Discounting for environmental effects in infrastructure project appraisal

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Abstract

The aim of this paper is to present an alternative methodology for discounting far distant future externalities genereted by an investment project: time-declining discount rates. First I present the experimental evidence on individuals' time-inconsistency. Second I consider the theoretical justification for using hyperbolic discounting.

1 Introduction

All infrastructure projects have some environmental effects, either positive or negative, since either directly or indirectly all projects will create some demand on natural resources and some waste products to be assimilated by the environmnt.

Recent policy discussion have stressed the importance of environmental sustainability to ensure that projects do not make demands on the environment that are excessive relative to the current stock of natural capital. However, whether or not environmental considerations are important for a particular project will vary with its characteristics; a simple classification may serve to illustrate the point. We can think:

1. projects where the main objective is to produce an environmental benefit, either in terms of an improvement to the environment or the avoidance of damage that would otherwise occur;

2. projects with non-environmental objectives, but with significant environmental effects (this is the main case for transport infrastructure);

3. projects with non-environmental objectives and relatively minor environmental effects.

If environmental effects can be quantified and valued they must be incorporated in a project analysis in the same way as other benefits and costs. This requires their reduction to present values through the procedure of discounting: however the use of ordinary discount rates to adjust environmental effects remains controversial.

The conventional justification for the use of discount rates is that resources hace an opportunity cost and that the resources that are available in the present can be invested to produce future income; tha marginal rate of return on invested resources thus provides a quantitative measure of the cost of waiting. The transfer of the concept of discounting, used tipically for relative short-term productive sector projects with tangible marketed outputs, to the appraisal of often long-term and normally high uncertain environmental effects has caused considerable debate and much unease. The most radical solution is one of using a special rate for the environmental effects of a project with a conventional rate applied to the non-environmental effects of the same project. Such a special discount rate would be either very low or zero. Different rationales can be used to justify this special treatment; the most rigourous argues that discounting should be about comparing the future values of goods and income streams with their value in the present and that in principle there could be a different rate of decline in value over time (and thus different discount rates) for all different goods and tyoes of income. The basis for this decline in value will be the diminishing additional utility that can be obtained from higher incomes allow.

The present paper aims to provide some support to the idea that exponential discounting for infrastructure costs and benefits do not take into account some recent acquisitions of psychology and economics. In fact, there is quite strong empirical evidence that people discount the future hyperbolically with larger annual discount rates to near-term that to returns in the distant future.

In this study I ask: *Can we use hyperbolic discount function rather than exponential one for public project appraisal?* My answer is that we have to use it to distant environmental effects (because they appear in far distant future).

The paper is organised as follow: section 2 and 3 present a review of experimental evidence and theoretical literature, section 4 contains come notes on the use of hyperbolic discounting in a project appraisal framework and 5 summarize some conclusion and a research agenda.

2 Experimental evidence

An important psychological finding on time preferences is that individual discount functions are hyperbolic, suggesting that people have a taste for immediate gratification. Furthermore, actual preferences over person's future delays in rewards are different than her future preferences over those same delays, so that preferences are not time consistent.

An example taken form Kocherlakota (2001) could better explain basic concepts:

> "*Jan is about to go out to her neighborhood 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, anche she wants to prevent her self from doing so*"
>
> [Kocherlakota (2001), p. 13]

Jan is exhibiting what economists call time-inconsistent preferences: her preferences for beer, at a given date and state, change over time without the arrival of new information.

Several models of time-variant discount rate have been developed by economists. Robert Strotz (1956) was the first one who sudied time-inconsistency in a dynamic framework:

> "*Special attention should be given, I feel, to a discount function...which differs froma a logarithmically linear one in that it "over values" the more proximate satisfaction relative to the more distant ones...My own supposition is that most of us ae "born" with [such] discount functions...*"
>
> [Strotz (1956), p. 177 quoted in Thaler (1981), p. 201-202]

Phelps and Pollak (1968) introduced hyperbolic discount functions in an intergenerational context on consumption and saving. They capture taste for immediate gradification with a simple two-parameter model that slightly modifies exponential discounting. Let $u_t$be the instantaneous utility of a person in period t. Then her intertemporal preferences at time t, U^t, can be represented by the following utility function, where both β and δ lie between 0 and 1

$$U^t(u_t) = \delta^t u_t + \beta \sum_\tau \delta^t u_t$$

The parameter δ determines how "time-consistently" patient a person is, just as in exponential discounting. If $\beta = 1$, then these preferences are simply exponential discounting. But for $\beta < 1$, these preferences capture in a parsimonious way the type of time-inconsistent preferences so widely observed.

Decrease in timing aversion has been observed in experimental studies concerning: people choosing between non-monetary alternatives [see Solnick et alii

(1980); Christensen and Szlanski (1984), Millar and Navarick (1984) and Cropper et al. (1992)]; people choosing [Thaler (1980); Ainslie and Haendel (1983), Horowitz (1988) and Benzion et al. (1989)]; animals choosing between types of food or between other alternatives [Raichlin and Green (1972); Ainslie (1975); Ainslie and Herrnstein (1981)]. As Harvey argues, 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 becomes small. Loewenstein and Prelec (1992) compare violations of constant discounting to the much more studied violations of expected utility as they observe that:

> *"unlike [expected utility] violations, which in many cases can only be demonstrated with a clever arrangement of multiple choice problem (e.g. Allais paradox), the counter-examples to DU [constant discounting] are simple, robust and bear directly on central aspects of economic behaviour"*
>
> [Loewenstein and Prelec (1992)]

As noted above, 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. The results of two types of experiments were introduced to support the hyperbolic discounting case:

The first type is discussed first by Thaler (1981). Some people prefer "one apple today" to "two apple tomorrow" to "one apple in one year". Ainslie and Haslam (1992) reports that

> *"a majoirty of subjects say they would prefer to have a prize of $100 certified check available immediately over $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"*
>
> [Ainslie and Haslam (1992)]

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 immagine 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 \$$y$ immediately, then we say that the subject's choice is consistent with the discount rate $\delta(x, t)$ defined by the equation

$$y \equiv \delta(x,t)^t x$$

The results show that the average discount rate is decreasing in t. However, it was also found that $\delta(x,t)$ is not constant but it is an increasing function of x. The larger the sum of money at stakes, the higher (closer to 1) the discount factor.

Rubinstein (2000), 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 reltions better explains the observations and is more intuitive.

3 Some few notes on theoretical literature

An increasing number of theoretical papers has been published in recent years.

Laibson (1994 and 1997) studies a one-person intertemporal decision problem of consumption and saving. His main findings are that we can distinguish an hyperbolic economy from an exponential one in two ways:

1. hyperbolic discounting predicts the empirical regularity that the elasticity of intertemporal substitution is less than the inverse of the coefficient of relative risk aversion;

2. hyperbolic discounting explains many features of the policy debate about undersaving.

Laibson's model suggests that financial innovation may have caused ongoing decline in U.S. savings rate, since financial innovation increases liquidity, eliminating commitment opportunities.

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 future choices of consumption and if utility is logarithmic, then the equilibrium resembles the standard results.

Krusell and Smith (2000) try to answer the question: *How do individuals with time-inconsistent preferences make consumption-savings decisions?* They consider a simple form of consumption-saving problem, assuming people discounting in a quasi-geometric way. They find that when 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 into this stationary point.

One of the most closely related study to this paper is Krusell, Kuruscu and Smith (2000). They consider a representative-agent equilbrium model where the consumer, as usual, has quasi-geometric time preference and cannot commit 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.

4 Hyperbolic discounting and infrastructure project appraisal

Discounting reflects the generally accepted idea that a given amount of resources available for use in the future is worth less than the the same amount of resources available today. This is because, through investment, one can transform resources in the future. Viewed some what differently, discounting is also needed because people prefer to consume a given amount of resources now rather than in the future.

The neoclassical theory of project evaluation (Arrow and Kurz, 1970) is based on models in which agents discount the future at a constant exponential rate: that the choice between two payoffs depends only on the absolute time interval separating them.

On the contrary, there are at least three reasons to consider using a time-dicling discount rate:

1. there is strong empirical evidence that individuals use lower discount rates for events that occur farther into the future;

2. a large enough positive discount rate gives negligible weight to costs and benefits that occur far into the future, using a time-diclining rate avoids having to choose between ignoring verty long-term environmental consequences (with a time-invariant, nonzero 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.

Cropper and Laibson (1999) find

Keller and Strazzera (2000) offer an axiomatic approach to hypebolic discount function starting from the hypothesis that different sets of behavioural assumtions generate different typs of discounting models. They refer to the general approach taken by Fishburn and Rubinstein (1982). Given a non-degenerate real interval X (the set of outcomes), and either a set T of successive non-negative integers, or an interval T of non-negative numbers (the set of time points), consider the topological space $X \times T$ (the dimensions of outcomes and time). Consider the axioms:

Axiom 1 $\geq$ *is a weak order on* $X \times T$*;*

Axiom 2 *If* $x > y$ *then* $(x, t) > (y, t)$*;*

Axiom 3 $\{(x, t) : (x, t) \geq (y, s)\}$*, and* $\{(x, t) : (x, t) \leq (y, s)\}$ *are closed in the product topology on* $X \times T$

Axiom 4 *If* $s < t$ *then* $x > 0$ *implies* $(x, s) > (x, t); x = 0$ *implies* $(x, s) = (x, t); x < 0$ *implies* $(x, s) < (x, t)$

The first three axioms ensure continuity, monotonicity, and orderiing, of outcomes in the space $X \times T$; the fourth is the behavioral assumption of impatience for positive outcomes, and procrastination for negative outcomes. Fishburn and Rubinstein show that this axiomatic structure implies the existence of a real valued function u on $X \times T$ that is monotonic in x and t; continuous and decreasing in x; continuous in t if t is continuous; decreasing (constant, increasing) in t if x is greater (equal, less) than zero.

Fishburbn and Rubinstein do not provide a specific functional form associated with the general set of Axioms 1-4. A representation function is instead provided when an axiom of stationarity is added to the previous set of axioms:

Axiom 5 *If* $(x, t)R(y, t + d)$ *then* $(x, s)R(y, s + d)$

The model implied by this axiomatic structure assumes the form

$$\alpha^t f(x)$$

known as the *exponential discounting model* when f is linear on x.

By inserting the stretching axiom proposed by Harvey (1986)[1]:

Axiom 6 *If* $(x, s)R(y, t)$ *then* $(x, d \cdot s)R(y, d \cdot t)$

we have the following representation, known as the *hyperbolic model*:

$$\frac{1}{(1+t)^\gamma} fx \tag{1}$$

where $\gamma > 0$ is a parameter that represents individuals' intertemporal preferences. Figure 1 graphs exponential and hyperbolic discount functions.

The main question, arising in recent years, is how to concile experimental evidence with economic logics. In psychological tests, subject are asked to choose between an amount x, t periods from now, and a smaller amount y now. The apparent discount factor is then calculated as the solution δ to the equation

$$xe^{-\delta t} = y \tag{2}$$

If we consider an hazard rate h (with a probability distribution $f(h)$), the subject would perform the following calculation:

[1] It states that the ordering of outcomes in two periods depends on the relative difference (the ratio) between two periods)

Figure 1

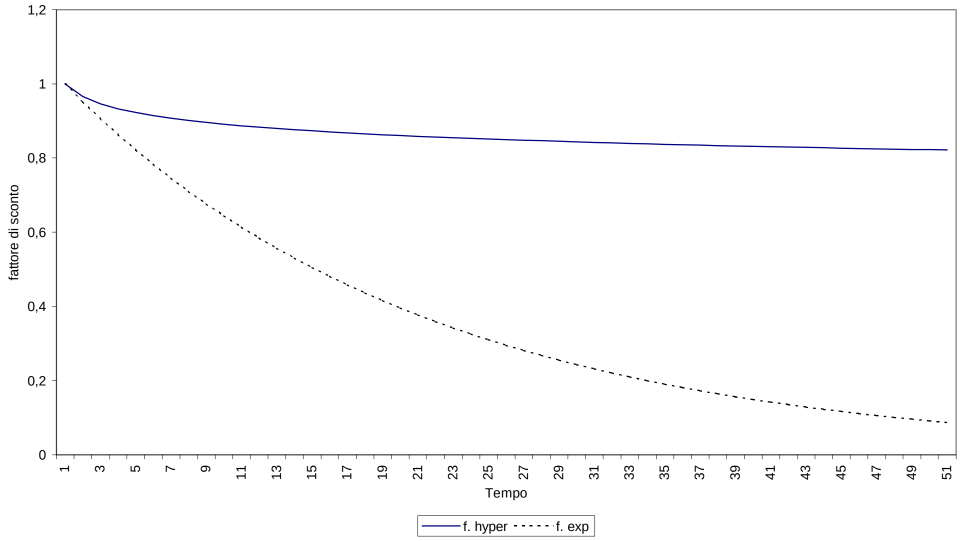

Figure 1:

$$NPV(x,t) = x\Pr(t)e^{-\delta t} = x\left(\int_0^t e^{-ht}f(h)\mathrm{d}h\right)e^{-\delta t} = y \tag{3}$$

where $NPV(x,t)$ is the net present value of getting x at time t, $\Pr(t)$ is the probability of getting x at time t, and $e^{-\delta t}$the true discount factor. Azfar demonstrates the following proposition.

Theorem 7 *If the hazard rate h has a non trivial probability distribution f(h), then the apparent discount rate declines over time t.*

Proof. The proof is a trivial application of Jensen's inequality. Let $t_1 < t_2$.

Combining Eqs.(2) and (3) δt_1 is calculated as the solution to ■

Proposition 8 ***Proof.***

$$e^{-\delta(t_1)t_1} = e^{-\delta t_1}\int_0^\infty e^{-ht_1}f(h)dh \tag{4}$$

then

$$e^{-\delta(t_1)t_1} < e^{-\delta t_1}\left(\int_0^\infty \left(e^{-ht_1}\right)^{\frac{t_2}{t_1}} f(h)dh\right)^{\frac{t_1}{t_2}} \tag{5}$$

by Jensen's inequality:

$$e^{-\delta(t_1)t_2} < e^{-\delta t_2}\left(\int_0^\infty e^{-ht_2} f(h)dh\right) \Rightarrow \delta(t_1) < \delta(t_2) \tag{6}$$

■

Thus, the discount rate declines as the time between the present and the discounted period rises because the presence of uncertainty about hazard rates.

Weitzman (1999) derived similar results from a quite different theoretical structure. In particular, he demonstrates the following proposition.

Theorem 9 *Let us assume*
$R(t)$ *as the certainty-equivalent discount rate*
$R^* \equiv \lim_{t\to\infty} R(t)$ *as the certainty-equivalent instantaneous discount rate*
$r^*_{\min} = \min_j \{r^*_j\}$ *as the lowest possibile far distant future discount rate for the j-th scenario*
Thus:

$$R^* = r^*_{\min}$$

Proof. *See Weitzman (1999)* ■

Previous propositions suggest that it may be essential to incorporate declining discount rates into any benefit-cost analysis for evaluating long term environmental effects generated by (infrastructure) projects.

Thus, in the world described by such theorems, the question is: *When is the far-distant future?*

Newell and Pizer (2001) find that costs and benefits in the distant futuresuch as those associated with global warming, long-lived infrastructure, hazardous and radioactive waste, and biodiversityoften 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 (which are indistinguishable based on historical data), they compute the certainty-equivalent ratethat is, the single discount rate that summarizes the effect of uncertainty and measures the appropriate forward rate of discount in the future.

Years in future	Discount rate model			Value relative to constant discounting	
	Constant	Mean reverting	Random walk	Mean reverting	Random walk
0	$100.000	$100.000	$100.000	1.0	1.0
20	49.369	51.681	54.526	1.0	1.1
40	24.373	25.679	30.168	1.1	1.2
60	12.033	12.750	17.561	1.1	1.5
80	5.940	6.387	10.906	1.1	1.8
100	2.933	3.237	7.218	1.1	2.5
120	1.448	1.661	5.055	1.1	3.5
140	0.715	0.865	3.713	1.2	5.2
160	0.353	0.457	2.840	1.3	8.0
180	0.174	0.246	2.246	1.4	12.9
200	0.086	0.136	1.824	1.6	21.2
220	0.042	0.076	1.517	1.8	35.7
240	0.021	0.044	1.286	2.1	61.3
260	0.010	0.027	1.108	2.6	107.0
280	0.005	0.017	0.967	3.2	189.3
300	0.003	0.011	0.855	4.2	339.1
320	0.001	0.007	0.764	5.8	613.7
340	0.001	0.005	0.689	8.2	1120.9
360	0.000	0.004	0.626	12.2	2063.7
380	0.000	0.003	0.574	18.8	3827.4
400	0.000	0.002	0.529	30.2	7144.5

Figure 2:

In particular, when the interest rate changes over time, the discount factor is:

$$\beta_\tau = \prod_{t=0}^{\infty} \frac{1}{(1+r_t)}$$

Alternatively, one can compute the discount factor recursively:

$$\beta_t = \frac{\beta_{t-1}}{1+r_t}$$

which can be re-arranged as

$$r_t = \frac{\beta_{t-1}}{\beta_t} - 1 \qquad (7)$$

By estimating (7), Newell and Pizer achieve the following results:

Table 1 *Value Today of $100 in the Future*
Source: Newell and Pizer (2001)

Table 1 contains the estimates of 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.

Afetr only 80 years, conventional discounting at a constant 4% undervalues the future by a facto of 2, based on 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 yet still significant results, raising the discount factor by a multiple of about 130 after 400 years.

Newell and Pizer find also that the difference between valuations using different initial rates is smaller when uncertainty about future rates is incorporated.

In order to answer the question *When is the far-distant future?*, the long term period in environmental effects appraisal is after 100 years.

5 Conclusion

The presence of uncertainty about future discount rates provides a rationale for using hyperbolic discount function in long term effects appraisal.

From a positive point of view, Weitzman (1999) defines two implications:

1. the declines in discount rates could be a significant phenomenon such that one might use hyperbolic discounting for any cost-benefit analysis of the effects in far-distant future;

2. it would be better to consider, for social choices tha low-interest-rate situation because, *coeteris paribus*, that situation will carry relatively more weight in determining the expected difference between present discounted benefits and costs.

Besides, theoretical literature should make an effort to provide a methodology to smooth estimeted environmental externalities over the future. It should also be noted that if we define the long term period as *after 100 years*, it is too difficult to allow for future effects generated by a transport infrastructure because the relatively small dimension of the investment project if compared to climate change mitigation programm or biudiversity preservation policy.

Further research could consider the possible link between hyperbolic discounting and real option theory and the existence of a spatial inconsistency.

First , an interesting theorem has been demonstrated by Nir (2000):

Theorem 10 *If individuals believe that their wealth might increase in future with a small-perceived probability that it will decrease, then they discount hyperbolically.*

Proof. *see Nir (2000)* ■

This result seems to be very close to real option approach to irrevesibility in environmental project evaluation.

Second, as Percoco (2002) has argued, re-arranging an original idea of Perrings and Hannon (2001), it should be important to consider space in externalities discounting and it should be the case for a space-inconsistency of individuals. Further research in this field should model space and time inconsistency in a benfit-cost analysis framework.

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