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Individuals Time Preference and Social Discounting: A Survey and a Meta-Analysis

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INDIVIDUAL TIME PREFERENCES AND SOCIAL DISCOUNTING: A SURVEY AND A META-ANALYSIS

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Abstract: The choice of an appropriate social rate of discount is critical in the decision-making process on public investments. In this paper we briefly review the literature on social discounting, and address in particular a recently growing field of related research, that is, individual time preferences. An explicit consideration and analysis of the behaviour of individuals regarding the concept and the use of an appropriate social discount rate are essential for balanced decision making in the public sector, for example, in the field of resource or environmental policy. It is noteworthy that the empirical literature shows considerable variation in the estimated values of individual discount rates. Therefore, we present here the results from a meta-analysis conducted over more than 40 experimental and field studies which report individual discount rate estimates. We find in our research that the experimental design of a study has a decisive impact on these estimates, and conclude that our meta-regression function has a low transfer value.

Keywords: Social Discounting, Individual Time Preference, Meta-Analysis

JEL Classification Numbers: H43, Q58, R42

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1. Introduction

Policy making is based on decisions under uncertainty, including the economic assessment of the demand and consumption of scarce resources over time, which prompts the need to evaluate government interventions by explicitly considering the temporal dimension of public decisions. The construction of a road, for example, incurs investment costs (that start several years before the actual project implementation), while it creates flows of socio-economic costs and benefits that appear all along the project life cycle. The history of economic evaluations of public projects has shown that cost-benefit analysis may then be a proper tool.

If policy makers take an investment decision by employing the Net Present Value (NPV) rule, then they need to utilize a social discount rate meant to capture the opportunity costs of delaying current consumption in order to make the investment concerned possible. According to a standard formulation of Squire and van der Tak (1975), the social discount rate should reflect *“value judgements by the government [which] determine[s] the weight to be given to future consumption relative to present consumption”* (p. 26).

However, the ordinary use of discount rates in economic research remains controversial. The transfer of the concept of discounting in business investment (typically used for short-term productive sector projects with tangible marketed outputs) to the appraisal of often long-term, system-wide and normally highly uncertain effects has, over the years, prompted considerable discussion among economists. This discussion is driven by the fact that, while the private sector has tangible alternatives for the choice of the appropriate discount rate (such as the cost of acquiring capital), the social discount rate does not have a clear or unambiguous market-based foundation.

To cope with the above issue, a number of methods have been proposed in the early economic evaluation literature (Boardman et al. 2001):

- *Using the marginal rate of return on private investment.* Harberger (1969), for example, argued that public investment should outperform private investment in order to be financed by tax revenues; thus the rate of return on private investment is the opportunity cost faced by society when financing (through taxes) government capital expenditure.
- *Using the weighted social opportunity cost of capital.* Sandmo and Drèze (1971), among others, claimed that public investment crowds out private investment, thus producing the need to account for the opportunity cost of the use of resources used in the public project and which could be used by the private sector.
- *Using the shadow price of capital.* Eckstein (1958) and Bradford (1975) proposed to convert gains or losses resulting from an investment project into consumption equivalents. The proper conversion rate is then the shadow price of capital.

In recent years, a growing body of literature has considered the pure rate of time preference of individuals as a fundamental ingredient in the definition of the discount rate to be used in appraising public actions. This alternative originates from critical observations made by a number of well-known scholars in the field of cost-benefit analysis¹ for whom individuals entering a social contract commit themselves to increase their total savings to invest in projects that produce net benefits for future generations. This behaviour results in a collective rate of investment higher than the individual (i.e. private) preference rate. If this “isolation paradox” holds, then the discount rate for cost-benefit analysis should be below the private rate of return on savings, and reflects to some extent the individual time preference.

In this vein, the traditional Ramsey formula (Ramsey, 1928) captures both the pure time preference and other, more economically-oriented elements such as the expected growth rate of the economy and the risk associated with the relative uncertainty over future outcomes. According to Evans and Sezer (2004), the Ramsey formula for the calculation of the social time preference rate (*stpr*) can be approximated by the following simple expression:

$$stpr = r + \mu g \quad (1)$$

where r is the individuals' pure time preference; μ is the absolute value of the elasticity of marginal utility of consumption; and g is the projected long-run annual growth of *per capita* real consumption.

It is clear that the estimate of value of the *stpr* depends critically on:

- a) an appropriate framework for defining r ;
- b) the assumed functional form of the utility function and its data approximation;
- c) uncertainty about future economic conditions.

In recent studies (Evans and Sezer, 2004; Evans, 2004), in the absence of strong empirical evidence, a 1-1.5% rate of pure time preference was suggested for six OECD countries (Australia, France, Germany, Japan, the UK and the USA) in order to calculate the *stpr*.

Recognizing the relevance and potential of individuals' pure time preference as a basis for evaluation analysis, we offer in this paper a brief review of the empirical literature on the estimation of r on the basis of experiments conducted on individuals, or based on inferences from their behaviour². In addition, a quantitative analysis is carried out in order to highlight the

¹ See, for instance, Baumol (1952), Eckstein (1957), Marglin (1963), and Sen (1961).

² See Cowell and Gardiner (1999), Evans (2004) for a description of the methods for estimating e .

determinants of the pure time preference rate on the basis of a meta-analytic approach. We will show that the empirical estimates of the individuals' time preference are decisively influenced by experimental design, and that country- and time-specific variables have less explanatory value. This implies that our meta-regression, though useful in explaining a part of the variability of estimates, has a very low transfer value potential. This, in turn, means that, when estimating the social discount rate for a given country, special attention should be devoted to the estimation of individual time preferences to be supported by extensive field surveys.

The paper is organized as follows. In Section 2, we review the relevant literature on the time preference of individuals; we give special attention to what, in the literature, is commonly called “anomalies”. Sections 3 and 4 are a review of the early and contemporary debates on social discounting and the recent literature on environmental policy implications of different discount structures and/or rates respectively. A meta-analysis of empirical individual discount rates found in applied studies is offered in Section 5, while in Section 6 we provide an interpretation of our analysis and suggest pathways for future research.

2. Individual time preference

When studying the individuals' time preference, we have to assume implicitly how psychology shapes human judgement, in this case, over time. Samuelson (1952) and Koopmans (1960) may be considered as the fathers of the Discounted Utility (DU) model, even though the historical origins of this approach can be found in early works of Eugen von Böhm-Bawerk, John Rae and Irving Fisher (Frederick et al., 2002). In the DU model, an intertemporal utility function,

$U^t(c_t, \dots, c_T)$, is assumed to depend on consumption profiles (c_t, \dots, c_T) over a certain time horizon t, \dots, T . The functional form describing a person's intertemporal utility function is:

$$U^t(c_t, \dots, c_T) = \sum_{k=0}^{T-t} D(k) u(c_{t+k}) \quad (2)$$

where $D(k) = \left(\frac{1}{1+r} \right)^k$, and r is the discount rate (i.e. the pure rate of time preference).

The DU model has some interesting, though not always realistic, features (Frederick et al., 2002), in particular:

- a) a time-consistent preference, implied by the fact that in (2) the discount rate r is constant over the time horizon T ;
- b) a path-independent utility;
- c) a time-independent consumption preference, i.e. the individual preference for consumption is not affected by past or future outcomes;
- d) an independence of discounting from consumption, that is, the discount rate is not a function of consumption;
- e) an integration of new alternatives with existing plans, i.e. additional consumption plans are evaluated by integrating them into current plans;
- f) the instantaneous utility is constant for each given time interval;
- g) a decreasing marginal utility.

However, as stated by Samuelson (1952) and demonstrated later on by Koopmans (1960), the DU model is not based on individual psychology, and hence it is not likely to be corroborated by empirical or experimental evidence. In what follows, we will highlight some prominent anomalies arising from empirical evidence on individuals' behaviour.

2.1 Hyperbolic discounting

Almost all discounting applications use the exponential discount factor and consider the discount rate as constant and independent of the time horizon. The main problem with this assumption is that recent experimental evidence on individuals' behaviour suggests that people's discount functions are hyperbolic, i.e. discount rates decrease over time. This fact implies an inconsistency in individuals' choices. An example taken from Kocherlakota (2001) clearly explains the behaviour underlying time inconsistency: *"Jan is about to go out to her neighbourhood bar. Before drinking anything there, Jan would like to sign a legally binding contract stating that she is allowed to drink only four beers that night. Why does she want to sign such a contract? She knows that after having four beers, she will want to have a fifth, and she wants to prevent herself from doing so"* (p. 13).

This example shows that Jan is exhibiting time-inconsistent preferences: her preferences for beer, at a given date and in a given state, may change over time without the arrival of new information.

Several models of time-varying discount rates have been developed and discussed by economists. Strotz (1956) was the first one who studied time-inconsistency in a dynamic framework. Phelps and Pollak (1968) introduced hyperbolic discount functions in an

intergenerational context of consumption and saving. They captured taste for immediate gratification by means of a simple two-parameter model that modifies exponential discounting. Let u_t be the instantaneous utility of a person in period t . Then his intertemporal preferences at time t , U_t , can be represented by the following utility function, where both β and δ fall between 0 and 1:

$$U_t = \delta^t + \beta \sum_t \delta^t u_t \quad (3)$$

The parameter δ determines how time-consistently patient a person is. If $\beta=1$, then these preferences imply exponential discounting. But for $\beta<1$, these preferences are time-inconsistent.

Decrease in timing aversion has been observed in experimental studies concerning *inter alia*: people choosing between non-monetary alternatives³; people choosing between monetary alternatives⁴; animals choosing between types of food or between other alternatives⁵. The main justification for the adoption of the hyperbolic discounting utility function is empirical evidence in the cognitive psychology literature which contradicts the predictions of utility functions with stationary fixed discount rates. However, as argued by Harvey (1994), many of these studies do not examine the decrease in people's discount rate as it becomes large, but rather the increase in their discount rate as time intervals become small.

In the empirical literature, there are two main types of experiments on the test of the hyperbolic discounting hypothesis. The first type was first discussed by Thaler (1981). Some people prefer 'one apple today' to 'two apples tomorrow' to 'one apple in one year'. Ainslie and Haslam (1992) report that "[...] a majority of subjects say they would prefer to have a prize of a \$100

³ See Christensen-Szlanski (1984); Cropper et al. (1994); Millar and Navarick (1984); Solnick et al. (1980). .

⁴ See Thaler (1981); Ainslie and Haendel (1983); Benzion et al. (1989); Horowitz (1996).

⁵ See Ainslie (1975); Ainslie and Herrnstein (1981).

certified check available immediately over a \$200 certified check that could not be cashed before 2 years; the same people do not prefer a \$100 certified check that could be cashed in 6 years to a \$200 certified check that could be cashed in 8 years”. Experiments of this type have been replicated with choices involving a wide range of goods and a wide range of subject populations. The second class of experiments is discussed in Thaler (1981) and Benzion et al. (1989). Subjects were asked to imagine that they had won a sum of money in a lottery, and that they could either take the money now or wait for an increased amount later. They were presented with several variations of the amount $\$x$ at time t and the amount $\$y$ immediately. Then we may say that the subject’s choice is consistent with the discount factor $D(r,t)$ defined by the equation:

$$y = D(r,t)x \tag{4}$$

The results show that the average discount rate is decreasing in t . However, it was also found that r is not constant, but rather an increasing function of t . The larger the sum of money at stake, the higher (closer to 1) the discount factor⁶.

Rubinstein (2003), on the contrary, using experimental results, argues that the same sort of evidence which rejects the standard constant discount utility functions can reject hyperbolic discounting as well. Furthermore, a decision-making procedure based on similarity relations better explains the observations and is more intuitive. In summary, the findings of hyperbolic time preference rates show much variation and do not lead to clear and conclusive results.

⁶ Keller and Strazzera (2002), by using data reported in Thaler (1981), examine the accuracy of the hyperbolic model vs. the exponential model and find a slightly higher effectiveness of the former.

2.2 Other anomalies

Hyperbolic discounting has certainly been the most debated time preference anomaly in recent years. However, other anomalies have been found as well in a number of experiments.

Often individuals appear to have a discount rate lower for losses than gains, exhibiting what is called the *sign effect*. Experimental evidence of such an anomaly is provided by Thaler (1981) and later on by Antonides and Wunderink (2001). On the other hand, Shelley (1994) found that individuals discount more a loss delay than a gain delay.

When small benefits are discounted more than large ones, we have the *magnitude effect* (Shelley, 1993). There is a consensus in the academic community about this anomaly in discounting, and several studies have been conducted in order to provide some more in-depth information about it. In fact, it has been documented that the effect is greater for smaller amounts and short delays (see, amongst others, Kirby, 1997; Green et al., 1997).

The *direction effect* postulates that discount rates depend on whether a change in time of delivery of a benefit is perceived as an acceleration or a delay from a reference point in time (Loewenstein, 1988). This anomaly was interpreted by Loewenstein (1988) as evidence of the plausibility of ‘prospect theory’. For that paradigm, making an intertemporal choice means losing something at one time and gaining something at another. People’s loss aversion behaviour implies that the substitute outcome needs to be considerably larger to compensate for the loss. For delay, the substitute outcome is the later amount, and hence the direction effect increases the discount rate; for expediting, the substitute comes out earlier, decreasing the discount rate⁷.

⁷ Recently, Caplin and Leahy (2004) proposed some arguments for the analysis of a benevolent government in the light of prospect theory.

The above description of the anomalies in individual discounting is certainly not comprehensive; it is mainly limited to those we think are more relevant from the viewpoint of social discounting and policy making⁸.

Table 1 reports a summary of the features, and a simple analytical sketch of the anomalies presented in this section.

<<Table 1 around here>>

At this point, the shortcomings of using a constant pure time preference rate in equation (1) should be clear. As the social discount rate formula is linear in r , a particular functional form for that term would influence the functional form of the social discount rate. For this reason, the recent debate on social discounting has focused on the aggregate implications of intertemporal preference anomalies, and pointed out some of the possible outcomes when individual characteristics are taken into account. In the next section, we offer a review of the recent developments in the theory of social discounting in the light of the features of individual preferences.

3. Social discounting

3.1 The theory of social discounting and the early debate

The Social Discount Rate (henceforth denoted SDR), as defined by the $stpr$, describes the trade-off between present and future consumption as a function of two components: a pure preference for present over future welfare (r), and another term (μg) which indicates that, if the expected

⁸ Besides the excellent paper by Frederick et al. (2002), a comprehensive survey on individual time preference features can be found in Read (2003).

growth in per capita consumption (g) is positive, then a unit of consumption in the future will yield less utility than in the present. The term μ is the absolute value of the elasticity of marginal utility with respect to consumption (a measure of the relative effect of a change in consumption on welfare).

The basis for the formal analysis of the SDR is offered by the Ramsey's (1928) classical growth model. In this approach, it is implicitly assumed that the economy reflects the preferences of individuals, and that "*these preferences ought to be reflected in the societal decision making process*" (Pearce et al., 2003). However, the consideration of intertemporal preferences is not without problems. Sen (1961) argues that, if in a democracy all people count in the decision making process, then there is no democratic solution to the intertemporal problem as future generations are not yet born. Eckstein (1958) argues that, if we consider the society to be driven by a sort of "consumers' sovereignty", then people's preferences, including their intertemporal ones, should be taken into account.

In his original formulation, Ramsey (1928) assumes an ethical position stating that discounting "*is ethically indefensible and arises merely from the weakness of the imagination*" (Ramsey, 1928). By relying on Arrow and Kurz (1970) and Koopmans (1960), Markandya and Pearce (1988) provide a simple derivation of the *stpr*, as defined in equation (1). Let us consider social welfare (W) at time t as a function of consumption at the same point in time (C_t), and formalized as:

$$W(C_t) = C_t^{1-\mu} e^{-rt} (1-\mu)^{-1} \quad (5)$$

The present value of social welfare if the consumer maximizes his consumption stream is such that:

$$W'(C_t) = \frac{W'(C_{t+1})}{1 + stpr}, \quad (6)$$

which is equivalent to:

$$stpr = \frac{W'(C_{t+1}) - W'(C_t)}{W'(C_t)} = \frac{\frac{dW'(C_t)}{dt}}{W'(C_t)}, \quad (7)$$

Substituting the derivatives of (5) into (7) yields:

$$stpr = \mu \frac{dC}{dt} C^{-1} + r, \quad (8)$$

Clearly, since $\frac{dC}{dt} C^{-1}$ is the growth rate of consumption (g), we directly obtain (1).

As stated in Section 1, the empirical definition of the $stpr$ depends on expectations of the growth rate of the economy, as well as on the pure time preference of individuals, as expressed by r , while both elements are characterized by a high degree of uncertainty. For this reason, there is no consensus, neither in the economic literature nor among policy makers, on the value of the SDR to be adopted⁹. As a consequence, there is high volatility in the computation of the SDR in both scientific studies and in practical guidelines, as reported in Tables 2 and 3.

<<Tables 2 and 3 around here>>

In particular, Table 2 reports general discount rates for several industrialized countries. It is shown that they vary between 3.5% for France and 6% for the UK. Greater variation is shown for SDRs for carbon sequestration projects as reported in Table 3. The information given in this

⁹ Actually, Rabl (1996) proposes a completely different approach, where the classical discount rate is applied for the short term (less than 30 years) and the growth rate of the economy for the long term.

table should be considered only as an example of SDR variation for sector-specific projects; in fact, rates of discount may vary in the interval [0%, 10%].

3.2 *The contemporary debate*

From formula (1) or (8), it is clear that the estimation of the pure rate of time preference of individuals, r , is crucial for the definition of the *stpr*. Sen (1967) argues that people enter into a social contract, in which they commit themselves to increase their total savings above the level they would choose privately, exhibiting what is widely known as the “isolation paradox”. As a consequence, the SDR, if assumed to be just r , is lower than the market rate. Warr and Wright (1981) claim that the “isolation paradox” does not necessarily imply a non-market SDR¹⁰. However, Newberry (1990), arguing against Warr and Wright (1981), shows that their analysis holds only under conditions of sub-optimal equilibria. In our opinion, the analysis in Sen (1967) points out the central role played by individuals’ preference in shaping public decision making, or, in other words, the fact that collective actions result from the aggregation of individual preferences.

As stated in the previous section, consumers time preferences are characterized by decreasing discount rates. In this context, Cropper and Laibson (1999) show that, if agents are quasi-hyperbolic, then they consume more and save less, suggesting a role for the government to subsidize interest rates through public expenditure. In their analysis, they do not provide an explicit rationale to use hyperbolic discounting as a social practice.

¹⁰ Horowitz (1996) shows that the choice of a non-market discount rate leads to time-inconsistent policy which is a feature of government action in several fields. For a survey on time inconsistent fiscal and monetary policy making, we refer to Catenaro (2000).

In an interesting contribution, Krusell and Smith (2003) try to answer the question: *How do individuals with time-inconsistent preferences make consumption-saving decisions?* They consider a simple form of a consumption-saving problem, assuming that people discount in a quasi-geometric way. They find that when the time horizon is infinite, the dynamic game played between a price-taking consumer's successive selves is characterized by several equilibria. This multiplicity takes two forms:

- there is a continuum of stationary points for the consumer's asset holdings;
- for each stationary point there is a continuum of paths leading to this stationary point.

Krusell et al. (2002) consider a representative-agent equilibrium model where the consumer, as usual, has a quasi-geometric time preference and cannot commit to future actions. The planner is a consumer representative who, without commitment but in a time-consistent way, maximizes his present value utility. The competitive equilibrium results in strictly higher welfare than does the planning problem whenever the discounting is not geometric.

On the other hand, Gollier (2002) and Gollier and Zeckhauser (2003) demonstrate that the aggregation of preferences of exponential individuals leads to hyperbolic discounting of collective action outcomes. This result is very interesting, as it provides a convincing rationale for the use of time-declining discount rates. To this debate, additional arguments have been provided by Azfar (1999) and Weitzman (1998), who argue that the presence of uncertainty leads agents to have decreasing discount rates¹¹. Weitzman (1998) also states that there are at least three reasons to use a time-declining discount rate in evaluating far-distant future effects of a given project or policy:

¹¹ It should be noted that some arguments on uncertainty over future outcomes are also present in the analysis proposed by Gollier (2002) and Gollier and Zeckhauser (2003).

1. there is strong empirical evidence that individuals use lower discount rates for events that occur farther into the future;
2. a sufficiently large positive discount rate gives negligible weight to costs and benefits that occur far into the future; using a time-declining rate avoids having to choose between ignoring very long-term environmental consequences (with a time-invariant, non-zero rate) and not discounting at all;
3. current market rates of interest or marginal rates of time preference reflect the preferences of individuals currently alive, not those not yet born. In other words, future impacts should have exactly the same weight as current impacts.

The second point, that is, a discount rate that declines over time and ascribes higher values to future net benefits, is a feature of particular interest for resource and environmental policy. In fact, many environmental projects and programmes are characterized by high short-run costs and net benefits that show up in the far distant future, and the use of a discount rate declining over time may lead analysts to accept a larger number of projects that produce environmentally-benign outcomes. In order to highlight this fact, in the next section we review some of the most relevant literature on the effect of time-declining discounting on environmental policy in a broad sense.

4. Relevance of social discounting for resource and environmental policy

Since the publication of the seminal paper by Nordhaus (1994), it has become clear that the choice of the discount rate/function deeply affects the choice and the making of environmental

policy¹². It is noteworthy that Newell and Pizer (2001) find that costs and benefits in the distant future such as those associated with global warming, long-lived infrastructure, hazardous and radioactive waste, and biodiversity often have little value today when measured with conventional discount rates. They demonstrate that when the future path of this conventional rate is uncertain and persistent (i.e. highly correlated over time), the distant future should be discounted at lower rates than suggested by the current rate. They then use two centuries of data on U.S. interest rates to quantify this effect. Using both random walk and mean-reverting models, they compute the certainty-equivalent rate, that is, the single discount rate that summarizes the effect of uncertainty and measures the appropriate forward rate of discount in the future. They estimate discount factors over the next 400 years based on a 4% rate of return in 2000. Discount factors are expressed in terms of the value today of \$100 provided at various points in the future, that is, the discount factors multiplied by 100. After only 80 years, conventional discounting at a constant 4% undervalues the future by a factor of 2, relative to the random walk model. Going further into the future, conventional discounting is off by a factor of over 40,000 after 400 years. The mean-reverting model produces less huge, but yet still significant, results, raising the discount factor by a multiple of about 130 after 400 years. Newell and Pizer also find that the difference between valuations using different initial rates is smaller when uncertainty about future rates is incorporated.

Similarly, Pearce et al. (2003) reported that the present value of the marginal damage of carbon emissions in the UK is extremely sensitive to different discount profiles. In particular, they find that by using a flat 6% discount rate, as suggested in the Green Book (1997) and reported in

¹² For a different perspective, criticizing the characteristics of the model used by Nordhaus (1994), we refer to Neumayer (1999).

Table 2 of the present paper, the social cost of pollutant emissions is underestimated by almost 200% with respect to the case of discounting *à la* Newell and Pizer (2001).

From a theoretical viewpoint, Weitzman (1994) was the first to propose an “environmental discount rate”. His line of reasoning runs as follows. A marginal investment creates economic growth as well as a need to increase expenditure to ensure that environmental quality remains unchanged. This cost reduces the return on investment, so that an adjustment of the discount rate is needed. Environmental expenditure is increasing over time, and hence the rate of discount should be considered as time-varying. Later on, this intuition led the author to formulate the analysis summarized in Weitzman (1998).

Discounting the future using declining discount rates implies a higher level of altruism with respect to the exponential function (Saez-Marti and Weibull, 2005). This is an important feature, as one of the requirements for sustainable development is the intergenerational equity, that is, an adequate level of intertemporal altruism. These results are substantially in line with Chichilnisky (1996) and Li and Lofgren (2000). The former, in particular, proposed a framework where decision makers maximize the discounted value of net benefits and the well-being of far-distant future generations.

Next, Barro (1999) modified the neoclassical growth model to allow for a non-constant rate of time preference. He finds that if the household cannot commit to future choices of consumption, and if utility is logarithmic, then the equilibrium resembles the standard results¹³. Li and Lofgren (2000) extend that analysis to the case of a growth model where environmental quality is also

¹³ By relying on Barro-type growth models, Michel et al. (2004) conduct an extensive study on the effect of altruism on the effectiveness of fiscal policy. They find that when individuals have different degrees of altruism, public debt does not affect the long-run equilibrium.

considered. They find that a decrease of the discount rate in the long run increases the social welfare in the steady state.

Some growth arguments are also used by Di Vita (2003) to show that the discount rate might explain the Environmental Kuznets Curve. In particular, by using the framework proposed by Pindyck (2002), he demonstrates that a low income implies a high discount rate which, in turn, constitutes a disincentive for pollution abatement policies to generate outcomes in the very long run. When income increases, as a consequence of growth, the discount rate falls and government actions to promote environmental quality are taken more easily. An inverse U-shaped income-pollution pattern results from these findings.

Finally, Karp (2004) studies the effect of hyperbolic discounting on policy making against global warming, by considering a linear quadratic programming problem with a benevolent government able to commit to future actions. It is found that optimal emissions (and consequent abatement) match the outcome under hyperbolic discounting. Our conclusion is thus that the SDR certainly matters in public choices as is witnessed by the literature on resource and environmental policy.

So far we have described some of the anomalies of individual intertemporal preferences and pointed out how one of them in particular, i.e. hyperbolic discounting, may lead to desirable environmental policy outcomes by giving more importance to far-distant future net benefits. However, as reported in Section 2 of this paper, empirical estimates of pure discount rates show a high variability according to experimental methodology, individual attributes, and even more variables. In the next section, we report the results of a quantitative meta-analysis in order to identify the determinants of discount rate estimates and discuss the value transfer potential of our meta-regression.

5. A statistical meta-analysis of the empirical literature on individual time preference rates

As discussed in previous sections, the SDR, or as indicated in (1), the *stpr*, is a function of the pure time preference of individuals, r . Since the choice of the rate of discount may have great effects on policy choices, a correct usage of r is crucial for efficient policies¹⁴. In this section, we will carry out a quantitative review of the empirical literature on individual time preferences by using a statistical methodology known as “meta-analysis”¹⁵. This analysis aims at identifying some of the determinants of discount rate values by estimating a meta-regression function that explains the determinants of variability in the outcomes of empirical studies.

In general, meta-analysis aims to estimate a meta-regression in the form of (see Florax et al., 2002):

$$Y = f(P, X, R, T, L) + \varepsilon \quad (9)$$

where Y is the variable under consideration; P is a vector of variables causing the outcome Y ; X is the set of characteristics of the sample used to estimate Y ; R is the research method deployed; and T and L represent a time and location coordinate over which the empirical study has been conducted.

The database used here substantially relies on publications cited by Frederick et al. (2002) and consists of 42 studies which aim to estimate the rate of time preferences at both an individual and a collective level (Table 3 gives a summary of these studies) with 76 discount rate estimates.

<<Table 4 around here>>

¹⁴ Interestingly, Foster and Mitra (2003) provide sufficient conditions to rank investment projects on the basis of the Net Present Value, irrespective of the discount rate.

¹⁵ For the use of meta-analysis in economics, we refer, amongst others, to Florax et al. (2002) and Nijkamp (2005).

One of the main problems in applying meta-analysis is the possible presence of a “publication bias”. This pitfall originates from what Rosenthal (1979) calls the “publication culture” of journal editors, as only studies that present significant results and reliable effects size estimates tend to be published in academic journals. Over the years, a number of procedures to deal with this issue have been proposed in the literature. Florax et al. (2002), in the course of providing an excellent review of them, describe the following possibilities:

- consider in the analysis both published and unpublished works;
- use the quasi-statistical graphical technique developed by Light and Pillemer (1984), that is, to draw a scatter plot of the estimates of Y and its standard deviation (and, in some cases, of the sample dimension);
- use proper tests such as the file drawer test of Rosenthal (1979) or the concordance tests on effect size;
- use estimates based on weighted distribution theory retrieving information on p values or on models of selection bias.

Although it cannot be excluded a priori, our meta-sample is not likely to be affected by a publication bias in the sense described by Rosenthal (1979), since, given the high variability in the dimension of the sample, what seems to be relevant in the discounting literature is the design of the experiment or the rigour of the methodology. In fact, in our meta-sample, there are studies reporting experimental evidence that use a sample of a few dozen people (as is done in the seminal paper by Thaler, 1981), but also works relying on econometric evidence from thousands of individuals (see, e.g. Laibson et al., 2004). Being concerned with what is considered to be the most relevant variable in explaining publication bias, we do not have estimates of the standard

deviation of the discount rates. In fact, in the case of experimental evidence, in a very few cases the standard deviation as well as the p values are reported in the text. This could be because the evidence in our meta-sample is not meant to corroborate or to reject a given theory; the quality of a study is assessed rather on the basis of the relevance of the research questions it tries to answer. With these considerations in mind, in the following analysis we will not assume any publication bias.

Articles may show contrasting outcomes, because of the types of methodology (experimental or field work, with a high predominance of the former), goods or objects of choice (money, life years or health); whether the situation that the individuals face is real or hypothetical, and because of the elicitation method used (choice, matching, ranking or other). The time period of publication in our sample ranges from 1978 to 2002. The summary statistics in Table 4 show that the data set is characterized by a high degree of volatility.

In performing our meta-analysis, we consider the following two sets of explanatory variables: a set of variables that aim to describe the research methodology, and a set of variables that describe the sample and the macroeconomic environment.

Variables for the description of the methodology are defined as follows. RANGE is the range of time to estimate the discount rate considered in the article (expressed in years). HYPO is a dummy variable assuming a value of 1 if the situation that individuals face is hypothetical. CHOICE, MATCHING and OTHER are dummies for the elicitation method.

MONEY, LIFE and HEALTH are dummy variables concerning the goods under consideration for an experiment or an estimation. FIELD is a dummy variable taking a value of 1 if the study is a field study rather than an experiment.

Other variables are: year of publication (YEAR); a dummy variable for non-U.S. studies (NONUS); the sample dimension (DIM); GDP per capita one year before the time of publication (GDP); and life expectancy one year before the time of publication (LIFE)¹⁶. The rationale for the inclusion of the latter two variables is as follows. Richer people tend to be more patient, and thus to have lower discount rates, implying a sort of wealth-effect on discounting¹⁷. Uncertainty also plays a central role in shaping time preference, as more uncertain outcomes are discounted higher than certain ones. In general, it has been widely proven that the discount rate is a function of the uncertainty that characterizes the future (see, for instance, Weitzman, 1998). According to Evans and Sezer (2004), life expectancy may be seen as a proxy for this uncertainty. Obviously, the implicit assumption that we are making on these variables is that all studies have been carried out one year before their date of publication.

<<Tables 5 and 6>>

In Table 5 we present results for the meta-regression where the dependent variable is the discount rate¹⁸. These results call for a brief interpretation. RANGE has a negative coefficient across all models; this, in turn, means that the longer the time horizon, the lower the estimated rate of time preference. People tend to underestimate their rates if faced with a hypothetical situation, as well as if asked to choose, having in mind MONEY or HEALTH. The elicitation method MATCHING presents a negative coefficient, though it is not statistically significant in models 2 and 3.

¹⁶ The source for these variables is the World Development Indicators, a data set maintained and distributed by the World Bank. GDP is expressed as thousands of dollars in 1995 Purchasing Power Parity.

¹⁷ Azar and Sterner (1996) explicitly consider the role of income distribution between rich and poor countries in social discounting and global warming policy making. By using different discount rates, they find that marginal costs of CO₂ emissions are 50-100 times larger than the estimates contained in Nordhaus (1994).

¹⁸ Notice that most of the studies present several discount rate estimates, so that we are allowed to have a sample of 513 observations.

The year of publication of the study has a positive sign, though it is not significant. GDP is highly significant and has a negative coefficient, implying that the higher the income the lower the rate of discount. Notice that this result provides some rudimentary evidence for the hypothesis proposed by Di Vita (2003), that is, that there is an inverse relationship between the level of per capita GDP and the discount rate.

In our analysis, uncertainty, as roughly measured by the variable LIFE, is not significant, but this could be due to the fact that life expectancy might not capture all of the uncertainty connected with the future economic position of individuals. In fact, when asked about their most relevant fears, people tend to show enormous concern about the well-being of future generations, rather than about their own health conditions or length of life.

Finally, the variable FIELD has a negative coefficient; thus, if our estimate relies upon the individuals' behaviour as, for example, revealed by their consumption habits, a lower discount rate will result.

One of the main benefits in using meta-analysis is that it might be possible to transfer the meta-analytical function to specific locations to predict the value of the dependent variable (in our case the individual time preference rate) in cases of absence of detailed primary analyses¹⁹.

Although there is extensive and positive experience of non-market value transfers in environmental analysis (Nijkamp, 2005), we are concerned in attributing a "transfer property" to our estimated regressions. In particular, our concern is driven by the explanatory variables that have been found to be relevant in explaining the variability of the rates of discount, that is, by variables that explicitly rely on the experiment/analysis design. For example, HYPO, HEALTH

¹⁹ Recall that meta-analysis was developed in the context of medical science to facilitate the anamnesis when there is limited information on a patient's condition.

and FIELD can be considered as study-specific variables, with no transfer properties. In addition, only GDP and NONUS can be considered as variables capable of measuring local conditions.

This implies that, according to our analysis, experimental results are not likely to be generalized and applied to a whole economy. As stated above, one of the main arguments in favour of the meta-analysis, which is a very appropriate tool for comparison of experiments, is that the results can be generalized and applied to other contexts by fitting the meta-regression function. However, our results reflect specific features of the sample and are deeply influenced by the design of the experiment. That is, estimates of discount rates are significantly affected by the experiment layout, rather than by socio-economic variables. This can be considered as a shortcoming in the literature, as it demonstrates that there is no consensus on the methodology to elicit individual discount rates. In other words, as the discount rate is a function of the eliciting methodology, only a relatively small portion of the variability of the rate of discount can be explained by socio-economic and environmental variables that are meant to be used to transfer the value of our dependent variable. As a consequence, policy makers or analysts should be cautious in using estimates found in the empirical literature to find a proxy for an *stpr* to evaluate plans or projects.

6. Conclusions

In this paper we have reviewed the literature on social discounting, and pointed out how individual preferences shape the social discount rate. However, people's intertemporal preferences present some anomalies that undermine the validity of the classical model that relies on an exponentially discounted utility. One of these anomalies is that individuals present time-decreasing discount rates, exhibiting what is widely called "hyperbolic discounting". We have

suggested some of the (positive) environmental policy implications when this feature is taken also into account in social discounting.

Recognizing the central role played by individual time preferences in the definition of the social discount rate, we have carried out a meta-analysis and found that empirical estimates are clearly influenced by location-independent attributes, showing little transfer properties. Consequently, policy makers and even analysts may be forced to conduct *ad hoc* analyses to estimate the pure time preference rate. In this realm, extensive surveys reporting individual observed behaviour in daily life are highly preferable, as discount rate estimates have been found to depend on the features of the experimental design. Laibson et al. (2004) provide a very interesting method to estimate discount functions/rates from life-cycle consumption choices reported in household expenditure surveys.

Finally, a word on future research, which we feel should be conducted mainly in two fields. Blundell and Stoker (2005) point out the importance of heterogeneity treatment in the estimation of economic aggregates. Gollier and Zeckhauser (2005) provide some necessary and sufficient conditions for the aggregation of individual time preferences into a social aggregate under very strict conditions. On this point, by using large data sets, such as the households surveys provided by most industrialized countries' governments or central banks, it would be interesting to investigate the cross-section distribution of individual discount rates, as well as to verify some of the basic theoretic postulates that can be drawn from the literature on the aggregation of preferences. Secondly, Laibson et al. (2004) propose the use of a general model to estimate individual discount functions by making use of simulated moments estimation procedures on data on credit card borrowing in the U.S. In the European context, it would be very useful to estimate such functions, as well as to investigate in this framework the impact of aggregation.

References

- Adams, R., D. Adams, J. Callaway, C. Chang, and B. McCarl, (1993), 'Sequestering Carbon on Agricultural Land: Social Cost and Impacts on Timber Markets', *Contemporary Policy Issues* XI(1):76-87.
- Ainslie, G. (1975), 'Specious reward: A behavioral theory of impulsiveness and impulse control', *Psychological Bulletin*, 82(4):463-496.
- Ainslie, G. and V. Haendel (1983), 'The motives of the will', in E. Gottheil, K. Durley, T. Skodola and H. Waxman (eds.), *Etiologic aspects of alcohol and drug abuse*, Charles C. Thomas, Springfield, IL.
- Ainslie, G. and N. Haslam (1992), 'Hyperbolic discounting', in G. Loewenstein and J. Elster (eds.), *Choice over time*, Russell Sage Foundation, New York, NY.
- Ainslie, G. and R.J. Herrnstein (1981), 'Preference reversal and delayed reinforcement', *Animal Learning and Behavior*, 9(4):476-482.
- Antonides, G. and S.R. Wunderink (2001), 'Subjective time preference and willingness to pay for an energy-saving durable good', *Zeitschrift Fur Sozialpsychologie*, 32(3), 133-141.
- Arrow K.J. and M. Kurz (1970), *Public investment, the rate of return and optimal fiscal policy*, The Johns Hopkins University Press, Baltimore.
- Azar, C. and T. Sterner (1996), 'Discounting and Distributional Considerations in the Context of Climate Change', *Ecological Economics*, 19: 169-185.
- Azfar, O. (1999), 'Rationalizing Hyperbolic Discounting', *Journal of Economic Behavior and Organization*, 38(2):245-252.
- Barro R. (1999), 'Ramsey meets Laibson in the neoclassical growth model', *Quarterly Journal of Economics*, 114: 1125-1152.
- Baumol, W. (1952), 'The Transactions Demand for Cash: An Inventory Theoretic Approach', *Quarterly Journal of Economics*, 66(4): 545-56.
- Benzion U., A. Rapaport and J. Yagil (1989), 'Discount rate inferred from decisions: an experimental studies', *Management Science*, 35:270-284.
- Blundell, R. and T.M. Stoker (2005), 'Heterogeneity and Aggregation', *Journal of Economic Literature*, 43:347-391.
- Boardman, A.E., D.H. Greenberg, A.R. Vining and D.L. Weimer (2001), *Cost-Benefit Analysis. Concepts and Practice*, 2nd Edition, Prentice Hall
- Boscolo M., J. Buongiorno, and T. Panayotou (1997), 'Simulating Options for Carbon Sequestration in the Management of a Lowland Tropical Rainforest', Harvard University, mimeo.
- Boscolo, M., J.R. Vincent and T. Panayotou (1998), 'Discounting Costs and Benefits in Carbon Sequestration Projects', Harvard Institute for International Development, Discussion Paper No. 638
- Bradford, D. (1975), 'Constraints on Government Investment Opportunities and the Choice of Discount Rate', *American Economic Review*, 65(5): 887-899
- Cairns, John A. (1992), 'Discounting and health benefits: Another perspective', *Health Economics*, 1: 76-79.

- Cairns, John A. (1994). 'Valuing future benefits', *Health Economics*, 3: 221-29.
- Cairns, John A. and M.M. van der Pol (1997), 'Constant and decreasing timing aversion for saving lives', *Social Science & Medicine*, 45(11): 1653-59.
- Cairns, John A. and M.M. van der Pol (1999), 'Do people value their own future health differently than others' future health', *Medical Decision Making*, 19(4): 466-72.
- Caplin, A. and J.V. Leahy (2004), 'The Social Discount Rate', *Journal of Political Economy*, 112(6): 1257-1268.
- Catenaro, M. (2000), 'Time Inconsistency: an Upadated Survey of the Literature', Università degli studi di Milano – Bicocca, Dipartimento di Economia WP 28.
- Chapman, G.B. (1996), 'Temporal Discounting and Utility for Health and Money', *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 22(3): 771-91.
- Chapman, G.B. (2000), 'Preferences for Improving and Declining Sequences of Health Outcomes', *Journal of Behavioral Decision Making*, 13: 203-218.
- Chapman, G.B. and E.J. Coups (1996), 'Time Preferences and Preventive Health Behavior: Acceptance of the influenza vaccine', *Medical Decision Making*, 19(3): 307-14.
- Chapman, G.B. and A.S. Elstein (1995), 'Valuing the future: Temporal Discounting of Health and Money', *Medical Decision Making*, 15(4): 373-86.
- Chapman, G.B. and J.R. Winkust (1998), 'The Magnitude Effect: Temporal Discount Rates and Restaurant Tips', *Psychonomic Bulletin & Review*, 5(1):119-23.
- Chapman, G.B., R. Nelson, and D.B. Hier (1999), 'Familiarity and Time Preferences: Decision Making About Treatments for Migraine Headaches and Crohn's Disease', *Journal of Experimental Psychology: Applied*, 5(1):17-34.
- Chesson, H. and W.K. Viscusi (2000), 'The Heterogeneity of Time-Risk Tradeoffs', *Journal of Behavioral Decision Making*, 13: 251-58.
- Chichilnisky, G. (1996), 'An Axiomatic Approach to Sustainable Development', *Social Choice and Welfare*, 13(2):231-257.
- Christensen-Szlanski, J.J. (1984), 'Discount Functions and the Measurement of Patients' Values', *Medical Decision Making*, 4(1):47-58
- Coller, M. and M.B. Williams (1999), 'Eliciting Individual Discount Rates', *Experimental Economics*, 2:107-127.
- Cowell, F.A. and K. Gardiner (1999), 'Welfare Weights', London School of Economics, STICERD Economics Research Paper 20.
- Cropper M., S.K. Aydede and P.R. Portney (1994), 'Preferences for Life Saving Programs: How the Public Discount Time and Age', *Journal of Risk and Uncertainty*, 8(2):243-265
- Cropper M. and D. Laibson (1999), 'The Implications of Hyperbolic Discounting for Project Evaluation', in P.R. Portney and J.P. Weyant (eds.), *Discounting and intergenerational equity*, Resources For the Future, Washington.
- Di Vita, G. (2003), 'Is the Discount Rate Relevant in Explaining the Environmental Kuznets Curve?', FEEM Note di Lavoro n. 83.203.
- Dolan, P. and C. Gudex (1995), 'Time Preference, Duration and Health State Valuations', *Health Economics*, 4: 289-99.

- Dreyfus, M.K. and W.K. Viscusi (1995), 'Rates of Time Preference and Consumer Valuations of Automobile Safety and Fuel Efficiency', *Journal of Law and Economics*, 38(1): 79-105.
- Eckstein, O. (1958), *Water Resource Development: The Economics of Project Evaluation*, Harvard University Press, Cambridge, MA.
- Englin, J. and J.M. Callaway (1995), 'Environmental Impacts of Sequestering Carbon Through Forestation', *Climatic Change* 31:67-78.
- European Commission (2002), *Guide to Cost-Benefit Analysis of Investment Projects*, DG Regional Policy, Luxembourg
- Evans, D. (2004), 'A Social Discount Rate for France', *Applied Economics Letters*, 11: 803-808.
- Evans, D. and H. Sezer (2002), 'A Time Preference Measure of the Social Discount Rate for the UK', *Applied Economics*, 34: 1925-1934.
- Evans, D. and H. Sezer (2004), 'Social Discount Rates for Six Major Countries', *Applied Economics Letters*, 11: 557-560.
- Fearnside, P.M., (1995), 'Global Warming Response Options in Brazil's Forest Sector: Comparison of Project-Level Costs and Benefits', *Biomass and Bioenergy* 8(5):309-322.
- Florax, R.J.G.M., H.L.F. de Groot and R.A. de Mooij (2002), 'Meta-Analysis', Tinbergen Institute, Discussion Paper 041/3, Amsterdam
- Foster and Mitra (2003), 'Ranking Investment Projects', *Economic Theory*, 22(3):469-494
- Frederick, S., G. Loewenstein, T. O'Donoghue (2002), Time Discounting and Time Preference: A Critical Review, *Journal of Economic Literature*, 40(2):351-401.
- Ganiats, T.G., R.T. Carson, R.M. Hamm, S.B. Cantor, W. Sumner, S.J. Spann, M. Hagen, and C. Miller (2000), 'Health Status and Preferences: Population-Based Time Preferences for Future Health Outcome', *Medical Decision Making: An International Journal*, 20(3): 263-270.
- Gately, D. (1980), 'Individual discount rates and the purchase and utilization of energy-using durables: Comment', *Bell Journal of Economics*, 11: 373-74.
- Gollier, C. (2002), 'Discounting an Uncertain Future', *Journal of Public Economics*, 85(1): 149-166
- Gollier, C. and R. Zeckhauser (2003), 'Collective Investment Decision Making With Heterogeneous Time Preferences', mimeo
- Gollier, C. and R. Zeckhauser (2005), 'Aggregation of Heterogeneous Time Preferences', *Journal of Political Economy*, 113(4):878-896
- Green, L., J. Myerson, and E. McFadden (1997), 'Rate of Temporal Discounting Decreases With Amount of Reward', *Memory & Cognition*, 25(5):715-23.
- Harberger, A.C. (1969), 'The Discount Rate in Public Investment Evaluation', *Conference on the Economics of Water Resource Development*, Western Agricultural Economics Research Council, Report No. 17, Denver, CO.
- Harrison, G.W., M.I. Lau, and M.B. Williams (2002), 'Estimating Individual Discount Rates in Denmark: A field experiment', *American Economic Review*, 92(5):1606-1617
- Harvey, C (1994), 'The Reasonableness of Non-Constant Discounting', *Journal of Public Economics*, 53:31-51
- Hausman, J. (1979), 'Individual Discount Rates and the Purchase and Utilization of Energy-Using Durables', *Bell Journal of Economics*, 10(1): 33-54.

- Hesketh, B. (2000), 'Time Perspective in Career-Related Choices: Applications of Time Discounting Principles', *Journal of Vocational Behavior*, 57: 62-84.
- HM Treasury (1997), *Appraisal and Evaluation in Central Government (The Green Book)*, HMSO, London.
- Hoehn, H.F. and B. Solberg (1994), 'Potential and Economic Efficiency of Carbon Sequestration in Forest Biomass Through Silvicultural Management', *Forest Science*, 40(3):429-451.
- Holden, S.T., B. Shiferaw, and M.Wik (1998) 'Poverty, Market Imperfections and Time Preferences of Relevance for Environmental Policy?', *Environment and Development Economics*, 3:105-30.
- Horowitz, J.K. (1996), 'Environmental Policy Under a Non-Market Discount Rate', *Ecological Economics*, 16:73-78
- Houston, D.A. (1983), 'Implicit discount rates and the purchases of untried, energy-saving durable goods', *Journal of Consumer Research*, 10: 236-46.
- Ismail, R. (1995), 'An Economic Evaluation of Carbon Emission and Carbon Sequestration for the Forestry Sector in Malaysia', *Biomass and Bioenergy*, 8(5):281-292.
- Johannesson, M. and P.-O. Johannesson (1997), 'Quality of life and the WTP for an increased life expectancy at an advanced age', *Journal of Public Economics*, 65: 219-228.
- Karp, L. (2004), 'Global Warming and Hyperbolic discounting', University of California at Berkeley, Department of Agricultural and Resource Economics, Paper 934R.
- Keller L.R. and E. Strazzera (2002), Examining predictive accuracy among discounting models, *Journal of Risk and Uncertainty*, 24(2):143-160.
- Kirby, K.N. (1997), Bidding on the future: Evidence against normative discounting of delayed rewards, *Journal of Experimental Psychology: General*, 126(1):54-70
- Kirby, K.N. and R.J. Herrnstein (1995), 'Preference reversals due to myopic discounting of delayed reward', *Psychological Science*, 6(2): 83-89.
- Kirby, K.N. and N.N. Marakovic (1995), 'Modeling myopic decisions: Evidence for hyperbolic delay-discounting with subjects and amounts', *Organizational Behavior & Human Decision Processes*, 64:22-30.
- Kirby, K.N. and N.N. Marakovic (1996), 'Delay-discounting probabilistic rewards: Rates decrease as amounts increase', *Psychonomic Bulletin & Review*, 3(1):100-104.
- Kirby, K.N., N.M. Petry, and W.K. Bickel (1999), 'Heroin addicts have higher discount rates for delayed rewards than non-drug-using controls', *Journal of Experimental Psychology: General*, 128(1): 78-87.
- Kocherlakota, N.R. (2001), 'Looking for evidence of time-inconsistent preferences in asset market data', *Federal Reserve Bank of Minneapolis Quarterly Review*, 25(3):13-24
- Koopmans, T.C. (1960), 'Stationary ordinal utility and impatience', *Econometrica*, 28: 287-309.
- Krusell, P. and A.A. Smith (2003), 'Consumption-savings decisions with quasi-geometric discounting', *Econometrica*, 71:365-375
- Krusell P., B. Kuruscu and A.A. Smith (2002), "Equilibrium welfare and government policy with quasi-geometric discounting", *Journal of Economic Theory*, 105:42-72
- Kula, E. (1984), 'Derivation of Social Time Preference Rates for the United States and Canada', *Quarterly Journal of Economics*, 99:873-882.

- Laibson, D., A. Repetto and J. Tobacman (2004), 'Estimating Discount Functions from Lifecycle Consumption Choices', Harvard University, mimeo.
- Li, C.Z. and K.G. Lofgren (2000), 'Renewable Resources and Economic Sustainability: A Dynamic Analysis with Heterogeneous Time Preferences', *Journal of Environmental Economics and Management*, 40(2): 236-250.
- Light, R. and Pillemer, D. 1984. *Summing Up: The Science of Reviewing Research*. Harvard University Press, Cambridge, MA
- Loewenstein, G. (1987) 'Anticipation and the Valuation of Delayed Consumption', *Economic Journal*, 97:666-684.
- Loewenstein, G. (1988), 'Frames of mind in intertemporal choice', *Management Science*, 34:200-214.
- Loewenstein, G. and D. Prelec (1992), 'Anomalies in intertemporal choice: Evidence and an interpretation', *Quarterly Journal of Economics*, 107(2):573-597.
- Madden, G.J., N.M. Petry, G.J. Badger, and W.K. Bickel, (1997), 'Impulsive and self-control choices in Opioid-dependent patients and non-drug-using control participants: Drug and monetary rewards', *Experimental and Clinical Psychopharmacology*, 5(3):256-262.
- Maital, S. and S. Maital (1978), 'Time preference, delay of gratification, and the intergenerational transmission of economic inequality: A behavioral theory of income distribution', in O. Ashenfelter and W. Oates (eds.), *Essays in labor market analysis*, Wiley, New York.
- Marglin, S. (1963), 'The Opportunity Cost of Public Investment', *Quarterly Journal of Economics*, 77(1):95-111.
- Markandya, A. and Pearce, D. (1988), 'Environmental Considerations and the Choice of the Discount Rate in Developing Countries', World Bank, Environment Department. Working Paper No. 3.
- Michel, P., E. Thibault and J.-P. Vidal (2004), 'Intergenerational Altruism and Neoclassical Growth Models', European Central Bank Working Paper n. 386.
- Millar, A. and D.J. Navarick (1984), 'Self control and choice in humans: effects of video game paying as a positive reinforcer', *Learning and Motivation*, 15(2):203-218
- Moore, M.J. and W.K. Viscusi (1988), 'The quantity-adjusted value of life', *Economic Inquiry*, 26(3):369-388.
- Moore, M.J. and W.K. Viscusi (1990a), 'Discounting environmental health risks: new evidence and policy implications', *Journal of Environmental Economics and Management*, 18:S51-S62.
- Moore, M.J. and W.K. Viscusi (1990b), 'Models for estimating discount rates for longterm health risks using labor market data', *Journal of Risk and Uncertainty*, 3:381-401.
- Moulton, R. and K. Richards (1990), 'Costs of sequestering carbon through tree planting and forest management in the United States', General Technical Report WO-58, US Department of Agriculture. Washington D.C.
- Neumayer, E. (1999), 'Global warming: discounting is not the issue, but substitutability is', *Energy Policy*, 27:33-43.
- Newberry, D.M. (1990), 'The Isolation Paradox and the Discount Rate for Benefit-Cost Analysis: A Comment', *Quarterly Journal of Economics*, 106:235-238
- Newell, R.G. and W.A. Pizer (2004), 'Uncertain Discount Rates in Climate Policy Analysis', *Energy Policy*, 32:519-529

- Nijkamp, P. (2005), 'Quantitative Research Synthesis in the Space-Economy: A Narrative Review of Meta-Analysis', *Studia Regionalia*, Polish Academy of Sciences, Warsaw, vol.15, pp.14-41
- Nordhaus, W.D. (1991), 'The Cost of Slowing Climate Change: A Survey', *The Energy Journal*, 12(1):37-65.
- Nordhaus, W.D. (1994) *Managing the Global Commons: The Economics of Climate Change*, The MIT Press, Cambridge, MA.
- Parks, P.J. and Hardie, I.W. (1995), 'Least-Cost Forest Carbon Reserves: Cost-Effective Subsidies to Convert Marginal Agricultural Land to Forests', *Land Economics* 71:122-136.
- Pearce, D., B. Groom, C. Hepburn, P. Koundouri (2003), 'Valuing the Future', *World Economics*, 4(2):121-141
- Pender, J.L. (1996), 'Discount rates and credit markets: Theory and evidence from rural India', *Journal of Development Economics*, 50(2):257-96.
- Percoco, M. (2006), 'A Social Discount Rate for Italy', *Applied Economics Letters*, forthcoming.
- Phelps, E.S. and R. Pollak (1968), 'On Second-Best National Saving and Game-Equilibrium Growth', *Review of Economic Studies*, 35(1):185-199.
- Pindyck, R. (2002), 'Optimal Timing Problems in Environmental Economics', MIT, mimeo.
- Rabl, A. (1996), 'Discounting of Long-Term Costs: What Would Future Generations Prefer Us to Do?', *Ecological Economics*, 17:137-145.
- Rachlin, H., A. Raineri, and D. Cross, (1991), 'Subjective probability and delay', *Journal of Experimental Analysis of Behavior*, 55(2):233-244.
- Ramsey, F.P. (1928), 'A Mathematical Theory of Saving', *Economic Journal*, 38:543-59.
- Read, D. (2003), 'Intertemporal Choice, London School of Economics and Political Science', WP. LSEOR 03.58.
- Redelmeier, D.A. and D.N. Heller (1993), 'Time preference in medical decision making and cost-effectiveness analysis', *Medical Decision Making*, 13(3):212-217.
- Rosenthal, R. 1979. 'The "file drawer problem" and tolerance for new results', *Psychological Bulletin*, 86:638-641.
- Rubinstein A. (2003), 'Is it "Economics and Psychology"?: The case of hyperbolic discounting', *International Economic Review*, 44:1207-1216.
- Saez-Marti, M. and J.W. Weibull (2005), 'Discounting and Altruism to Future Decision-Making', *Journal of Economic Theory*, 122:254-266.
- Samuelson, P. (1952), 'Probability, utility, and the independence axiom', *Econometrica*, 20(4): 670-78.
- Sandmo, A. and J.H. Dreze (1971), 'Discount Rates for Public Investment in Closed and Open Economies', *Economica*, 38(152):395-412
- Sen, A. (1961), 'On Optimising the Rate of Savings', *Economic Journal*, 71:479-496.
- Sen, A. (1967), 'Isolation Assurance, and the Social Rate of Discount', *Quarterly Journal of Economics*, 81:112-124.
- Shelley, M.K. (1993), 'Outcome signs, question frames and discount rates', *Management Science*, 39:806-815.

- Shelley, M.K. (1994), 'Gain/loss asymmetry in risky intertemporal choice', *Organizational Behavior & Human Decision Processes*, 59(1):124-159.
- Shelley, M.K. and T.C. Omer (1996), 'Intertemporal framing issues in management compensation', *Organizational Behavior & Human Decision Processes*, 66(1):42-58.
- Solnick, J., C. Kannenberg, D. Eckerman, and M. Waller (1980), 'An experimental analysis of impulsivity and impulse control in humans', *Learning and Motivation*, 11(1): 61-77.
- Squire, L. and H.G. Van der Tak (1975), *Economic Analysis of Projects*, The Johns Hopkins University Press, Baltimore.
- Stavins, R.N. (1999), 'The Costs of Carbon Sequestration: a Revealed-Preference Approach', *American Economic Review*, 89(4):994-1009
- Strotz R.H. (1956), "Myopia and inconsistency in dynamic utility maximization", *Review of Economic Studies*, 23(1):165-180
- Thaler R. (1981), "Some empirical evidence on dynamic inconsistency", *Economics Letters*, 8(2):201-207
- Van der Pol, M.M. and J.A. Cairns (1999), 'Individual time preferences for own health: an application of a dichotomous choice question with follow up', *Applied Economics Letters*, 6:649-54.
- Van der Pol, M.M. and J.A. Cairns (2001), 'Estimating time preferences for health using discrete choice experiments', *Social Science & Medicine*, 52:1459-1470.
- Viscusi, W. K. and M.J. Moore (1989), 'Rates of time preference and valuation of the duration of life', *Journal of Public Economics*, 38(3):297-317.
- Wahlund, R. and J. Gunnarsson (1996), 'Mental discounting and financial strategies', *Journal of Economic Psychology*, 17(6):709-730.
- Warner, J.T. and S. Pleeter (2001), 'The personal discount rate: Evidence from military downsizing programs', *American Economic Review*, 91(1):33-53.
- Warr, P.G. and B.D. Wright (1981), 'The Isolation Paradox and the Discount Rate for Benefit-Cost Analysis', *Quarterly Journal of Economics*, 95:129-145.
- Weitzman, M.L. (1994), 'On the "Environmental" Discount Rate', *Journal of Environmental Economics and Management*, 26(1):200-209.
- Weitzman, M.L. (1998), 'Why the Far-Distant Future Should Be Discounted at Its Lowest Possible Rate', *Journal of Environmental Economics and Management*, 36(3): 201-208.
- Weitzman M. (2001), 'Gamma discounting', *American Economic Review*, 91(1):260-271

Table 1: Discount models and their characteristics

<i>Model/Anomaly</i>	<i>Choice</i>	<i>Characteristics</i>	<i>References</i>
Exponential	$u(x_1) = u(x_2)$	The discount factor is: $\left(\frac{1}{1+r}\right)^t$	Samuelson (1952)
Hyperbolic	$u(x_1) = u(x_2)=u(x_3)$	The discount factor is $\left(\frac{1}{1+\alpha t}\right)^{\beta/\alpha}$ that approximates a discount factor with $r(t)$	Loewenstein and Prelec (1992)
Sign effect	$u(x_1^+) = u(x_2^+)$ $u(x_1^-)=u(x_2^-)$	$\frac{x_1^+}{x_2^+} > \frac{x_1^-}{x_2^-} \rightarrow r^+ > r^-$	Antonides and Wunderink (2001); Thaler (1981)
Magnitude effect	$u(x_1^S) = u(x_2^S)$ $u(x_1^L)=u(x_2^L)$	$\frac{x_1^L}{x_2^L} > \frac{x_1^S}{x_2^S} \rightarrow r^L > r^S$	Kirky (1995); Shelley (1993)
Direction effect	$u(x_1) = u(x_2^D)$ $u(x_1^E)=u(x_2)$	$\frac{x_1}{x_2^D} > \frac{x_1^E}{x_2} \rightarrow r^D > r^E$	Loewenstein (1988)

NOTES: This table relies on results and notation in Read (2003). In the second column “Choice” are the choices an individual faces when testing different models/anomalies. In the third column “Characteristics” are the main results from the experiment/model.

LEGENDS: The sign “=” means that the individual has to make a choice or to reveal a preference. For instance, $u(x_1) = u(x_2)$ means that an individual is asked to reveal his discount rate for which he is indifferent in having x at time $t=1$ or at time $t=2$. Subscripts denote time $t=1,2,3$; r is the discount rate; α, β are parameters of the generalized hyperbolic model. Superscripts’ meanings are as follows: +: gain; -: loss; S: small; L: large; D: delayed; E: expedited.

Table 2: A sample of Social Discount Rates across countries

<i>Country</i>	<i>Social Discount Rate</i>	<i>Source</i>
Australia	4.7%	Evans and Sezer (2004a)
Canada	5.2%	Kula (1984)
EU	5%	European Commission (2002)
France	3.8%	Evans (2004)
France	3.5%	Evans and Sezer (2004)
Germany	4.1%	Evans and Sezer (2004)
Italy	3.7-3.8%	Percoco (2006)
Japan	5.0%	Evans and Sezer (2004)
UK	4.2%	Evans and Sezer (2004)
UK	3.71-4.84%*	Evans and Sezer (2002)
UK	6%	HM Treasury (1997)
USA	4.6%	Evans and Sezer (2004)
USA	5.3%	Kula (1984)

(*) The range is due to different assumptions on altruistic behaviour

Table 3: Social Discount Rates for Carbon Sequestration Projects

<i>Country</i>	<i>Social Discount Rate</i>	<i>Source</i>
Brazil	0-5%	Fernside (1995)
Global	6%	Nordhaus (1991)
Malaysia	0-3%	Ismail (1995)
Malaysia	6-10%	Boscolo et al. (1997)
Norway	2-7%	Hoen and Solberg (1994)
USA	4-8%	Moulton and Richards (1990)
USA	10%	Adams et al. (1993)
USA	2.5-10%	Stavins (1999)
USA	4%	Parks and Hardie (1995)
USA	2-10%	Englin and Callaway (1995)

NOTE: This tables relies on data reported in Boscolo *et al.* (1998).

Table 4: Characteristics of the studies

Article	Type	Real or Hypo	Elicitation Method	Good
Maital & Maital (1978)	experimental	h	choice	money & coupons
Hausman (1979)	field	r	choice	money
Gateley (1980)	field	r	choice	money
Thaler (1981)	experimental	h	matching	money
Ainslie & Haendel (1983)	experimental	r	matching	money
Houston (1983)	experimental	h	other	money
Loewenstein (1987)	experimental	h	pricing	money & pain
Moore and Viscusi (1988)	field	r	choice	life years
Benzion et al. (1989)	experimental	h	matching	money
Viscusi & Moore (1989)	field	r	choice	life years
Moore & Viscusi (1990a)	field	r	choice	life years
Moore & Viscusi (1990b)	field	r	choice	life years
Shelley (1993)	experimental	h	matching	money
Redelmeier & Heller (1993)	experimental	h	rating	health
Cairns (1994)	experimental	h	choice	money
Shelley (1994)	experimental	h	rating	money
Chapman & Elstein (1995)	experimental	h	matching	money & health
Dolan & Gudex (1995)	experimental	h	other	health
Dreyfus and Viscusi (1995)	field	r	choice	life years
Kirby & Marakovic (1995)	experimental	r	matching	money
Chapman (1996)	experimental	h	matching	money &

Kirby & Marakovic (1996)	experimental	r	choice	health money
Pender (1996)	experimental	r	choice	rice
Wahlund & Gunnarson (1996)	experimental	h	matching	money
Cairns & Van der Pol (1997)	experimental	h	matching	money
Green, Myerson & McFadden (1997)	experimental	h	choice	money
Johannesson & Johansson (1997)	experimental	h	pricing	life years
Kirby (1997)	experimental	r	pricing	money money & heroin
Madden et al. (1997)	experimental	h	choice	
Chapman & Winquist (1998)	experimental	h	matching	money
Holden, Shiferaw & Wik (1998)	experimental	r	matching	money & corn
Cairns & Van der Pol (1999)	experimental	h	matching	health money & health
Chapman, Nelson & Hier (1999)	experimental	h	choice	money
Coller & Williams (1999)	experimental	r	choice	
Kirby, Petry & Bickel (1999)	experimental	r	choice	money
Van Der Pol & Cairns (1999)	experimental	h	choice	health money
Chesson & Viscusi (2000)	experimental	h	matching	health money
Ganiats et al. (2000)	experimental	h	choice	money
Hesketh (2000)	experimental	h	choice	
Van Der Pol & Cairns (2001)	experimental	h	choice	health money
Warner & Pleeter (2001)	field	r	choice	
Harrison, Lau & Williams (2002)	experimental	r	choice	money other money
Weitzman (2001)	experimental	h	choice	
Laibson et al. (2004)	field	r	choice	

Source: Frederick *et al.* (2003)

Table 5: Descriptive statistics of estimated discount rates and factors

	Mean	St. Dev.	Max	Min
Discount rate	0.141	0.148	0.960	-0.0006
Discount factor	0.877	0.871	1.001	0.510

Table 6: Meta-Regression (Dependent variable: Discount rate)

	1	2	3
C	0.061*** (0.007)	0.045*** (0.009)	0.039* (0.023)
RANGE	-0.002 (0.011)	-0.004 (0.004)	-0.007** (0.003)
HYPO	-0.035*** (0.011)	-0.023*** (0.009)	-0.021** (0.010)
YEAR		0.0012* (0.0014)	0.0011* (0.0008)
GDP		0.0018* (0.0012)	0.009** (0.004)
LIFE		0.015 (0.991)	0.018 (0.894)
NONUS		0.005 (0.105)	0.002 (0.299)
FIELD		-0.071** (0.032)	-0.135 (0.044)
CHOICE			-0.089 (0.108)
MATCHING			-0.0136 (0.011)
HEALTH			-0.025* (0.019)
MONEY			-0.011 (0.0188)

Pseudo-R ²	0.183	0.246	0.262
Nobs	513	513	513

NOTES: OLS estimates; Standard Errors are in parenthesis.

*** significant at 99%; ** significant at 95%; * significant at 90%