Implications of declining discount rates: Climate Change Policy in the UK

Groom, Ben and Hepburn, Cameron and Koundouri, Phoebe and Pearce, David

2007

Implications of declining discount rates: Climate Change Policy in the UK

Ben Groom[1]

Phoebe Koundouri[2]

1 Introduction

Discussions about applied Cost Benefit Analysis are incomplete without the thorny issue of discounting emerging at some point. Indeed, since the calculation of Net Present Values (NPV), and hence the efficiency of a project or policy, hinges so crucially upon the level of the discount rate applied across time, the analysis of time preference and discounting has become an active area of research in its own right. Nowhere is this debate more hotly contended that when CBA is used to evaluate projects with impacts that extend into the far distant future such as biodiversity conservation, nuclear power and, of course, climate change. This chapter aims to review some of the more recent contributions to this debate and in particular, the theory that underpins recent calls for the use of declining discount rates (DDRs). We then discuss how a schedule of DDRs can be estimated and illustrate their impact upon two topical policy questions: climate change and nuclear power.

Economists and others have argued at length over which of several potential discount rates should be used as the SDR (e.g. Marglin 1963, Baumol 1968, Lind 1982). Several candidates exist, the most widely recognised of which are the social rate of return on investment (r) and the rate at which society values consumption at different points of time, the Social Rate of Time Preference (δ). The distinction between these discount rates is most important in the second best world in which distortions to the economy, such as corporate and personal taxes or environmental externalities, prevent these rates from being equalised. The choice of SDR is inherently complicated in such situations[3]. Common practice in CBA has been that, however one chooses the SDR, the relative weights applied to all adjacent time periods would be invariant across the time horizon considered.

A common critique of discounting is that it militates against solutions to the long-run environmental problems mentioned above. Some policy questions and projects need to be evaluated over a time horizon of several hundred years. With a constant rate, the costs and benefits accruing to generations in the distant future appear relatively unimportant in present values terms. Hence decisions made today on the basis of CBA appear to tyrannise future generations and in extreme cases leave them exposed to potentially catastrophic consequences. Such risks can either result from current actions, where future costs are carry no weight, e.g. nuclear decommission, or from current inaction, where the future benefits carry no weight, e.g. climate change. Hence the question arises: What is the appropriate procedure for such long time horizons? There is wide agreement that discounting at a constant positive rate in these circumstances is problematic, irrespective of the particular discount rate employed. These intergenerational issues associated with discounting have puzzled generations of economists. Pigou (1932) referred to the apparent myopia of exponential discounting with regard to future welfare as a 'defective telescopic faculty'. More recently Weitzman (1998) summarises this puzzle succinctly when he states:

> *'to think about the distant future in terms of standard discounting is to have an uneasy intuitive feeling that something is wrong, somewhere'.*

Discounting also appears to be contrary to the widely supported goal of 'sustainability' which by most definitions implies that policies and investments now must have due regard for the need to secure sustained increases in per capita welfare for future generations (Wald Commission on Environment and Development 1987, Atkinson et al. 1997). Also, by attaching little weight to future welfare conventional discounting appears to ignore any notion of intergenerational equity. So, in short, the correct procedure in these circumstances is not immediately obvious.

[1] Department of Economics, University College London.
[2] School of Business, Department of Economics, Reading University.
[3] See Lind (1982) for an excellant review of thes issues.

A recently proposed solution to this problem is to use a discount rate which declines with time, according to some predetermined trajectory, this raising the weight attached to the welfare of future generations. It is immediately obvious that using a declining discount rate (DDR) would make an important contribution towards meeting the goal of sustainable development. So, what formal justifications exist for using a DDR and what is the optimal trajectory of the decline?

As far as the former issue is concerned, there are a number of rationales that effectively assume a deterministic world. For example, Dasgupta (2001) shows that DDRs can arise as a result of known changes in the growth rate or the consumption smoothing/risk aversion parameter. A seminal contributions by Krutilla and Fisher (1975) was the first to suggest that the evolution of willingness to pay for the environment could also be captured by the discount rate, a theme also touched upon by Weitzman (1994) in the presence of environmental externalities. The strengths and weaknesses.of these rationales have been well documented (e.g. Arrow et al 1995, Horowitz 2002).

Additional motivations emerge once uncertainty is considered. Uncertainty of the discount rate itself provides a simple and intuitive approach in a risk neutral environment (Weitzman 1998, 2001). In the presence of uncertain growth Gollier (2002a,b) shows that the shape of the yield curve, that is the term structure of the interest rate, depends upon preferences for risk and prudence, and higher order moments of the utility function. DDRs also emerge from the specification of a 'sustainable' welfare function á la Chichilnisky (1997) and Li and Löfgren (2000). Lastly, there is considerable empirical and experimental evidence to show that individuals are frequently hyperbolic discounters (e.g. Lowenstein and Prelec 1992, Frederick et al 2002)[4]. Bateman and Henderson (1995) argue that this is sufficient reason for similar discounting schedules to be employed in social decision making.

Once a rationale for DDR has been subscribed to, implementation requires the practitioner to identify a particular set of parameters, i.e. an answer to the second question raised: what trajectory a DDR should follow? The required parameters for determining the time invariant discount rate in the deterministic case have been discussed extensively elsewhere (see, for example, Pearce and Ulph, 1999) and are well understood. In this chapter, we focus upon the application of the more recent contributions. Section 2 gives the background literature, section 3 dicussed the the implications of declining discount rates by using a case study on the climate change policy in the UK and section 4 concludes the paper.

2 Background Literature

2.1 Uncertainty and DDRs

In the case of Gollier (2002a,b, 2004b) and Weitzman (1998) it is uncertainty that drives DDRs, with regard to future growth and the discount rate respectively. One thing common to both of these approaches is that the eventual schedule of discount rates is highly dependent upon the characterisation of the background uncertainty and hence the question of implementation is one of characterizing the uncertainty of the uncertain variables in some coherent way. However, of these two approaches it is Weitzman (1998) that has proven to be more amenable to implementation mainly because the informational requirements stop at the characterization of uncertainty, and do not extend to specific attributes of future generations' risk preferences as would be unavoidable in the case of Gollier[5].

Weitzman's Certainty Equivalent Discount Rate (CER) is a summary statistic of the distribution of the discount rate. and the level and behaviour over time of this statistic is clearly dependent upon the features (static and dynamic)of the associated probability distribution. The two applications that exist have taken different approaches stemming from different interpretations of uncertainty. Weitzman (2001) defines uncertainty by the current lack of consensus on the appropriate discount rate for the very long term. His survey of professional economists results in a gamma probability distribution for the discount rate which leads to the so-called 'gamma discounting' approach, a version of which can also be seen in Sozou (1998).

In particular, Weitzman uses certainty equivalent analysis for risk-neutral agents and defines the *certainty equivalent discount factor* (CEDF) as the expectation of the discount factor. From this he derives the

[4] See Groom et al (2004a) for a review.

[5] Weitzman (1998) assumes risk neutral agents for exposition, but this represents a special case of his general point. For realistic scenarios, determination of DDRs a la Gollier (2002a, 2002b) requires knowledge of the 4th and 5th derivatives of utility functions, something that he admits is very far from being accomplished.

certainty equivalent discount rate (CER). Supposing that each potential discount rate r_j is realised with probability p_j, such that $\Sigma p_j = 1$ and $r_j \in [r_{\min}, r_{\max}]$ $(j = 1, ..., n)$. Defining the discount factor for a particular scenario is $a_j(t) = \exp\left(-\int_0^t r(s)\,ds\right)$, the certainty equivalent discount factor for a risk neutral agent is defined as:

$$A(t) = E\left[\exp\left(-\int_0^t \tilde{r}(s)\,ds\right)\right] = \sum_j p_j a_j(t) \tag{1}$$

From this it is possible to define both the average and marginal certainty equivalent discount rates at time t, corresponding to the definitions in Section 2: r_a^{CER} and r_m^{CER} respectively:

$$\exp\left(-r_a^{CER}(t)\,t\right) = A(t) \Longrightarrow \tag{2}$$

$$r_a^{CER}(t) = -\frac{1}{t}\ln\left[A(t)\right] \tag{3}$$

$$r_m^{CER}(t) = -\frac{\frac{\partial}{\partial t}A(t)}{A(t)} \tag{4}$$

The former is the rate of discount that if applied in every period from 0 to t would yield the same value as the expected discount factor at time t. The latter is the instantaneous, period-to-period rate. Weitzman (1998) works with r_m^{CER}, noting that at the limit, as $t \to \infty$, they are precisely the same. Importantly he shows that r_m^{CER} declines continuously and monotonically over time and that its limit as $t \to \infty$ is $r_{\min}$. More generally, Gollier (2002b) explains that an arbitrage exists if, prior to realisation of r, (2) does not hold. Hence, the certainty equivalent discount rate is the equilibrium socially efficient rate for risk neutral agents prior to the realisation of $\tilde{r}$.

The mechanics behind the result are shown in Appendix 1, however, the intuition is as follows. In calculating the weighted average that is the certainty equivalent each potential realisation of the discount rate is weighted by a term which contains $a_j(t)$, the discount factor associated with that scenario. In scenarios with higher discount rates the discount factors decline more rapidly to zero. As such, the weight placed on scenarios with high discount rates itself declines with time, until the only relevant scenario is that with the lowest conceivable interest rate. In effect, the power of exponential discounting reduces the importance of future scenarios with high discount rates to zero, since the discount factor in these scenarios goes to zero. Since in the ex ante equilibrium the certainty equivalent rate of discount must equal the socially efficient discount rate in all periods of time, this results in a SDR which declines over time.

2.1.1 Numerical Example of Weitzman's CER:

Suppose that there are two potential realisations of the discount rate (r_1, r_2) with associated probabilities (p_1, p_2). Using the definitions (1) and (4) we obtain the certainty equivalent discount factor and rate at time t:

$$A(t) = p_1\exp(-r_1 t) + p_2\exp(-r_2 t) = p_1 a_1(t) + p_2 a_2(t) = \sum p_j a_j(t)$$

$$r_m^{CER} = -\frac{\dot{A}(t)}{A(t)} = \frac{r_1 p_1 a_1(t) + r_2 p_2 a_2(t)}{p_1 a_1(t) + p_2 a_2(t)} = w_1(t)\,r_1 + w_2(t)\,r_2 = \sum w_j(t)\,r_j$$

where the weights are $w_1(t) = p_1 a_1/(p_1 a_1 + p_2 a_2)$ and $w_2(t) = p_2 a_2/(p_1 a_1 + p_2 a_2)$ and $\Sigma w_j(t) = 1$. This formula is used for r_m^{CER} in Table 1 below. The formula for r_a^{CER} is:

$$r_a^{CER} = -\frac{1}{t}\ln\left[p_1\exp(-r_1 t) + p_2\exp(-r_2 t)\right]$$

Using (11) and the fact that:

$$\dot{w}_j(t) = \frac{p_j a_j(t)}{\Sigma p_j a_j(t)} \cdot \frac{\Sigma r_i p_i a_i(t)}{\Sigma p_i a_i(t)} - \frac{r_j p_j a_j(t)}{\Sigma p_j a_j(t)} = w_j(t)\left(r_m^{CER} - r_j\right)$$

the derivative of r_m^{CER} with respect to time then becomes:

$$\frac{d}{dt} r_m^{CER} = -\left[w_1\left(r_m^{CER} - r_1\right) r_1 + w_2\left(r_m^{CER} - r_2\right) r_2\right] = -\sum \omega_j(t)\left(r_m^{CER} - r_j\right)^2$$

which is clearly negative.

Table 1 shows the resulting schedule of marginal and average discount rates over continuous time assuming that $(r_1, r_2) = (5\%, 2\%)$ and $(p_1, p_2) = (0.5, 0.5)$. Table 1 reflects the aspects of the certainty equivalent discount rate described above. Both the average and the marginal certainty equivalent rates are declining monotonically through time while approaching the lowest possible realisation in the long-run: $r_{\min} = 2\%$.

	Year (t)				
	10	50	100	200	500
Discount factor $(a_1(t))$	0.819	0.368	0.135	0.018	0.000
Discount factor $(a_2(t))$	0.607	0.082	0.007	0.000	0.000
CEDF $(A(t))$	0.713	0.225	0.071	0.009	0.000
Marginal CER $\left(r_m^{CER}\right)$	3.277%	2.547%	2.142%	2.007%	2.000%
Average CER $\left(r_a^{CER}\right)$	3.388%	2.983%	2.645%	2.345%	2.139%

Table 1. Numerical Example of Weitzman's Certainty Equivalent Rate

More recently, Newell and Pizer (2003) consider the interest rate as a stochastic process, that is there is uncertainty in the future about interest rates. N&P characterise this uncertainty using time series econometric modelling of the autocorrelation process of interest rates. The estimated model is used to forecast future rates based upon their behaviour in the past. From these forecasts they derive numerical solutions for the CER. In doing so they are also able to provide a test of another assumption important to the Weitzman (1998) result, namely the presence of persistence of discount rates over time. They compare the discount rates modelled as a mean reversion process to a random walk model, and find support for the latter. The practical implications of implementing the declining discount rates that result are significant.

When applied to global warming damages, the present value of damages from carbon emissions increases by 82%, compared with the same damages evaluated at the constant treasury rate of 4%. In monetary terms this translates into an increase in the benefits of carbon mitigation from \$5.7/ton of carbon, to \$10.4/ton of carbon. However, using UK interest rate data Groom et al (2004) provide a more thorough econometric analysis of the extent to which uncertainty in the future causes DDRs and find that model specification is crucial to the analysis, not least because of the distributional assumptions contained therein. Indeed, they find little evidence of the persistence noted by Newell and Pizer, suggesting that in the UK context the effect of future uncertainty upon the valuation of global warming damages is minimal.

The rationale for declining discount rates provided by Gollier (2002a, 2002b) is perhaps the most theoretically rigorous of all the contributions, given the indeterminacy surrounding Weitzman (1998). But determination of the trajectory requires very specific information concerning the preferences of current generations at the very least, and, in the long-run, the preferences of future generations[6]. These parameters include the aversion to consumption fluctuations over time, the pure time preference rate, and the degree of relative risk aversion. For the case with zero recession, restrictions on the 4th and 5th derivatives of the utility function become necessary. In addition, the probability distribution of growth needs to be characterised in some way. Clearly, the informational requirements of the Gollier approach could be daunting.

2.2 Intergenerational Equity and Sustainability

Then we have the contributions which take sustainable growth and inter-generational equity as their departure point. The main focus of the discussion is on the important contributions of Chichilnisky (1996, 1997)

[6] With the infinitely lived representative agent approach there is effectively only one agent, and thus one generation. The reference to current and future generations is therefore an intuitive interpretation of the long-run.

and Li and Löfgren (2000), both of which explicitly introduce the notions of intergenerational equity and sustainability. Each paper models optimal sustainable economic growth and each is concerned with deriving the welfare effects of growth paths which are sustainable in the sense that they satisfy particular axioms with regard to intergenerational equity. The axioms employed imply social preferences which are 'sustainable' or 'intertemporally equitable'. Welfare is measured in terms of the utility of a social planner and, with utility as their numeraire, the discussion of discount rates concerns the utility discount rate, ρ, rather than the social rate of time preference, δ, or the social rate of return, r. Both contributions show that a declining utility discount rate is consistent with a rule whereby current (future) generations must always take into account the well-being of future (current) generations. That is, there must be no 'dictatorship' of one generation over another.

Chichilnisky (1997) introduces two axioms for sustainable development[7]. She also characterises the preferences that satisfy these axioms. The axioms require that the ranking of alternative consumption paths is sensitive not only to what happens in the present and immediate future, but also to what happens in the very long run. Sensitivity to the present means that there is no date before which events are given zero weight. Sensitivity to the long-run future means that there is no date where changes after that date do not matter, in the sense of affecting the ranking. Chichilnisky's criterion can be represented in the following objective function:

$$\max_{c,s} \pi \int_0^\infty u\left(c\left(t\right), s\left(t\right)\right) \exp\left(-\rho t\right) dt + \left(1-\pi\right) \lim_{t\to\infty} u\left(c\left(t\right), q\left(t\right)\right) \tag{5}$$

Instantaneous utility $u\left(.\right)$ is a function of consumption (c) and the resource stock (s) at each time period (t), while $\exp\left(-\rho t\right)$ is the conventional exponential utility discount factor. $u\left(.\right)$ is assumed to be the same for all dates so that generations are assumed to be the same in the way they rank alternatives.

Intuitively, the limit term reflects the sustainable utility level attained by a particular policy decision regarding $c\left(t\right)$ and $s\left(t\right)$. This can be interpreted as the well-being of generations in the far distant future. Chichilnisky's approach is a mixture of the two approaches seen so far: a generalisation of the discounted utilitarian approach, mixed with an approach that ranks paths of consumption and natural resource use according to their long-run characteristics, or sustainable utility levels. This criterion can be applied under the two main axioms regarding the ranking of alternative utility paths. Notice that $\pi \in [0,1]$, can be interpreted as the weight that the decision maker applies to each component of the criterion, with π providing the weight given to the present generation, and $(1-\pi)$ representing the weight placed upon the future generation.

In contrast to Chichilnisky (1997) who treats present and future generations as separate entities in the objective function of the decision maker, Li and Löfgren (2000) treat the future differently. Li and Löfgren assume society consists of two individuals, a utilitarian and a conservationist, each of which makes decisions over the inter-temporal allocation of resources. The utility functions of these two individuals are identical, and again have consumption and the resource stock as their arguments. The objective function employed by Li and Löfgren is:

$$\max U = \pi U_1 + \left(1-\pi\right) U_2 = \int_0^\infty u\left(c\left(t\right), s\left(t\right)\right) D\left(t\right) dt$$

where,

$$U_1 = \int_0^\infty u\left(c\left(t\right), s\left(t\right)\right) \exp\left(-\rho_U t\right) dt \tag{6}$$

$$U_1 = \lim_{\rho_C \to 0} \int_0^\infty u\left(c\left(t\right), s\left(t\right)\right) \exp\left(-\rho_C t\right) dt \tag{7}$$

where $D\left(t\right)$ is the discount factor. The important difference between these two decision makers is that they are assumed to discount future utilities at different rates. The utilitarian, who wants to maximise the present value of his utility (U_1), has a rate of time preference equal to ρ_U. The conservationist, who derives utility from conserving the stock of the natural resource, has a rate of time preference equal to ρ_C and maximises

[7] A discussion of this model is also found in Heal (1998).

his utility. The overall societal objective is to maximise a weighted sum of wellbeing for both members of the society, given their different respective weights upon future generations. The effective utility discount rate in Li and Löfgren is given by:

$$\rho(t) = -\frac{1}{t}\ln\{(1-\pi)\exp(-\rho_C t) + \pi\exp(-\rho_U t)\} \tag{8}$$

A time profile of discount rates can therefore be found by merely selecting the discount rates for the conservationist and the utilitarian, ρ_C and ρ_U respectively. For example, if the conservationist discounts the future at a rate of zero: $\rho_C = 0$, the discount factor becomes:

$$D(t) = (1-\pi) + \pi\exp(-\rho_U t) \tag{9}$$

In the distant future when t is large it has a minimum value of $(1-\pi)$, the weight attached to the conservationist, or future generations. It is in this way that the effective discount rate can be thought of as declining over time to zero. Thus, unlike the utilitarian discount function, which tends to zero as time reaches towards infinity, the weighted discount function tends to the weight for the far distant future. Hence Li and Löfgren's model results in a positive welfare weight for the conservationist and there is no dictatorship of present over future generations. As the utilitarian's welfare level is explicitly considered, there will also not be any dictatorship of the future over the present. Thus, the model explicitly considers intergenerational equity. Within this framework, the conservationist will dominate the far-distant future. Therefore the discount rate will be a declining function of the time horizon.

Implementation of the Li and Löfgren and Chichilnisky approaches requires the identification of several other parameters, including specification of the utility discount rate for the 'utilitarian', and perhaps more importantly, the relative weight to be assigned between 'conservationist' and 'utilitarian' preferences. Although the selection of this weighting might appear to be relatively arbitrary, it makes the trade-off between present and future generations explicit, and could possibly be determined by an appropriate political process.

3 Implications of declining discount rates: climate change policy in the UK

In this section we describe a declining discount rate schedule derived from the application of the estimation procedure used by Newell and Pizer (2003) (N&P) to UK interest rate data. In short, interest rates are forecasted over a period of 400 years using the results of an estimated reduced form random walk model. The schedule of certainty equivalent discount rates is derived from the simulation of up to 100,000 interest rate forecasts and use of Weitzman's definition of the certainty equivalent discount rate (CER). We also present the results of a 'state-space' model applied to the UK data which takes into account the possibility of structural breaks and allows for the autocorrelation process driving interest rates to change over time. These are important determinants of discount rate uncertainty, which represent a more appropriate methodology for forecasting discount rates for the very long-term and a departure from N&P.

Figure 1 compares the schedule of the certainty equivalent discount factors derived from the two forecasted models to the discount factor that is derived from discounting at a flat rate of 3.5%. It is easy to see that schedule of certainty equivalent discount factors derived from the state space model is higher than those derived from the N&P method, whilst the latter is fractionally higher than with constant discounting. These results are similar to those of N&P for the US: interest rate uncertainty in the UK provides a rationale for DDRs to be employed in project appraisal. However, there are two further practical points that arise from this analysis. Firstly, in applying N&P, we fail to establish the existence of persistence, indicating that the mean reverting model is more appropriate than the random walk model. This is the inverse of N&P's finding for the US. Secondly, model selection is important. The state space model[8] is introduced to improve upon

[8] See Newell and Pizer (2003) for their empirical specification. The State Space model employed here is as follows:

$$r_t = c_1 + \alpha_t r_{t-1} + e_t$$

$$\alpha_t = c_2\alpha_{t-1} + u_t$$

where u_t and e_t are vectors of serially independent zero-mean normal disturbances. In other words, we model uncertainty of

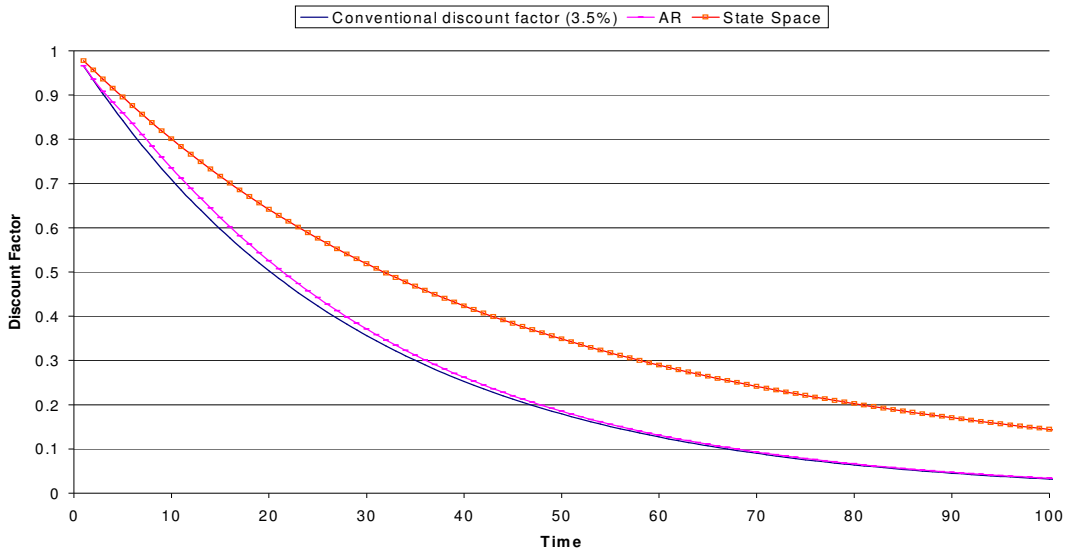

Figure 1: Conventional and Empirical Discount Functions

the misspecified mean reverting model. The model and results show the importance of introducing flexibility into the characterisation of uncertainty e.g. accounting for structural breaks and autocorrelated coefficients. Indeed there are a number of other empirical issues that need to be addressed before an acceptable schedule can be determined empirically. These issues are discussed at length in Groom et al (2004b). The implications of these estimates are described below.

3.1 Social Cost of Carbon

The social cost of carbon is an estimate of the present monetary value of damage done by anthropogenic carbon-dioxide emissions. The UK has an 'official' value of this shadow price (Clarkson and Deyes 2002) at £ 70 per tC, although the validity of the number is disputed (Pearce 2003) and the official value is under review at the time of writing. Self-evidently, higher values of the social cost of carbon imply that investment in climate change mitigation is more attractive. The discounting framework employed has a significant impact upon such estimates. It is obvious, for instance, that a lower (constant) discount rate will increase the present value of the marginal damage from emissions. For example, the marginal damage values from the Fund 1.6 model (Tol 1999) increase from \$20/tC to \$42/tC to \$109/tC, as the discount rate declines from rates of 5% to 3% to 1% respectively.

In order to illustrate the difference between the various discounting frameworks on the social cost of carbon, we start with an approximate profile of the economic damage done by one tonne of carbon emissions in 2000, shown in Figure 2. This is the profile of damages generated by the DICE model of Nordhaus and Boyer (2000). Applying the various discounting regimes to this damage profile over the next 400 years results in estimates of the social cost of carbon presented in Figure 3. For the 200-year period, the estimates vary from approximately £ 2.50/tC at a 6% flat discount rate, to about £20.50/tC under a discounting regime based on the Li and Löfgren approach.

Increasing the time horizon from 200 to 400 years makes no difference when constant discount rates are employed, because the discount factor approaches zero well before the 200 year mark. In contrast, marginal damage estimates under declining discount rate regimes are noticeably larger when the time horizon is extended to 400 years.

Furthermore, the application of N&P's methodology to UK data increases the 400 year estimates of

the interest rate as an $AR(1)$ process with $AR(1)$ coefficients. Details of this and other specifications can be found in Groom et al (2004).

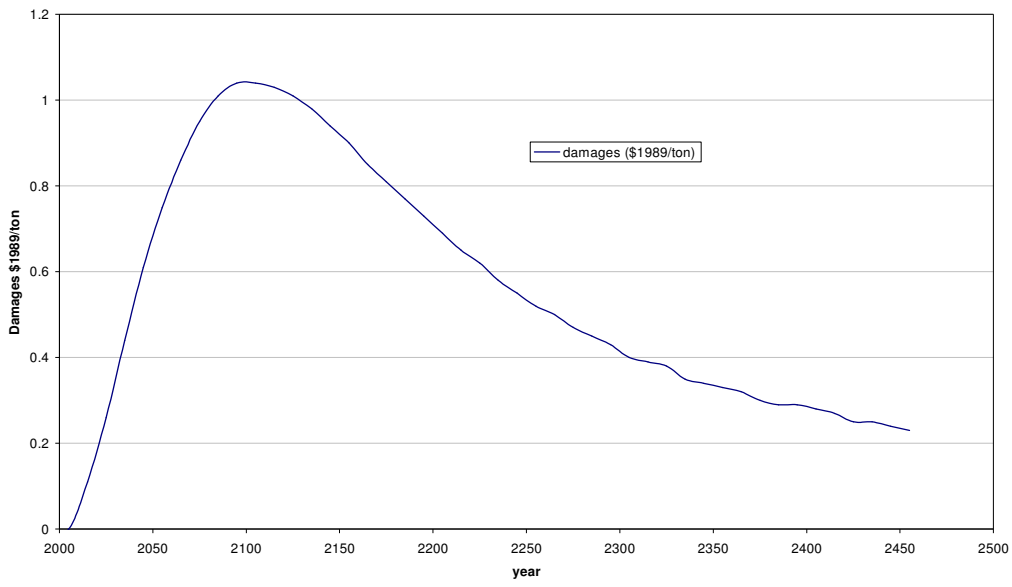

Figure 2: Profile of Carbon Damages from the DICE model

marginal damage costs by a mere 4.3% compared to the constant discounting regime. This contrasts with N&P's finding of an 84% increase. This reflects the lower level of persistence found in the UK case compared to the US, resulting in the mean reverting model being more appropriate than the random walk model of N&P. The state-space model leads to a 150% increase in the value of marginal damage. This model is well specified and is therefore more credible. The magnitude of the differences reflects once more the practical implications of model selection in determining the schedule of CER.

This illustration suggests that estimates of the social cost of carbon are likely to at least double if declining discount rates are employed. This would have formidable implications for policy in several areas. For example, a higher social cost of carbon would make it more likely that commitments to Kyoto targets would pass a cost-benefit test (Pearce, 2003).

4 Conclusions

The realisation that actions taken today can have long term consequences presents a challenge to decision makers in assessing the desirability of policies and projects. The use of the classical net present value (NPV) rule to assess the economic efficiency of policies with costs and benefits that accrue in the long term is felt by many to be particularly problematic. The welfare of future generations barely influences the outcome of such a rule when constant socially efficient discount rates are used for all time. The deleterious effects of exponential discounting ensure that projects that benefit generations in the far distant future at the cost of those in the present are less likely to be seen as efficient, even if the benefits are substantial in future value terms. In this respect it appears that the present wields a dictatorship over the future. The idea of using Declining Social Discount Rates (DDRs) has emerged largely in response to these awkward implications and recently DDRs have even been entertained at an official level in the UK (HM Treasury 2003).

The approaches reviewed here are predominantly theoretical contributions to an inherently practical issue. Ultimately, the practitioner is faced with a potentially confusing array of rationales and a sense that almost any discount rate can be applied. Moreover, it is important that the practitioner is aware that the implications of employing declining discount rates are of considerable moment. As our case studies show, there is the potential to reverse the recommendations of social cost benefit analysis in the long-term policy arena. This is especially important given the nature of this policy arena and the considerable changes that might be required in order to prevent the impact of global warming.

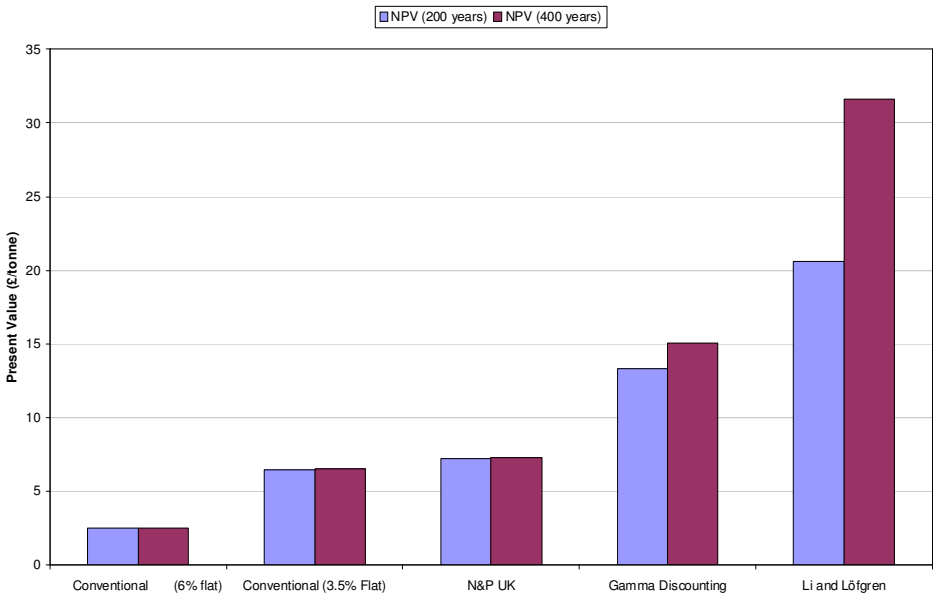

Figure 3: The discounted value of carbon mitigation

That social discount rates should be declining is still not clear, despite the sometimes compelling contributions described above. In many cases only the conditions under which DDRs are said to exist have been defined. Whether or not these conditions prevail is another question altogether. Indeed, the use of DDRs may put us in danger of placing more weight upon potentially far richer individuals in the far distant future that we place on present, or even near future generations. What is more widely agreed is the limited extent to which discount rates can be manipulated to simultaneously reflect the numerous underlying issues that have motivated their investigation, namely inter-generational equity, sustainability and efficiency. Practitioners would be wise to note this as well as the potentially fundamental limitations of CBA in dealing with long -term investments (Lind 1995).

References

Arrow, K., Cline, W., Maler, K-G., Munasinghe, M., Squitieri, R. and Stiglitz, J. 1995. Intertemporal equity, discounting and economic efficiency, in Bruce J.P., Lee, H., and Haites, E. (eds), p128-144. Cambridge University Press, Cambridge.

Atkinson, G., Dubourg, R., Hamilton, K., Munasinghe, M., Pearce, D.W and Young, C. 1997. Measuring Sustainable Development: Macroeconomics and the Environment, Cheltenham: Edward Elgar.

Baumol, W.J. 1968. On the social rate of discount. American Economic Review, 57, p788-802.

Broome, J. 1992. Counting the Cost of Global Warming. Cambridge: White Horse Press.

Chichilnisky, G., 1996. An axiomatic approach to sustainable development. Social Choice and Welfare, 13, p231–257.

Chichilnisky, G., 1997. What is sustainable development? Land Economics, 73, p467–491.

Chichilnisky, G., and Heal, G., 1997. Social choice with infinite populations: construction of a rule and impossibility results. Social Choice and Welfare, 14(2): p303-319.

Clarkson, R and Deyes, K., 2002. Estimating the Social Cost of Carbon Emission, Government Economic Service Working Paper 140, London, HM Treasury, February. Available at www.hm-treasury.gov.uk/documents/taxation work and welfare/taxation and the environment.

Dasgupta, P., 2001. Discounting: How and why?. mimeo. Beijer Institute.

Fisher and Krutilla 1975. 'Resource Conservation, Environmental Preservation, and the Rate of Discount'. Quarterly Journal of Economics, 89(3) p358-70.

Frederick, S., Loewenstein, G. and O'Donoghue, T. 2002, Time discounting and time preference: a critical review, Journal of Economic Literature, XL, p351–401.

Gollier, C., 2002a. Time Horizon and the Discount Rate. Journal of Economic Theory, 107(2): p463-73.

Gollier, C., 2002b. Discounting an uncertain future, Journal of Public Economics, 85, 149-166.

Gollier, C., 2004a. Maximizing the Expected Net Future Value as an Alternative Strategy to Gamma Discounting. Finance Research Letters, vol. 1, n. 2, June 2004, p. 85-89.

Gollier., C 2004b. The Consumption based determinants of the discount rate. LERNA working paper # 04.20.157.

Groom, B, Hepburn C, Koundouri P and Pearce D (2004a). Declining Discount Rates: The long and the short of it. mimeo. UCL.

Groom, B., Koundouri, P., Panopoulou, K., and Pantelides, T. 2004b. Model Selection in discounting the distant future. Department of Economics, University College London Discussion paper 04/02.

Heal, G., 1998. Valuing the Future: Economic Theory and Sustainability, New York: Columbia University Press.

Henderson, N and Bateman, I., 1995. Empirical and public choice evidence for hyperbolic social discount rates and the implications for intergenerational discounting, Environmental and Resource Economics, 5, 413-423.

Hepburn, C., 2003. Hyperbolic discounting and resource collapse, Oxford University Department of Economics, Working Paper 159.

HM Treasury, 2003. The Green Book: Appraisal and Evaluation in Central Government: London: HM Treasury.

Horowitz, J., 2002. Preferences in the Future. Environmental and Resource Economics 21, 241-59.

Li, C. Z., and Lofgren, K. G., 2000. Renewable Resources and Economic Sustainability: A Dynamic Analysis with Heterogeneous Time Preferences' Journal of Environmental Economics and Management, 40, 236–250.

Lind, R., 1982. A Primer on the Major Issues Relating to the Discount Rate for Evaluating National Energy Options', in Discounting for Time and Risk in Energy Policy, edited by R. Lind. Washington, Resources for the Future, p21-114.

Loewenstein, G and Prelec, D., 1992. Anomalies in intertemporal choice: evidence and an interpretation, Quarterly Journal of Economics, 107, p573-597.

Laibson, D. I., A. Repetto, and J. Tobacman 1998. Self-Control and Saving for Retirement. Brookings Papers on Economic Activity, 1, p91-196.

Maddison, A. 2001. The World Economy: A Millennial Perspective. Paris: Organisation for Economic Cooperation and Development.

Manne, A.S., 1995. The rate of time preference: implications for the greenhouse debate. Energy Policy 23(4/5) p391-394.

Newell, R. and Pizer, W. 2003. 'Discounting the benefits of climate change mitigation: how much do uncertain rates increase valuations?' Journal of Environmental Economics and Management, Vol. 46(1), p 52-71.

Nordhaus, W.D. and Boyer, J., 2000. Warming the world: Economic Models of Global Warming, MIT Press, Cambridge, MA

OXERA, 2002. A Social Time Preference Rate for Use in Long-term Discounting. London: Office of the Deputy Prime Minister, Department for Environment, Food and Rural Affairs, and Department for Transport.

Pearce, D.W., 2003. 'The social cost of carbon and its policy implications'. Oxford Review of Economic Policy, 19(3), pp.362-384.

Pearce, D.W. and Ulph. D., 1999. A social discount rate for the United Kingdom, in Pearce, D.W., Environmental Economics: Essays in Ecological Economics and Sustainable Development. Cheltenham: Edward Elgar, p268–285.

Pigou, A. 1932. The Economics of Welfare. 4th edition, Macmillan, London.

Portney, P and Weyant, J. (eds). 1999. Discounting and Intergenerational Equity, Washington DC: Resources for the Future

Weitzman, M. 1994. On the 'environmental' discount rate. Journal of Environmental Economics and Management, 26(1), p200-9

Weitzman, M., 1998. Why the far distant future should be discounted at its lowest possible rate, Journal of Environmental Economics and Management, 36, 201–208.

Weitzman, M., 1999. 'Just keep on discounting, but...'. In P.Portney and J.Weyant (eds), Discounting and Intergenerational Equity, Washington DC, Resources for the Future, 23-30.

Weitzman, M., 2001. Gamma Discounting, American Economic Review, 91, 1, March, 261–271.

Appendix 1 The mechanics of Weitzman's results are as follows. From (1) and (4) it is easy to show that the certainty equivalent marginal rate can be written as a weighted average of the potential realisations of r:

$$r_m^{CER} = \sum_j w_j(t) r_j \tag{10}$$

where the weights in this case are simply: $w_j(t) = p_j a_j(t) / \Sigma p_j a_j(t)$ and $\Sigma w_j(t) = 1$. Taking the derivative of this with respect to time we obtain:

$$\frac{d}{dt} r_m^{CER} = \sum_j \dot{w}_j(t) r_j = -\sum_j w_j(t) \left(r_j - r_m^{CER}\right)^2 \tag{11}$$

which is clearly negative[9]. That the limit of $\lim_{t\to\infty} r_m^{CER} = r_{\min}$ comes from noticing that, where $r_1 = r_{\min}$:

$$\lim_{t\to\infty} \frac{w_j(t)}{w_1(t)} = 0$$

which means that as $t \to \infty$ the weights associated with all but the lowest discount rate tend to zero due to the presence of $a_j(t)$, and yet, since $\Sigma w_j(t) = 1$, the weight for the lowest discount rate, $w_1(t)$, must tends towards 1[10].

[9] The last step is not entirely obvious, so we elaborate. Dropping the m subscript from r_m^{CER}, note that: $\dot{w}_j(t) = w_j(t)(\Sigma w_i(t) r_i - r_j) = w_j(t)\left(r^{CER} - r_j\right)$, therefore $\frac{d}{dt} r^{CER} = \sum w_j(t)\left(r^{CER} r_j - r_j^2\right) = \left(r^{CER}\right)^2 - \sum w_j(t) r_j^2$. This term is equal to that obtained by multiplying out (11). That is, noting that $\Sigma w_j(t) = 1$ we get: $-\sum w_j(t)\left(r_j^2 + \left(r^{CER}\right)^2 - 2 r_j r^{CER}\right) = 2\left(r^{CER}\right)^2 - \left(r^{CER}\right)^2 - \sum w_j(t) r_j^2$ and we are done.

[10] Gollier (2002a) provides an elegant proof of the following: $\lim_{t\to\infty} r_a^{CER} = r_{\min}$, i.e. for the averager CER, by appeal to Pratts Theorem.