Discounting Behavior and Environmental Decisions

Richard T. Carson
Department of Economics
University of California, San Diego
and
Centre for the Study of Choice
University of Technology, Sydney

Brigitte Roth Tran
Department of Economics
University of California, San Diego

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Abstract

Discounting plays a major role in the life cycle of environmental and natural resource policies. Evaluating centuries-scale problems like climate change with standard discount rates yields results that many find ethically unacceptable. Paradoxes abound. Low discount rates are urged for determining the net benefits of climate change while households fail to undertake energy conservation actions that have payback periods of only a few years. Efforts to uncover discount rates from revealed and stated preferences suggest that a variety of confounding factors may be simultaneously in play. Common property resources provide an example of how market failures can lead to behavior consistent with extreme discounting that can be addressed through effective policy. Finally, politicians, who make final policy decisions, may have incentives to act in accordance with discount rates not socially optimal.

Key Words: benefit-cost analysis, climate change, contingent valuation, discount rate

As our scientific understanding of our long-term impact on the environment grows, so does our physical capacity for doing damage. It therefore comes as no surprise that in environmental economics increasing attention is being paid to the evaluation of extremely long-lived problems such as climate change, biodiversity, and nuclear waste disposal.

The prevailing approach for evaluating environmental projects is to perform a benefit-cost analysis in which all of the associated costs and benefits over the lifetime of a project are estimated in current dollar values and then discounted using the standard exponential approach with a social discount rate to determine the net present value of the project. If the result is positive, then the project is generally considered a good investment.

Unfortunately, applying this methodology using standard discount rates on centuries-scale problems yields results that many, including many economists, find ethically unacceptable. Consider climate change mitigation which combines very high upfront costs with an extremely long stream of benefits continuing centuries into the future. When discounted at standard constant discount rates, the power of compounding results in negligible present values for these far-distant future benefits. Under standard exponential discounting, even the loss of the entire current world output two hundred years from now is discounted down to relatively small amounts under any rate commonly used for financial transactions. Consequently there has been much focus recently on developing alternative methods for discounting very long-term cost and benefit streams.

A robust and broadly accepted approach to long-term discounting will significantly improve our ability to credibly evaluate policies for dealing with centuries-scale issues. However, successful implementation of these policies will be contingent upon how individual agents respond to incentives. Therefore, in addition to developing a theoretical framework for discounting long-lived costs and benefits, it is also important to understand how individual agents make shorter-term intertemporal trade-offs.

Consider, for example, the actions needed to reduce current greenhouse gas emissions. Even when the payback period in terms of lower utility bills is only a few years, most consumers do not purchase more energy efficient appliances. This suggests that consumers have very high discount rates. A closer look indicates that there are complicating elements, including information sets, budget constraints, transactions costs and expectations about the future, that play into these sorts of purchasing decisions.

Another class of environmental problems in which discounting plays a crucial role is that of policies directed at reducing risks to life at different time horizons. In order to better understand the appropriate social discount rates to apply to such policies and to predict the political support for life risk reduction efforts, it is important to also understand how people discount in making life risk reduction choices. Interestingly, some similar results emerge around inconsistencies in discounting in this context.

Another example that demonstrates the importance of individual discounting behavior is agent response to incentives involving common property resources. In unregulated common access fisheries for example, market failures lead to extreme discounting on the part of individual agents. Implementing effective policies can correct for these failures so that the discount rates implicit in fisheries' behaviors are more consistent with social discount rates.

In the end it is politicians, not economists or scientists who set the parameters of environmental policies. It is interesting to ask questions about the temporal incentives these policymakers may be responding to. Do politicians tend to act in accordance with social discount rates, or are they selfishly motivated to stray from societal goals?

The aim of this paper is to explore discount rates in the life cycle of environmental policies. This paper is laid out as follows. First, the theoretical underpinnings of discounting as applied to environmental policy evaluation of long-lived projects are reviewed, with climate change as the canonical example. Second, discount rates implicit in energy-consuming durables are considered as an example of agent response to policies. Third, measurement of implicit discount rates for health risks is addressed with a focus on stated preference data and the effort to infer discounting "preferences" from choice behavior. Fourth, common property access to a natural resource provides an example of the interaction between policies and agent discounting. Fifth, the key role of politicians and their implicit discount rates in implementing environmental policies is examined. Finally, some concluding observations are offered.

Controversial Role of Discounting in Environmental Project Evaluation

The prevailing approach for evaluating environmental projects is to perform a benefit-cost analysis (Zerbe and Dively, 1994; Boardman, *et al.*, 2001; Pearce, Atkinson and Mourato, 2006). All of the associated costs and benefits over the lifetime of a project are estimated in current dollar values and then discounted to determine the net present value of the project. If the result is positive, then the project is generally considered a good investment. Debate in this literature focuses on three main facets of the problem. The first is how to measure benefits of environmental policies, particularly those that are not priced in the market place. The second has to do with measuring costs, which would be more straightforward if there were no induced technological change over time or general equilibrium impacts on the larger economic system. The third is the appropriate discount rate or discount rate function to use in evaluating environmental/natural resource policies with a strong time dimension. In this paper, we largely ignore issues related to measuring benefits and costs and concentrate solely on the question of discounting.

Ramsey Rule

The standard economic approach to discounting is to use the Ramsey (1928) Rule,

(1) $r = \rho + \theta g$,

where r is the social (or individual) rate of return, ρ the pure rate of time preference (which is often confused with r), g the growth of consumption and θ the elasticity of marginal utility, defined in the sense of intertemporal substitution.[1] Net present value or discounted net benefits is then given by:

(2) $\sum (B_t - C_t)/(1 + r)^t$,

where B_t represents the benefits of the policy at time t, C_t is the cost at t, and the summation is performed from t=0 to T. In this sense discounting using r defines how to tradeoff net benefits in different time periods. The functional form of (2) implies exponential discounting by the factor e^{-rt} in continuous time models so that the only thing that matters in comparing two quantities is their distance in time. Intuitively, the Ramsey Rule says that discount rates are higher the more impatient people are, the faster the economy is growing, and the more people are willing to substitute consumption across

[1] Dasgupta (2005) provides an overview of how the Ramsey formulation can be looked at from several different perspectives and a discussion of the technical difficulties including a consideration of the implication of infinite time horizons.

time periods given a positive economic growth rate. It is straightforward to show that failure to use this rule leads to inefficient and/or inconsistent decision making.

The Ramsey Rule embodies two key concepts, ρ, a preference component, and θg, a component involving the product of the economy's growth rate and the marginal utility of additional consumption. Depending on these parameter values, the social rate of return can be positive, zero, or even negative, if current actions lead to lower future growth rates. The preference parameter ρ is often confused with r. However it is r which rational individuals should used to discount future costs and benefits. Even if all individuals have a constant ρ, r can vary across time or individuals due to differences in beliefs about g or differences in the other preference parameter θ.

While applying discounting based on the Ramsey Rule in typical policy analysis situations may be fairly straightforward, many issues arise when evaluating centuries-scale environmental problems like climate change, nuclear waste storage, dams, and ecosystem restoration. As seen in Table 1, discount rates impact present discounted values by orders of magnitude on a 200-year time scale and have a substantial impact even in 10- or 30-year time frames.[2] Any project with costs that are primarily front-ended and benefits that stretch out over long periods of time looks less and less attractive as the discount rate used to evaluate the project increases.

[Insert Table 1 About Here.]

[2] To help put this table in perspective, the U.S. Office of Management and Budget (OMB Circular A-94 Revised, 1992) currently mandates that U.S. government agencies use a real (expected inflation removed) discount rate of 7% in benefit-cost analyses of government regulations. A different and lower discount rate (~3%) based on current Treasury Department yields on its securities is allowed for evaluating purely internal government projects such as energy efficiency investments in public buildings.

Debate over the Ramsey Rule takes two forms. The first, among those who accept its validity, is over obtaining estimates of the parameter values for ρ, θ, and g. Arrow, *et al.,* (1996) identified two main approaches to estimating these parameter values; the "descriptive" approach, which relies purely on empirical values such as market rates, and the "prescriptive" approach, in which the values of these parameters are based on ethical arguments. Among those who reject the validity of the Ramsey Rule on ethical grounds, the second debate, which we don't address here, is over whether discounting should be used at all for evaluating long-term environmental projects. The first debate has become more fluid over time, particularly in the realm of climate policy. The difficulties involved in obtaining "correct" empirical estimates of the parameters have been examined from a variety of perspectives. Because use of the Ramsey Rule requires two estimated preference parameters, questions naturally arise about how people discount future costs and benefits.

Although proponents of descriptive discounting agree that discount rates should be based on empirical values, there is no clear consensus on actual parameter values for long-lived environmental issues. Depending on the data, different market rate estimates emerge. For example, Mehra and Prescott (2003) show that in four different data sets the historical real "relatively riskless" rate of return varies between 0.4 % and 2.9 %. These rates are based on very short-term instruments such as U.S. Treasury bills. Long-term rates of return from the stock market or long-term high grade corporate bond interest rates are also frequently invoked[3], particularly when reference is made to policies that would force business investment in pollution control equipment. Reference is sometimes made to the

[3] The difference between the riskless rate of return on short-term U.S. government securities (~1%) and typical stock market returns (~7%) is often referred to as the equity premium puzzle and has close ties to the interpretation of the Ramsey Rule. Brekke and Johansson-Stenman (2008) make a connection between the discount rate used in evaluating climate change and equity premium from a behavioral economics standpoint.

interest rates paid by consumers on their credit cards when upgrading consumer durables is required. However, in looking at policies with time horizons well beyond the 30-year maturity for U.S. Treasury bonds (*e.g.,* water projects are often considered to have 50+ year time horizons and climate policies often look at 200-year time horizons), there are no accepted market guideposts to look at.

The elasticity of marginal utility θ is often assumed to equal 1, which is consistent with the well-known logarithmic utility function u=log(c) where c is consumption. Statistical evidence comes from two sources. Research from recent studies suggests values for the elasticity of marginal utility in a somewhat higher (1.2 to 1.4) range (Evans 2005; Layard, *et al.,* 2008). However, in macroeconomics, which has long been focused on the intertemporal substitution in response to changes in interest rates, there are long-standing disagreements (*e.g.,* Hall, 1988; Beaudry and van Wincoop, 1996) which place this elasticity either close to zero or close to one. This θ parameter also has an ethical dimension as it relates to preferences toward the distribution of income within a society or across countries (Dasgupta, 2008) with higher values being associated with a greater desire for equality.

The pure time preference parameter ρ is difficult to isolate from other factors in making empirical estimates, and hence is often inferred given a market based estimate of r and estimates for θg. This leads to the crux of the debate over climate change. Most defensible choices for r, including the lowest yielding long-term U.S. Treasury bonds, result in substantial estimates for ρ. For instance, Nordhaus and Boyer (2000) use an estimate of 3% for ρ in much of their work on climate change. Corporate bond rates or typical consumer interest rates can result in much larger estimates for ρ.

A different and altogether more troubling situation occurs if the same person exhibits different discount rates in various contexts. One can imagine here that a person might have different discount rates for automobile purchases, personal health effects, and long-run climate policies. Frederick, *et al.* (2002) discuss several "anomalies" in time preference research that indicate that discount rates vary based on what individuals are discounting. For example, studies have shown that individuals discount differently if the amounts in question are smaller or larger, gains or losses, delayed or expedited, or in increasing or decreasing sequences. In compiling data from 42 experimental and field studies performed since 1978, Frederick, *et al.* (2002) also found that there has not been any methodological progress in narrowing the range of discount rate estimates over time, likely indicating that the studies have not yet succeeded in isolating pure time preference from other factors influencing discounting. The way out of this dilemma is to follow the line advocated by Kopp and Portney (1999) who suggest conducting mock referenda in a survey context to capture the public's willingness to pay (WTP) for specific proposals as well as to provide information on their political feasibility.[4]

It is also possible to start from the reverse position and make an ethically-based prescriptive choice for ρ and derive the r for use in evaluating policies. Environmentalists have argued for years that the problem in evaluating government dam projects was the artificially low discount rate favored by the U.S. Army Corps of Engineers. However, they strongly support using low discount rates in evaluating climate change projects. This

[4] Recently researchers have started to use contingent valuation surveys to look at various aspects of climate change programs (*e.g.,* Cameron, 2005). Layton and Brown (2000) is perhaps the most directly relevant to the discussion here. They look at climate-related forest programs having impacts in 60 versus 150 years and show that WTP for the program with the 150 year time horizon is roughly 40% less than that for the 60 year program which is consistent with an (exponential) discount rate of less than 1%. Carson, *et al.,* (1994) compare WTP for an accelerated ecosystem recovery program for two treatments, one where natural recovery would take 50 years and one in which it would take 150 years, and find significant differences controlling for respondent characteristics with an implicit discount rate estimate around 2%.

highlights the fungible nature of basic preferences and discounting. While economists tend to steer clear of these sorts of value-based judgments, the extreme nature of issues like climate change and the potential total disregard of future generations have prompted some economists to make ethically-based arguments for setting discount rates.

Stern (2007) cites arguments put forward by Ramsey, as well as other prominent economists such as Amartya Sen and Robert Solow, to the effect that the only reason to discount future generations' welfare is uncertainty about the existence of those future generations.[5] This suggests that assuming the existence of future generations, one should use a pure time preference rate of zero for centuries-scale analyses, which is consistent with the idea that although the pure rate of time preference typically reflects impatience with respect to one's own consumption, when the time horizon is on the scale of hundreds of years, discounting becomes more a question of intergenerational equity.[6]

To operationalize this view, Stern (2007) sets ρ equal to .1 (avoiding the zero problem by taking account of a small positive probability that all human life on the planet could end, say by being hit by a large asteroid), θ to 1 and g to approximately 1.3 to get r equal to 1.4.[7] Much of the difference between the policy recommendation of the Stern Review to take immediate aggressive action on climate change and the more traditional

[5] The usual argument against this approach (*e.g.,* Montgomery, 1999) is that failure to use the market discount rate in policy evaluation can result in inefficiencies. Economists taking this view often argue that intergenerational distribution goals should be addressed through redistribution after efficient policies have been set. Nordhaus (1999) points out that setting artificially low discount rates selected for ethical reasons may result in inefficient policies for climate change and tends to result in greater temperature changes, and therefore greater environmental damages than a policy aimed explicitly at a target of climate stabilization.

[6] A zero discount rate implies that one cares about the welfare of someone a million years in the future as much as someone in the present. It also implies that the present generation should accept a subsistence level of living in order to invest in productive investments that will improve the well-being of future generations. This same logic then applies to each subsequent generation.

[7] Dasgupta (2008) points out an inconsistency in assuming a value for ρ close to zero and $\theta \sim 1$. Putting essentially equal weight on all future generations implies an almost infinite willingness to sacrifice current income to improve the well-being of future generations while using a value of θ that is close to one suggests the decision maker has little concern about the large degree of current cross-sectional inequality.

economic view of starting slowly and ramping up over time (associated with the work of Nordhaus) turns on the magnitude of r used (Dasgupta, 2007).[8]

Implicit in the formulation of the Ramsey Rule given in equation (1) is the notion that the preference parameters ρ and θ are invariant across time and type of policy. From a practical standpoint, g is usually assumed to be constant or very slowly changing. In actuality, there is considerable uncertainty over all components of the Ramsey Rule. Issues also arise as to how to determine the correct value of ρ and θ for policy purposes given that there may be a distribution of values for these parameters in the population of interest. Economists have long recognized that differences in discount rates have large implications for accumulating wealth. Further, they have found ways to empirically estimate the underlying distribution of discount rates which suggest that wealthier and more highly educated people have lower discount rates (Lawrance, 1991). Here, economists have generally accepted the market's aggregation over individual agents. These issues therefore become particularly vexing if the policies of interest involve goods not routinely bought and sold in the marketplace, so that reference to "market" rates cannot be made. As discussed below, heterogeneity of preferences provides some theoretical grounds for non-constant discounting.

Non-Constant Discount Rates

Recent research on discounting in the context of long-term environmental problems has focused a great deal on declining discount rates, where costs and benefits more distant in time are discounted at lower rates than nearer ones. Support for declining discount rates

[8] For highly critical critiques of the Stern Review, including its discounting assumptions, see Tol and Yohe (2006) and Nordhaus (2007). Quiggin (2008) provides a nice overview of the various controversies that have sprung up around the discounting approach used by the Stern Review and how they are linked.

comes in the form of working with non-constant or uncertain parameters for the Ramsey Rule, modifying the rule itself, or developing alternatives to the rule.

The Ramsey Rule yields a non-constant r if the values or associated uncertainty of any of the rule's three components are not constant over time. First consider θ. While a utility function that is logarithmic in consumption is convenient, there is no reason for θ to be constant. Its value may depend upon income levels and borrowing constraints.

The pure rate of time preference component ρ has received the most attention due to the long acknowledged empirical evidence (*e.g.,* Thaler, 1981) that people do not seem to engage in the sort of exponential discounting implied by (2).[9] Behavioral economists and psychologists (*e.g.,* Laibson, 1997) have argued that hyperbolic discounting, whereby discount rates are initially quite high relative to the exponential discounting case and then at some point fall to substantially below the constant exponential discounting rate, provides a much better fit to the available empirical data.[10] Proponents of hyperbolic discounting argue that it more accurately reflects observed discounting behavior and that the increased weight it places on benefits far into the future makes it more appropriate for evaluating long-lived environmental projects.[11]

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[9] Thaler (1981) found that the median prize that subjects would accept in order to delay an immediate $15 prize were $20 in one month, $50 in one year, and $100 in ten years, implying (exponential) discount rates of 345 %, 120 %, and 19 %, respectively.

[10] The question of whether hyperbolic discounting provides an adequate as opposed to simply a better approximation of what people do in practice still seems to be an open question. Rubenstein (2003) shows that some of the same experimental approaches that have been used to reject exponential discounting can also be used to reject hypotheses that logically follow from hyperbolic discounting.

[11] Sometimes a hybrid variant of hyperbolic discounting is advocated. Cline (1999), for example, proposes applying the conventional discount rate to the first thirty years of costs and benefits, a social rate of time preference involving shadow pricing, and a pure time preference of zero to all costs and benefits occurring in subsequent years. He suggests this as a way to counteract the "outright dismissal of future generations" due to the power of compound interest.

Historically, g has not been constant, as there have been periods of great productivity increases as well as periods of substantial income declines. Consumption growth looks very uncertain when looking hundreds of years into the future. Whether economies can grow indefinitely or are doomed to eventual stagnation is a long-standing debate on "limits to growth" (Weitzman, 1999). It is not even clear that growth will be positive hundreds of years into the future, let alone what the specific rate will be. One of the main issues that arises with climate change is the possibility of large scale negative feedback to the economy which could manifest through reductions in g over time. In most policy simulations these reductions are small and gradual. However, Weitzman (2009) has looked at the ties between low probability catastrophic events and discount rates, finding that this extreme uncertainty can make standard cost benefit analyses arbitrarily inaccurate.

If the growth rate is uncertain, then the Ramsey Rule needs to be modified to take account of this uncertainty, even if the two preference parameters ρ and θ are constant. The most straightforward case has log-normally distributed consumption with the growth rate g of consumption distributed $N(\mu, s^2)$, which is often assumed in asset pricing models. The Ramsey Rule can now be rewritten as:

(3) $$r = \rho + \theta\mu - \tfrac{1}{2}\theta^2 s^2.$$

As discussed earlier, one can attack this problem either by estimating the variability of r or by considering the properties of s.[12] The first approach was followed by Weitzman (1998 and 2001), who showed that when individuals have different constant discount rates the aggregate discount function is hyperbolic. To empirically look at the issue, he surveyed

[12] It should be noted here that the introduction of uncertainty introduces two more potential sources of heterogeneity. The first involves differences in beliefs concerning s while the second involves differences in risk aversion now that the growth rate is characterized by uncertainty.

a group of over 2,000 professional economists and asked them to provide their preferred values of r for discounting a long-term project. The discount rates in his sample are asymmetric and are well-fitted by a two-parameter gamma distribution. The mean discount rate is approximately 4% with a standard deviation of 3%. This leads to a 4% discount rate being approximately appropriate for the first 5 years, a 3% discount rate for 6 to 25 years, 2% for 26 to 75 years, 1% for 76 to 300 years and close to 0% after 300 years. Newell and Pizer (2003) estimate r using two centuries of U.S. interest rate data rather than just the post-World War II experience typically used and obtain a numerically similar result.

The second approach is examined by Weitzman (2009) who argues that there is deep uncertainty surrounding s. This turns out to be a fundamentally more difficult question: what are the properties of s when there is the possibility of catastrophic harm? The main practical difficulty with respect to climate change, which Weitzman calls the "Dismal Theorem", is that it is difficult to learn much about the high damage extreme right tail using existing data. This is because such events are rare and because humans have not yet experienced similar conditions. Given the possibility of catastrophes, Weitzman's analysis suggests that the use of a thin-tailed distribution (like the normal) for damages is inappropriate and shows that the situation is much better approximated by the use of a t-distribution with a low degree of freedom. Because s tends toward infinity in such a distribution, the implicit Ramsey Rule discount rate becomes increasingly small. Weitzman (2007) argues that Stern (2007) got things right but for the wrong reason. Its treatment of the Ramsey Rule in equation (1) was incorrect because the relevant equation is (3), and an appropriate treatment of the uncertainty surrounding climate change leads to the need for low discount rates, not the assumptions surrounding the pure rate of time preference ρ or the intertemporal rate of substitution θ.[13]

Gollier (2002a and 2002b) has also examined the impact of uncertainty on discounting. He finds that given prudence and decreasing risk aversion on the part of consumers, uncertain growth results in a declining socially optimal discount rate. In particular, he estimates that the discount rate for the medium term (defined as between 50 and 100 years in the future) should be no greater than 5% and that in the very long run (more than 200 years) the discount rate should be around 1.5% (Gollier 2002b).

Following on this work, Groom, *et al*. (2007) compare different discounting models' forecasting performance as a means to select a model for determining certainty equivalent rates. They also examine the impact of implementing different discounting models. They find that the statistical state space models, which are favored in terms of forecasting performance, result in a 150% higher present value of carbon emissions reduction than a standard constant discount approach. Hepburn, *et al*. (2009) build on the aforementioned Newell and Pizer (2003) work to apply two methods to estimate four countries' social discount rates. Consistent with other findings, they show that the regime-switching model which fits best with past interest rate behavior also corresponds to fairly rapidly declining certainty equivalent discount rates.

Alternative approaches that take ethical considerations as starting points have also received some attention. Chichilnisky (1996 and 1997) builds on two basic axioms for sustainability that imply there should be neither dictatorship of the present over the future nor of the future over the present. Working through various implications of this, she shows

[13] See Nordhaus (2009) for a critique of Weitzman's Dismal Theorem.

that in order to satisfy these axioms the discount rate must decline asymptotically to zero in order for a solution to exist (Chichilnisky 1997). The welfare function she proposes for evaluation takes the form of a weighted average of a discounted utilitarian problem's objective function and the undiscounted limiting utility. In a similar vein, Li and Löfgren (2000) develop a model in which a weighted average of the value functions of a conservationist (with a constant discount rate of zero) and a utilitarian (with a constant discount rate greater than zero) is used to evaluate a project. This model also leads to a declining discount rate, and is shown to have a stable steady-state solution.

It follows that the case for declining discount rates can be made on the basis of empirical evidence, theoretical grounds and basic ethical arguments (see Groom, *et al.* (2005) and Pearce, *et al.* (2003) for comprehensive examinations of the issues involved in using declining discount rates.) Henderson and Bateman (1995) show that declining discount rates are already implicitly in use in public policies. In particular, there is a pattern of governments using unusually low discount rates in evaluating intergenerational projects. However, discount rates that are time varying for *any* reason can be problematic from a policy perspective because of time-inconsistency, and the possibility of wanting to reverse a previous action even though no other aspect of the situation, such as the available information set, has changed (Strotz, 1956; Heal, 1998). A policy implemented today that is based on a relatively low discount rate for distant future periods may not be adhered to when those future periods arrive and the policy is reevaluated at a higher near-term discount rate. As Horowitz (1996) puts it: "future regulators will not want to follow the current regulator's optimal plans, even when the current regulator has perfect foresight and there is no uncertainty." One way to address this issue is to set up some sort of commitment, such as making investments in capital-intensive pollution control equipment like scrubbers on power plants so that future decision makers cannot easily back out of the investments made in earlier periods.

When dealing with long-lived problems like climate change, the simple task of performing cost benefit analyses to evaluate policies becomes very complicated. Application of the standard Ramsey Rule requires parameters for which there is no market data given the time horizons. Using constant standard discount rates results in a complete disregard for the far-distant future and is not necessarily consistent with the way people really discount the future. Declining discount rates may solve many of these issues and have some theoretical foundations, although the issue of time-consistency remains a concern. Consensus on a robust approach to discounting will significantly help with the credible evaluation of long-lived environmental problems. However, the successful implementation of these policies will also hinge on the ability to predict agents' responses to different incentives in making intertemporal purchasing and consumption decisions.

Purchasing Consumer Durables: The Achilles' Heel of Energy Conservation

If the analysis of preventing long-term climate change is mired in a debate over how low the discount rate should be, the on-the-ground implementation of steps to combat climate change is bogged down by consumers and firms making decisions regarding the energy conservation attributes of appliances, automobiles, building improvements, and machines *as if* they have very high discount rates.[14] Jaffe and Stavins (1994) referrto this

[14] The "as if" qualification here is important because much economic analysis proceeds as if the only thing underlying the choice of whether to adopt an energy saving technology after the readily observable cost components were taken into account is the consumer's implicit discount rate the consumer for making intertemporal tradeoffs. Many aspects of this approach have been questioned.

as the paradox of the energy-efficiency gap. It lies at the heart of the contradictory bottom-up versus top-down estimates of effectiveness of policies to improve energy efficiency.

The bottom-up approach uses a standard social discount rate (3% to 7%) to look at life cycle financial implications of an action, like purchasing a new water heater to replace an older model. It predicts that consumers will purchase the new water heater if the net present value of the action is positive. The top-down approach looks at penetration rates over time as a function of the cost of an appliance and its associated energy. Consistent with consumers having very high discount rates, it predicts dramatically less adoption and suggests that adoption rates go up with lower appliance prices and higher energy costs. Economists favor the top-down approach because it models actual behavior. By construction, forecasts based on the top-down approach tend to be reasonably accurate. But advocates of the bottom-up approach, including engineers and technology advocates, often have the attention of policymakers because they sing the siren song of energy conservation on the cheap. In contrast, the economist's story requires either subsidizing new energy technology or increasing energy prices to increase adoption rates.[15]

The pioneering economic study on appliance adoption and implicit discount rates was Hausman (1979) who looked at air conditioner purchases. Using data on sample household air conditioner models and utility bills, he estimated an implicit discount rate of about 25% per year on household purchasing decisions. He also found that discount rates varied negatively with income, ranging from 5% to 89% for the highest and lowest income categories, respectively.[16]

[15] There have, of course, been some efforts to reconcile the main potential sources of the divergence between the bottom-up and top-down approaches (*e.g.,* Shama, 1983; Koopmans and te Velde, 2001).
[16] Damon (2007) finds a 5% discount rate when looking at a recreational boat hull coating replacement decision using stated preference data with a very high income sample.

With the energy crisis of the early 1980's, considerable attention has become focused on the appliance adoption issue. Train (1985) surveys studies that estimate discount rates involving heating systems, air conditioners, refrigerators, water heaters, automobiles, and building efficiency upgrades. The studies take a variety of approaches to estimating discount rates and yield a broad range of results. Air conditioner discount rates range from 3% to 29%, while refrigerators are discounted at rates ranging from 39%-100%. Fourteen of the studies Train (1985) reviews also examine the relationship between income and discount rates. In all instances, higher income levels are associated with lower discount rates. Subsequent studies continue to show similar results for a wide range of consumer products (*e.g.,* Sultan and Winer, 1993; Dreyfus and Viscusi, 1995). Winer (1997) argues that consumers are likely to have discount rates that differ both across product classes and attributes of products.

Policy analysis is greatly complicated if discount rates vary with commodities and income. Resistance to incorporating this variance into analyses has encouraged a deeper examination of what lies behind the discount rates estimated by studies in the adoption of energy efficient technology. One key factor is that of liquidity constraints. Almost all of the economic models used to estimate implicit discount rates assume that individuals have unlimited access to credit at prevailing interest rates. This assumption is also built into engineering lifecycle analyses. However, this is clearly not the case. Lower income individuals may not be able to borrow much at all and likely pay significantly higher interest rates when they do. Credit card rates for consumers with poor credit are often in the 18% to 24%, range and other sources of credit run even higher. Thus, higher implicit discount rates for lower income individuals may not reflect fundamental differences in preferences but simply the higher interest rates available to them and their lack of liquidity.

The discount rate-education relationship suggests that the appearance of high discount rates may be driven in part by information asymmetries/failures whereby many consumers do not have the same information used in engineering estimates of likely long-run cost reductions or have difficulties making the necessary calculations. Again, the economic models used to estimate the implicit discount rates and the engineering lifecycle models assume that consumers have full information. Closely related to information issues are uncertainties over future energy usage or prices, the possibility of adverse selection, marginal cost-induced changes in use patterns and the concept of the full transaction cost associated with acquiring the commodity that may be considerably larger than its nominal price (Howarth and Sanstad, 1995). The key implication of all of these factors is that the underlying model used to estimate the discount rate, though consistent with observed behavior, is incorrect.

The particular source of difficulty with a model can often have large policy implications because they tend to get incorporated in the discount rate estimate (Metcalf and Rosenthal, 1995).[17] For example, in deciding whether to buy a hybrid car or the comparable standard gasoline model, a consumer may base her decision on expectations of uncertain factors like future gas prices, the lifetime of the vehicle, the realization of reported mileage rates, and the prospects of even more fuel efficient vehicles being available next year. If she expects to drive 15,000 miles per year, believes the

[17] Some of these effects act through the usual desire to retain flexibility of action in the future and avoid irreversible investments. In this sense, the promise of much better technology around the corner can freeze adoption of currently available technology which is a large improvement over a household's existing technology. Dixit and Pindyck (1994) provide an extensive discussion of investment under uncertainty.

government's reported difference in mileage of 13 miles per gallon between the two models, sees an initial sticker price cost difference of $5,000, and expects gas prices to be $2 per gallon on average, then she will expect to recover her initial extra outlay for the hybrid model after about 15 years. However, if she expects gas to cost $5 per gallon on average, then the additional initial costs will be recovered in only 6 years.

Various adjustments have been made in the literature to address these sorts of issues. For instance, Kooreman (1995) focuses on the uncertain lifetimes of durable goods, arguing that discount rate estimates that do not account for these uncertainties may be substantially biased. As an illustration, Kooreman incorporates a lifetime uncertainty adjustment, recalculates the estimated 26% discount rate from Hausman (1979) to be 19% and argues that this new discount rate estimate is in line with consumer credit costs.

A deeper problem is the divergence between the lifecycle engineering cost saving estimates and those actually experienced by consumers who adopt the energy saving technology. Looking at attic insulation investments, Metcalf and Hassett (1999) found actual returns of only about 10% versus engineering-estimated returns that suggested about a 50% cost savings. Thus, it is not unreasonable for consumers to be skeptical of energy savings claims. Use of lower cost savings estimates can, of course, result in dramatically lower estimates of implicit discount rates.

In firms (and households), structural problems can occur if budgetary authority over different parts of the operation is given to different agents. The classic example is that of a maintenance operation refusing to replace burnt out low efficiency light bulbs with only marginally higher cost high efficiency light bulbs (which would quickly pay for the cost differential with lower electricity bills) because maintenance pays for the new light bulbs while another part of the operation pays for the electricity. As long as the two groups are independently judged on their budgets, there is no reason for maintenance to put in the high efficiency light bulbs, and the transaction cost involved in either having the agent paying the electric bill put up money or a higher authority in the company mandating the change can be large relative to the cost savings. This firm would appear to have a very high discount rate based on the choice of light bulbs.

Motivated by early work that showed that the payment vehicle used could influence estimates of WTP (Mitchell and Carson, 1989), there is a strand of stated preference literature that looks at the nature of the stream of payment obligations which is critical to adoption decisions. Kahneman and Knetsch (1992) compare a single lump sum payment to annual payments for five years for a toxic waste facility in British Columbia and find that the median lump sum payment ($20) is equal to the median annual payment.[18] They argue that their result suggests that people ignored the difference in the payment obligation because they were not capable of discounting. The claim has been controversial for several reasons. The short question asked by Kahneman and Knetsch does not resemble the standard detailed CV survey (Smith, 1992). Further, Carson, *et al.* (1992) point out that with toxic wastes, annual payments ensure provision, allaying the public fear that companies will walk away from their obligations. They look at a situation where payment duration is less likely to be tied to provision, installing and operating a scrubber on a power plant in Columbus, Ohio. Median WTP for the one-time lump sum payment is twice that of the annual payment clearly rejecting ($p < .01$) that respondents do not distinguish between the two payment streams, but still suggesting high discount rates or borrowing constraints.

[18] Mean WTP is $141 for the lump sum payment versus $81 for the annual payment but the authors argue that the mean estimates are strongly influenced by a small number of outliers.

From a practical standpoint, requiring initial connection costs to be paid as a single lump sum fee versus including this cost in monthly charges can have a large impact in developing countries with respect to the fraction of households who decide to hook up to electricity, pipe water, and sewage. This strand of the literature continues to evolve with Kim and Haab (2009) providing a recent review. They point out that researchers on this topic have made potentially unwarranted assumptions about time separability in the utility function for tractability and have assumed that error variances across different temporal treatments are the same, which is also unlikely to be justified in many cases.

The open question from a policy perspective is what should be done if implicit discount rates appear to be sufficiently high such that societal objectives for reducing energy consumption are unlikely to be met? The two competing poles are to: (a) respect the public's preferences and assume that they are better informed than the experts about their own particular situation or (b) force people to adopt energy saving technology under the guise that a high implicit discount rate represents either a mistake on the public's part or something that should be ignored for the greater social good. Most economists fall somewhere in the middle. They are willing to concede that there are likely to be substantial informational deficiencies where the government (and industry) can play a useful role. They also believe that finding ways to relax credit constraints may be important for key segments of society. On the other hand, they believe that the bottom-up engineering approach favored by technology optimists and many decision makers will provide poor estimates of what is likely to actually happen on the ground and form a poor basis for policy analysis. Gillingham, Newell and Palmer (2006) provide a comprehensive review of these issues.

The Temporal Pattern of Reducing Risk to Life

The previous sections covered policies that deal with climate change and energy efficiency which are closely tied to traditional notions of production and consumption and their related ecosystem feedbacks. Many environmental policies, however, are explicitly directed at reducing risks to life. Moore and Viscusi (1990) provide a useful motivating example. A particular pesticide regulation can be aimed at reducing acute exposure to farm workers or it can be aimed at reducing pesticides in the food and water supply. In the first case, any health effects prevented tend to be immediate while in the latter case, the health effects prevented may occur decades later.

Moore and Viscusi (1990) lay out several approaches (and their key assumptions) that allow the calculation of discount rates from observed wage rates using a hedonic pricing approach. These assumptions revolve around worker knowledge of risk levels and timing on different jobs and selection into jobs based on risk tolerance. Effectively, these assumptions also tend to move away from a static concept of maximum WTP to save a statistical life to the dynamic concept of saving life years.[19] Different approaches yield discount rates ranging from 2% to 12%.

While the hedonic pricing approach has remained the most popular one for looking at the value of statistical lives related to immediate work-related risk, attention has largely shifted to survey-based contingent valuation (CV)/stated preference (SP) approaches (Mitchell and Carson, 1989; Bateman, *et al.*, 2002) for dealing with non-work related and long-term risks. This shift in focus is largely due to the conceptual drawbacks of the

[19] WTP to save a statistical life is simply the average monetary amount the public is willing to give up in order to obtain a risk reduction of z (*e.g.,* 1/10,000) multiplied by 1/z. The concept of a statistical life is based on the notion that many programs developed to save lives do not save specific lives but rather reduce the risk of the loss of life in the population of interest by small amounts.

hedonic wage approach for valuing risks to either children or the elderly who do not have current wage rates but are the focus of much government policy (Dickie and Ulery, 2004). It is also due to the fact that the hedonic pricing approach assumes that people are aware of: (a) the time profile of mortality risks on their current jobs, (b) the time profile of mortality risks on competing jobs, and (c) that the time profile of morbidity risks on their current and competing jobs is orthogonal. Assumption (a) has long been seen as dubious, although it is possible to make a reasonable argument that objective indicators of risk are strongly correlated with subjective measures and serve as a valid statistical instrument. Assumptions (b) and (c) seem untenable given recent work from stated preferences studies (Bosworth, Cameron, and DeShazo, forthcoming) which suggest that morbidity and mortality effects are substitutes and information about risk levels is often poor.

The first study to use a CV survey to look at an explicit long-term health risk was Mitchell and Carson (1986), which examined WTP to reduce trihalomethane (THM) concentrations in drinking water. THMs are a class of low level carcinogens that have been shown to cause urinary tract cancer with a latency period of over twenty years. The estimated value of a statistical life from the study is substantially lower than those obtained from hedonic wage studies. Initially, this puzzled many economists since they thought that CV surveys tended to overestimate rather than underestimate. However, Carson, *et al.,* (1996), through a large meta-analysis, showed that on average, estimates from hedonic pricing studies tend to be higher than comparable estimates from CV studies. Further, the estimated value of a statistical life was quite reasonable when compared to the range of consensus values from hedonic studies if it was assumed that people had discounted their

WTP with rates similar to those used by the government for policy evaluation (Carson and Mitchell, 2006).

In a pair of related and highly influential papers Cropper, *et al.* (1992; 1994) explored tradeoffs where respondents chose between programs that saved different numbers of lives in different years.[20] There were three striking results in this work. The first was that the pattern of implicit discount rate estimates was more consistent with hyperbolic discounting, which was just beginning to be empirically explored in the economics literature (Thaler and Loewenstein, 1989), than exponential discounting, with discount rates declining from approximately 17% at 5 years to under 4% at 100 years.

The second result was that there was considerable heterogeneity in the responses and a belief structure that made uncovering discount rates problematic. For instance, Cropper, *et al.* (1994) found that approximately 10% of the respondents always chose a present-oriented program regardless of how many lives the future program would save. When asked why, roughly 10% believed that the future is sufficiently uncertain that it was impossible to make commitments to future policies, while over 20% believed technological progress would make it likely that more people in the future could be saved than the survey implied. Neither of these two beliefs is inherently irrational but they are inconsistent with the assumptions under which the implicit discount rate was estimated.

[20] These and most of the other papers in the environmental economics literature have followed the approach put forward by Horowitz and Carson (1990) of fixing the number of (statistical) lives saved with the current period policy option and then randomly assigning respondents alternative policies that save different numbers of lives in the future. One can then determine the implicit distribution of discount rates in the population assuming an exponential discounting rule. Doing this for different time periods relative to the present allows one to determine whether the implied discount factors at each time period are (statistically) consistent with exponential discounting (Horowitz, 1991). Harrison, Lau and Williams (2002) conduct a large field experiment using a lottery approach for real money payoffs in Denmark to estimate the distribution of discount rates in the population using a variant of this basic approach. They find discount rates which lie in a plausible range but which are higher than those generally used for policy analysis. They also find that discount rates are higher for periods less than twelve months than for longer time horizons, out to three years, and that higher income people have lower average discount rates.

Thus, individuals who do not believe the underlying claims in a situation, whether it is the premise of a survey or the claims made on behalf of a product, could even appear to have infinite discount rates.

The third result of note was that discount rates were estimated to be higher for older people, which advanced the possibility that older people placed a lower value on a statistical life, something termed a "senior discount" that has occupied considerable attention from subsequent literature and policymakers.[21] For example, using a large CV survey done in Taiwan, Hammitt and Liu (2004) look at the role of disease type and latency on WTP to reduce environmentally-driven chronic degenerative diseases. They find WTP to avoid cancer to be about a third larger than otherwise similar non-cancer diseases and estimate an average implicit discount rate of 1.5% for a 20-year latency period. Alberini, *et al.* (2006) use data from two CV surveys conducted in Canada and the United States to show that substantially delaying the time at which a risk reduction occurs by 10 to 30 years can reduce WTP by more than 60% for respondents aged 40 to 60. They find implicit discount rates ranging from 3% to 9% for Canada and 1% to 6% for the United States depending on the treatment. Krupnick (2007) reviews this literature and concludes that while the larger studies using better statistical techniques tend to find age-related effects, where older people have lower WTP, there is no robust useful policy finding, in part because other factors seem to play a large role.[22]

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[21] Canada has been using a discount rate of 25% for statistical lives for those over 65, the European Commission recommends using a value that declines over time, and the U.S. Environmental Protection Agency, after considerable controversy, has decided to use an age invariant rate (Aldy and Viscusi, 2007).

[22] Aldy and Viscusi (2007) provide a similar review of the hedonic wage literature and come to some of the same conclusions. They contend that theory and empirical evidence favor some temporal variation in the value of a statistical life year, but that the relationship can be complicated. Indeed, they find some support for an inverted U-shaped relationship between discount rates and age. But there are other factors also at work such as people becoming more risk averse as they grow older.

Like other areas of discounting behavior, studies of WTP for reductions to life risks reveal that individuals' discounting preferences are influenced by their beliefs, vary with different types of risks (or goods), and are inversely related to time remaining (or wealth). Understanding these types of preferences will help predict the level of public support for different types of environmental policies relating to life risk reductions. Before we examine how discount rates affect policymakers as they decide which policies to implement, we look at discounting in common property resources as an example of market failures leading to extreme discounting behavior that can be corrected by effective policies.

The Curse of Infinite Discount Rates: Common Property Resources

There are a number of natural resource sectors with discount related common access management problems including fisheries, common groundwater aquifers, hunting and trapping competitions that have driven animals to extinction, and forests in developing countries where expropriation has led to premature deforestation.[23] To examine the role of discounting in common property resources, consider a fishery in a contained area such as a very large lake. The quantities of interest are fish population size, number of fish caught, fish prices (which are assumed to be exogenous), and effort put into harvesting the fish. This effort is a function of factors like the number of fishing vessels, type of equipment and number of hours spent fishing. The standard biological objective is a maximum sustainable yield (MSY), with a simple growth function like the logistic:

$dS/dt = gS(1 - S/K)$,

[23]A major reason advanced by Saddam Hussein for his invasion of Kuwait was that Kuwait was pumping the oil field that straddled the border of the two countries at a quicker rate than Iraq had wanted.

where S is stock size, g the growth rate, K the carry capacity, and no stochastic shocks are assumed to occur. MSY is achieved when S = K/2 and annual harvest is gK/4.

The standard bioeconomic model (Clark, 1976) recognizes that one can catch more fish now than the MSY, put the money in the bank earning a rate of interest r, but catch fewer fish in the future. The higher the interest rate, the lower the fish stock that maximizes the net present value of rents from the fishery. However, if the marginal cost of fishing increases as fish stocks fall, the economically optimal catch may be less than the MSY.[24]

If a fishery has a sole owner who expects to have continued control over the resources, the catch should be set to maximize the discounted net present value of all future net returns (Scott, 1955). The more fish that are harvested now, the smaller the population that remains, the fewer fish will be available for harvest in future periods, and the more expensive it will be to yield the same catch in future periods given the usual diminishing returns to scale assumptions. In maximizing net present value, the lower the discount rate, the more willing the owner will be to forgo current harvest opportunities for higher future yields. At the optimal solution, the marginal benefit of catching one more fish today equals the discounted present value of the marginal future loss associated with that extra catch (Clark, 1976). Thus, with a discount rate of zero and no dependence of fishing cost on stock size, a sole owner optimizes by setting fishing levels to the MSY.

[24] After a certain level of effort, it is also often the case that each additional boat that enters a fishery to compete for fish lowers the amount of fish available in that fishery, thereby raising the costs of the other players (Clark 1976). This increase in costs constitutes what is known as a congestion externality, a social cost not borne by the agent who has caused it. These congestion externalities have ties to discounting and can be seen as a type of coordination failure but will not be considered further here.

This result does not hold if multiple boat owners are competing for the fish. If a boat owner does not pay rent to fish or bear the social costs of his activities, he is incentivized to harvest as much as possible before others beat him to it (Gordon, 1954). He maximizes economic returns by harvesting as much fish in the immediate term as economically viable, up to the point where marginal cost equals the price per unit. This effectively ignores the value of leaving the stock to grow, and it is straightforward to show that this behavior is equivalent to a sole owner with an infinite discount rate (Clark, 1976).

In response to this open access problem, governments regulate fisheries by setting total allowable catch (TAC) limits for many commercial fisheries. This solves the biological problem of preventing the fish stock from being decimated but does not solve the problem of open access driving economic rents in the fishery to zero. Boats race to catch the TAC, at which point the fishery is closed down. In extreme cases, the entire TAC may be caught in one or two days, leaving a large amount of capital stock idle for much of the year. The way out of this dilemma is to give or sell tradable property rights known as individual transferable quotas (ITQs) to specific fractions of the TAC. First, the TAC is set using updated information on the condition of the fishery and the social discount rate. Second, the ITQ system allows individual fishing vessels to behave in accordance with their true discount rates, capturing lower costs by stretching out their fishing efforts over longer periods of time instead of catching as many fish as quickly as possible. Grafton, *et al.* (2006) provide an overview of most of the key fishery policy issues and the role discount rates play.

Fisheries provide a good example of how individual agents' intertemporal choices, (reflecting extreme discounting) under unregulated market conditions, can be shaped by policies. However, achieving those efficient solutions requires political support. In the next section we explore the incentives motivating policy makers' discount rates.

Politicians, the Public and the Possibility of Different Discount Rates

The standard long-standing theoretical model for the actions of political representatives is the median voter model whereby politicians pursue the preferences of the median voter in the political district they represent (Black, 1948).[25] This implies that an elected official's discount rates should match the median voter's discount rate. As such, discount rates can vary by district or region. It seems clear that voters in states such as California, which is pursuing environmental policies requiring long-term investments to reduce its greenhouse gas emissions, probably have relatively low discount rates.

The actual making of public policy decisions often diverges from what might be considered ideal. The public elects representatives to represent their interests, but these political representatives do not always function as unbiased agents aggregating public preferences. Rather, the voting records of political representatives typically reflect both the public's preferences and their own ideologies (Carson and Oppenheimer, 1984; Kalt and Zupan, 1984).[26] Ultimately, it is these political representatives who vote on policy proposals, determine discount rates for policy analyses, and develop regulations or other incentives to counteract the negative impacts of a divergence between the high discount rates used by consumers and firms and the much lower discount rate(s) that are thought to be socially optimal. A key question then is: what are elected officials' discount rates?

[25] A substantial literature has grown up around Black's fundamental insight that makes modifications for party structure and ties between issues. The general result that reelection chances are maximized by moving toward the median voter (keeping campaign financing constant) is fairly robust to these modifications.

[26] This ideological deviation can reflect personal convictions or pecuniary gains and reduces the representative's future election chances.

In analyzing the political process of a sequence of votes, Kramer (1977) describes "myopic" behavior on the part of politicians. He argues that "many observers have noted the relatively short horizons of elected officials and the fact that their preoccupations rarely extend beyond the next election." A political representative concerned about reelection has an incentive to champion policies with outcomes that can be realized in time for the next election rather than longer-term policies. This kind of behavior is akin to having a relatively high discount rate.

Myopic behavior will be especially pronounced in elected officials who expect to win or lose the next election by a narrow margin of votes. On the other hand, a key insight of the literature on estimating the ideology of individual political representatives is that representatives in "safe" districts have more scope for exercising their own ideology. Politicians who reliably expect to win reelection by a wide margin or who decide not to run for reelection (whether voluntarily or due to term limits) should act more consistently with discount rates dictated by their personal values. Tien (2001), for instance, looks at voting behavior by members of the U.S. House of Representatives who voluntarily retire and shows that they exhibit larger deviations from the expected voting patterns for their districts than those running for reelection. It is an open question as to whether such officials tend to favor longer term projects than those facing close reelection contests.[27]

Just as politicians can develop policies to shape individuals' behaviors in different settings, institutional rules (*e.g.,* U.S. Office of Management and Budget, 1992) can be formulated to address some of the issues above. Implementing procedures that require the application of specific discount rates for specific settings or mandating a certain level of

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[27] Because political representatives are almost always wealthier and better educated than the median constituent of their district, one would expect them to hold lower discount rates.

transparency for the analyses performed in support of proposed policies can go a long way in countering some of the more self-serving activities in which politicians may be tempted to engage. And while politicians are, as individuals, often the ultimate decision-makers, we come full circle by emphasizing the importance of the work described in the previous sections. It is the role of social scientists, after all, to develop clear and consistent evaluation methodologies that are founded on solid theories and evidence and that can help guide politicians in making effective policy decisions that serve the public interest.

Concluding Remarks

Timing decisions are affected by many factors other than discounting. Liquidity constraints, beliefs, structural problems in firms, risk aversion, and attitudes toward different commodities are examples of factors that may affect choices by individuals and firms with respect to timing. Whether using market-based or stated preference data, the inability to isolate discounting preferences from other factors makes it difficult to obtain definitive discount rate estimates. However, some consistencies do emerge from the data.

Discounting behavior varies across individuals and commodities. Wealthier individuals tend to have lower discount rates, probably due to their higher capital, better credit access, and possibly superior or more advanced education. Discount rates appear to decline as time periods increase, consistent more with hyperbolic discounting than the standard exponential model with a constant discount rate. However, even if each person held a constant discount rate, differences in those rates across individuals will result in a declining aggregated discount rate (Weitzman, 2001).

These results and others raise serious issues for environmental policy analysis. On the one hand, there are those who believe that we can address issues like climate change largely through technology. However, technology adoption rates predicted based on standard discounting methods have been too high. Analyses that incorrectly rely upon assumptions like complete information and lack of liquidity constraints run the risk of overestimating our ability to mitigate climate change through technology adoption.

Likewise, applying standard discounting to benefit-cost analyses of centuries-scale policies can result in our undervaluing future costs and doing too little. While economists often prefer to rely on market data to estimate aggregate parameters, there is no market data on which to base discount rates for hundreds of years into the future. There is, as of yet, no clear consensus on how to approach such problems. Although standard discounting has the potential to discount enormous future amounts to unacceptably insignificant levels, discounting is nonetheless a powerful tool in identifying efficient outcomes.

Thus the problems of environmental economics push the limits of discounting. Whereas pure rate of time preference usually reflects impatience, this perspective no longer applies when applied to time frames of 200 years. How can one be impatient with respect to something that will occur decades after one is no longer alive? We are instead dealing with questions of intergenerational equity, in the face of a great deal of uncertainty.

As new ideas emerge on how to best evaluate policies that address these long-lived environmental problems, the final decisions on which plans to pursue lie in the hands of our elected officials. It is the discounting approach that is most palatable to our policymakers that will ultimately be used to evaluate policy decisions. As with the fisheries, incentives can be put in place to encourage the public to behave as if it has a lower or higher discount rate. However, it is not only discounting, but also the myriad other factors that drive all the little individual decisions on what refrigerators, light bulbs, and cars to buy that will determine how effectively environmental issues with long-term consequences are addressed in the end.

Table 1

Present discounted value of $10 trillion dollars			
discount rate (percent)	10 years in the future	30 years in the future	200 years in the future
0.0	10,000,000,000,000	10,000,000,000,000	10,000,000,000,000
0.5	9,512,294,245,007	8,607,079,764,251	3,678,794,411,714
1.0	9,048,374,180,360	7,408,182,206,817	1,353,352,832,366
3.0	7,408,182,206,817	4,065,696,597,406	24,787,521,767
5.0	6,065,306,597,126	2,231,301,601,484	453,999,298
7.0	4,965,853,037,914	1,224,564,282,530	8,315,287
10.0	3,678,794,411,714	497,870,683,679	20,612
12.0	3,011,942,119,122	273,237,224,473	378

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