Gay	10.93%	14.75%	27.87%	46.45%
Environment	0.00%	6.01%	46.99%	46.99%

Table 6: Financial Rewards Discount Function

	Parameter	Fixed Parameter Estimate	Fixed Parameter t-ratio	Random Parameter Estimate	Random Parameter t-ratio
First-Stage Estimate of Curvature Parameter:					
Hyperbolic?	α	0.686*	11.626	0.686*	11.626
Second-Stage Estimate of Discount Function Parameters:					
Constant	τ	0.049*	13.097	0.049*	9.564
Risk Aversion	r	0.765*	104.723	0.711*	58.283
Delay	δ_0	-0.214*	-58.207	-0.180*	-14.604
Std. Dev. Of Delay	σ_δ			0.076*	46.759
Age	δ_1			0.001*	6.095
Gender	δ_2			0.025*	7.463
HHSize	δ_3			-0.002*	-1.193
Income	δ_4			-0.002*	-4.444
Num. Smoke	δ_5			0.043*	5.104
Num. Drink	δ_6			0.002	1.459
BMI	δ_7			0.007	1.789
Pollution Price	δ_8			-0.018*	-3.863
Recycle	δ_9			-0.075*	-13.199
Envt. Org.	δ_{10}			0.003	0.558
Envt. Dollar	δ_{11}			-0.008*	-4.721
Envt. Vol.	δ_{12}			0.005	1.441
Std. Deviation	σ			0.007*	332.689
Log Likelihood Function		-540.93		-1,528.29	

Table 7: Environmental Rewards Discount Function

	Parameter	Fixed Parameter Estimate	Fixed Parameter t-ratio	Random Parameter Estimate	Random Parameter t-ratio
First-Stage Estimate of Curvature Parameter:					
Hyperbolic?	α	1.302*	25.44	1.302*	25.44
Second-Stage Estimate of Discount Function Parameters:					
Constant	τ	0.112*	10.248	0.173*	32.044
Risk Aversion	r	0.954*	264.285	0.930*	290.584
Delay	δ_0	-0.319*	-63.315	-0.124*	-4.666
Std. Dev. of Delay	σ_δ			0.071*	21.068
Storm	γ_2			-0.031*	-3.867
Carbon	γ_3			-0.107*	-10.925
Age	δ_1			-0.001*	-2.417
Gender	δ_2			-0.020*	-2.450
HHSize	δ_3			0.003	0.919
Income	δ_4			-0.002	-1.846
Num. Smoke	δ_5			0.164*	7.726
Num. Drink	δ_6			-0.013*	-3.647
BMI	δ_7			-0.006	-0.767
Pollution Price	δ_8			-0.036*	-3.130
Recycle	δ_9			-0.075*	-5.065
Envt. Org.	δ_{10}			-0.039*	-3.501
Envt. Dollar	δ_{11}			0.001*	6.278
Envt. Vol.	δ_{12}			0.001	1.750
Std. Deviation	σ			0.252*	267.792
Log Likelihood Function		-358.597		-108.862	