INTER-GENERATIONAL JUSTICE, DISCOUNT RATES AND CLIMATE CHANGE

A Report Commissioned for
the Garnaut Climate Change Review

by

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Glossary

Agent-relative ethics	A philosophy in welfare analysis that justifies placing successively lower consequence of the utilities of all future generations.
Anthropogenic	Having its origins in the activities of man.
Business-as-usual	The likely scenario if no low carbon policies are implemented and long term trends in population, investment, technical change continue.
Cardinal value	A series of values that can be logically added, subtracted, multiplied and otherwise transformed mathematically. By contrast ordinal values can only be ranked so that we can say 4 is higher than 2 but not twice 2.
Climate change	The variation in the global or regional climate over time. These changes may be natural or caused by human activities.
Consumption	The selection, adoption, use, disposal and recycling of goods and services for personal satisfaction.
Consumption pathway	A time series of consumption levels.
Cost	The cost of an activity is the benefits one forgoes from not using the resources and labour time in alternative activities. Also called opportunity cost.
Discontinuous	When the set of points of a function are discrete (unconnected). In practical terms, this can mean that after rising or falling incrementally, a variable, such as rainfall or temperature, suddenly drops or rises.
Discount rate	How many units, of say money or goods, we need to give up today in order to receive one unit tomorrow. For example, if a government bond promises to pay $100 in a years time and this bond only costs $80 today, the discount rate is 0.2 (20%).
Economic model	An economic model is a theoretical construct that represents economic processes by a set of variables and a set of logical and quantitative relationships. It abstracts from complex human behavior to provide insight into an aspect of that behavior. Most often, this abstraction is reduced to a series of interrelated mathematical equations.
Elasticity of marginal utility of consumption	The difference in weighting given to income from the rich and income from the poor in a measure of satisfaction or utility. To accept that this value has meaning one has to accept that satisfaction or utility can be converted into a cardinal metric.
Excludability	The ability to prevent one party from consuming a good or service, usually though the possession of property rights.
Externality	An externality is a cost or benefit resulting from an economic transaction that is borne or received by parties not directly involved in the transaction.
Free ride	When a party can consume a good or service without paying for it. Primarily occurs when the good or service is non-excludable.

Greenhouse gases	Greenhouse gases are components of the atmosphere that contribute to the climate change. Some occur naturally while others result from human activities such as burning coal. Greenhouse gases include water vapour, carbon dioxide, methane, nitrous oxide, and ozone.
Inter-generational justice	When present generations are obligated by considerations of justice not to pursue policies that create benefits for themselves but impose costs on those who will live in the future.
IPCC	The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 by two United Nations organizations, the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP), to evaluate the risk of climate change brought on by humans.
Irreversibility	When we can't delay or bring forward an event or investment without making a permanent change to the world. Common irreversibilities are the loss of the Barrier Reef and loss of animal species.
Marginal variation	A small deviation or change from a given situation (usually the current situation).
Market failure	When there is an under or over provision of goods and services by the market. Occurs for three main reasons. (1) A producer uses its market power to restrict supply (2) Externalities exist (3) Consumption is non-excludable.
Natural capital	Natural resources such as minerals, the fertility of agricultural land, forests, oceans, clean air.
Normative	Normative statements and analysis is concerned with what *ought* to be. It focuses on what particular policy actions should be recommended to achieve a desirable goal.
Optimal policy path	The one policy scenario from a collection of all potential policy scenarios that produces the highest social welfare.
Parameters	In mathematical equations, parameters are quantities that define relatively constant characteristics of the equation.
Path-dependence	Path-dependence means that the history of the system being studied affects the current parameters of the system. For example, past investments into low carbon technologies may affect the costs and benefits of current investments by changing scientific and economic opportunities.
Pigovian tax	A Pigovian tax is a tax levied to correct the negative externalities of a market activity. It includes taxes that are levied on producers who pollute the environment to encourage them to reduce pollution. The term is named after the English economist Arthur Pigou who first coined the idea of internalising externalities through such a tax.
Policy-action pathway	A particular set of government policies which are enacted at given points in time.
Positive	Positive statements and analysis are concerned with what *is*. It focuses on facts and cause-and-effect relationships.

Pure rate of time preference	The rate at which a person or society as a whole discounts the value of something in the future simply because it is in the future. If I claim that 9 units of satisfaction today gives me as much satisfaction as 10 units of satisfaction in one years time, then my rate of time preference is 0.1 per annum. This is one type of discount rate (see above).
Risk	When we cannot know that an event will occur with certainty but we have enough past data on the occurrence of this event that we can construct a probability distribution density function of it occurring. For example, the probability of tossing heads on a fair coin is a risky event.
Rivalry	When the use of a good or service by one party precludes its use by another party.
Social cost	The cost resulting from an economic transaction that is borne or received by all parties in the economy including those party to the transaction (private costs) and those not directly involved in the transaction (external costs). See externality above.
Static framework	The economic model or problem being analysed has only one time period.
Supply side	From the production base.
Uncertainty	Uncertainty over a future event occurs when the event is such a unique occurrence that we have no data or information on which to make a calculation of its probable occurrence. See risk above for a contrast.
Utility	The intrinsic property of something that leads an individual to choose it rather than something else.
Utilitarianism	Utilitarianism is the ethical doctrine that the moral worth of an action is determined by its contribution to overall happiness or satisfaction of all people. Under this doctrine, best policies are those that maximise overall happiness – however defined.
Welfare	A holistic measure of a person's or group of people's satisfaction or happiness. It is not limited to happiness derived through the consumption of goods and services. Nor does it necessarily imply a particular concern for low income people. Social welfare is the collective welfare of the whole population however defined.

Introduction

Given the growing concerns about the predicted effects of global climate change, the Garnaut Climate Change Review will examine the impacts of climate change on the Australian economy, and recommend medium to long-term policies to achieve sustainable prosperity. As part of its remit, the Review acknowledges the need for a broader framework to guide government intervention and a deeper understanding of how climate change and related policy options will impact the economy. The Review was commissioned by Australia's State and Territory Governments on 30th April, 2007. The final draft of the Review is due on 30th September 2008.

This background paper has been commissioned by the Garnaut Review Secretariat in order to provide a critical overview of how social welfare functions, and their implied discount rates, are used to determine the timing of policies to address climate change.

In conjunction with climate change warnings such as the ongoing severe drought in Australia, the Hurricane Katrina disaster in New Orleans, Al Gore's documentary *An Inconvenient Truth* and the release of the Stern Review of Climate Change in late 2006, many Governments around the world (including Australia) are seriously considering policy action to mitigate the effects of climate change. Such policies may include cap-and-trade schemes or Pigovian taxes. Before such action is warranted, however, a case must be made for action and this requires substantial economic modelling. Although there have been numerous attempts to model the economic effects of climate change over the last 20 or so years, the Stern Review brought the issue into the glare of the public eye. The analysis presented here relates to all economic models of climate change since they all must tackle issues relating to discounting and intergenerational justice, but we pay particular attention to the Stern Review since its economic modelling is both the most recent and most influential of all recent attempts to model the costs of action/inaction.

Aside from the debate over the scientific evidence contained in the Stern Review, the main economic issues raised by critics of the Stern Review relate to its use of discount rates. The use of discount rates is a crucial part of modelling climate change since it can have a critical effect on the level and timing of the optimal policy action to mitigate climate change. Controversy surrounding the use of discount rates revolves around two issues: how we value happiness now versus happiness received in the future (known as the rate of pure time preference) and how we value consumption by the rich versus the poor (known as the elasticity of marginal utility of consumption).[1] Both of these issues must be addressed if the cost of climate change is to be estimated. Most of these critics argue that Stern's main result – that urgent action on climate change is required – is purely a function of the choices made with regard to these two parameters. While this is partly true, it is incorrect to argue that Stern picked this parametric value to suit his conclusion since there is a long history of discussion of this issue in the economics and philosophy literatures – which we review here – and Stern's position is consistent with the dominant (utilitarian) perspective.

In this paper, we critically review issues associated with economic models of climate change, in particular the role of the rate of pure time preference and the marginal elasticity of substitution. In doing so, we consider the philosophical arguments underpinning alternative choices for these parameters. However before doing so, we must first take a brief look at the simple economics of climate change and the way social welfare calculations are used to rank policy responses.

The standard approach adopted in these models is to contrast the costs and benefits of "business-as-usual" where no policy action is taken with the costs and benefits under different policy scenarios. Policy action is essentially about the degree and timing of incentives given to develop low-carbon technologies. In the final section of this paper, we provide some concluding comments about the lessons learned from recent experience with modelling climate change and how this might be incorporated into models of the Australian economy. Our conclusion is that there are strong arguments in favour of using a low rate of pure time preference however there are a range of defensible levels of the marginal utility of consumption. We also argue that more emphasis should be placed on issues such as the potential loss of natural capital.

The Simple Economics of Climate Change

Although it is a simplification of the issue, analysis of climate change contains two fundamental elements: a scientific component and economic component. The scientific

[1] A glossary of all of the terms used in this report can be found at the beginning of the report.

component addresses issues such as the measurement of greenhouse gases in the atmosphere, long-term changes in temperature, and whether these changes can be attributed to human activity. Put simply, the science addresses two key questions: is the temperature of the Earth's atmosphere increasing; and, if so, is it (partially) due to man's emission of greenhouse gases? Despite statements to the contrary, the best available evidence suggests that the widespread scientific consensus on both these questions is "yes". While there are some who disagree that a consensus has been reached, the overwhelming majority agree that global warming is occurring and that it is at least partly anthropogenic (see the IPCC Fourth Assessment). Rather than review this debate here, we take the consensus expressed in IPCC 4 as legitimate and consider what light economic analysis can shed on the issue.

The economic component analyses how to value the effects of climate change and how to decide what is the optimal timing of policies to mitigate its effects. Before we examine issues associated with valuing the effects of climate change, it is necessary to examine some basic economic principles since climate change has a number of features which can be explained by economic tools and techniques. In economic parlance, the Earth's climate is an example of a 'commons' – that is, it is an asset whose consumption by one person affects its consumption by others (i.e. it is rivalrous); but because of the nature of the asset, it is difficult to prevent or exclude people from consuming the asset (i.e. it is non-excludable). The first concept – rivalry – means that there is only a finite amount of clean air in the atmosphere and that the human race is now operating at the margin whereby one person's 'consumption' of clean air affects another person's ability to 'consume' that clean air. The second concept – excludability – means that it is difficult to charge people for consuming clean air because it is hard to prevent people from doing so.

The amount of clean air in the atmosphere is affected by the release of greenhouse gases, some of which are by-products of human production processes. That is, when we manufacture new products, we often create pollution as well. This is essentially undesirable (and is not included in the price of the final good), but it goes unnoticed for the most part because no single individual or organisation has property rights over the atmosphere. Economists refer to phenomena such as pollution as "negative externalities" and they have long known that non-excludability leads to over-consumption of an asset and that the presence of negative externalities can lead to over-production. These two characteristics suggest that the climate suffers from a classic case of market failure (i.e. the unfettered market fails to produce the optimal outcome). While there are many such examples of market failure, climate change is a market failure with some atypical characteristics in that:

- It is a global externality (where every country has an incentive to free ride);
- Today's emissions of greenhouse gases will last for the next 100 years (so early generations have an incentive to free ride);
- The impacts of global warming are uncertain,[2] discontinuous and irreversible; and
- Low-carbon position policies are highly path-dependent.

While, the most simple and straightforward remedy for negative externalities is to internalise them, this is notoriously difficult to implement in practice. With respect to the environmental debate, internalisation means determining the *correct price* for CO_2e emissions based on the marginal between private and social cost. Imposing this cost on producers of greenhouse gases would encourage them to consider their costs when deciding the technology of how to produce goods and service and the price they will sell these goods and services for. In a nutshell, the essence of an optimal policy is deciding this correct price for CO_2e emissions.

However, this marginal calculation is complicated since the scientific view, discussed above, maintains that the true cost of CO_2e emissions depends on the current and future levels of CO_2e levels in the atmosphere. And the stock of greenhouse gases in the atmosphere is something which is very hard to predict since the pollution we produce today will stay in the atmosphere for 100 years or more. All this means is that it is very hard to estimate the "true" price of pollution.

[2] In the tradition of Frank Knight (1921), uncertainty is different to risk: the latter has a probability distribution which we can observe (and therefore, we can form predictions about the future), while the former is such a unique occurrence that we are unable to form anything more than just subjective expectations about the possibility of occurrence. Being uncertain, however, does not mean the phenomenon is unlikely or that its effects are small – instead, it means we lack data upon which to calculate objective probabilities. And this is exactly what characterizes catastrophic climate change – something which may have a minute chance of occurring, but whose effects on humanity would be huge.

Environmental economics textbooks often examine negative externalities by comparing the social cost of carbon – which is the total damage in the future caused by the emission of greenhouse gases today – with the marginal abatement cost – which represents the cost today of reducing one extra unit of greenhouse gas emissions. The optimal level of abatement occurs at the intersection of these two functions. In a 2-period world, this is easy to comprehend. But over an infinite time period, it is much harder since static frameworks have difficulty accounting for fact that the social cost of carbon depends on the level of *future* greenhouse gas emissions. What is required to analyse the dynamics of the problem is an understanding that the social cost of carbon can only be determined if some assumptions are made about the path of future greenhouse gas flows and stocks.

In order to estimate stocks of greenhouse gases, assumptions must also be made about environmental feedback mechanisms and about irreversibilities. There are many environmental feedbacks which may affect greenhouse gas stocks in the atmosphere. Consider, for instance, the effect of the Siberian permafrost thawing. Underneath the permafrost lies a vast environment of peat soil and moss which is almost always under a layer of ice. Scientists have predicted that if this ice were to melt, it would result in the release of vast amount of greenhouse gases, but the exact extent of which is unknown. In other words, there is a complex set of interactions between increasing temperature and the amount of greenhouse gases released into the atmosphere.

On top of this is the problem of irreversibility. Economists tend to assume in all their models that investment decisions can always be delayed without compromise. A bridge can be delayed until another day and depreciation can undo an investment and return us to the original position. But climate change raises the possibility of irreversibility – once a species is extinct, it cannot be brought back. And once the West Antarctic ice shelf collapses, it cannot be reformed. So, the questions about whether investments into low-carbon technologies should be made now must some how account for the fact that, if we don't, we may suffer irreversible loss of natural capital. The problem is that we just don't know how likely these problems are to occur or what their effects will be – that is the essence of uncertainty.

In sum, economic analysis of the costs of climate change is complicated by the fact that climate change involves long time horizons in which risk and uncertainty and irreversibility play an important role. It is essential that any model of climate change account for the fact that the effects of climate change are likely to have an even more significant effect for future generations than for those alive today. The fundamental issue that must be addressed is: how much should the current generation care about how its actions affect future generations? In this context, economic analysis of climate change must address serious ethical issues surrounding the treatment of inter-generational justice. To do so requires a calculation of the present value estimates of the damages bill associated with climate change. Given the long time horizons involved, the optimal policy path is highly sensitive to the way in which future costs are discounted. The methodology used to make this calculation will therefore be the focus of much of our attention in the next section of the report.

Economic Modelling of Climate Change

Although economic analyses of climate change have existed since the 1970s (see Nordhaus 1977, for example), it was not until the 1990s that the production of these studies accelerated. These studies include (but are not limited to) Nordhaus (1994), Cline (1992), Maddison (1995), Fankhauser (1995), Manne and Richels (1992), Schelling (1992), Dietz (2007) and Stern (2006). We briefly summarise these approaches (and their results) in order to: 1) understand the complexity of the climate change problem; and 2) analyse the role that discounting plays in economic models of climate change.

With the exception of Cline (1992) and Stern (2006), these studies all conclude that climate change is a problem but that one which only requires moderate action in the medium term. Stern and Cline, however, argue that immediate and decisive action is required. The difference among these models boils down (primarily) to two issues: first, the assumed rate of pure time preference and the conversion of consumption into cardinal utility; and secondly, whether estimates of damage due to climate change are drawn from the lower or upper end of the distribution. While this paper only examines the first issue, the second is nonetheless as important in the overall assessment.

Utility theory and social welfare functions

Utility theory, and its associated welfare analysis, is the economists' way of laying bare the main assumptions and value judgements adopted by policy makers when deciding between different policy actions. It is essentially a cost-benefit approach that reduces all the costs and benefits of different actions into a measure of human happiness called utility. Utility is most often assumed to depend on the satisfaction derived from consuming goods and services. The doctrine of utilitarianism regards the maximization of utility as a moral criterion for the organization of society. According to utilitarians, such as Jeremy Bentham (1748-1832) and John Stuart Mill (1806-1876), society should aim to maximize the total utility of individuals – called social welfare – aiming for 'the greatest happiness for the greatest number'.

A properly constructed social welfare function should included formula to enable aggregation across individual utility functions. However, this requires the analyst to make strong and inevitably controversial assumptions about inter- and intra-personal comparisons (in order to convert utility into a cardinal value[3]). Welfare needs to be specified explicitly in terms of all members' individual utility and the latter needs to be defined in terms of the main variables considered to affect the welfare of the society.

The form of the social welfare function should express the morals and objectives of a society. For example, a social welfare function (*U*) that is the simple addition of individual utilities (*u*), such as $U = u_1 + u_2 + ... + u_n$, implies that the distribution of utility among members of society does not matter. That is, more utility adds to equally to welfare regardless of whether it accrues to the rich or to the poor. Many would find such a social welfare function reprehensible since it underweights the relative plight of the poor. By contrast, Rawls' Max-Min utility function ($U = \min[u_1, u_2, ..., u_n]$) implies that social welfare depends on the utility of the least satisfied member of society. Somewhat in between, Sen has proposed that ($U = Per\,capita\,income \times (1 - inequality)$) which assumes that both per capita income and the distribution of income contribute positively

[3] A cardinal value is a series of values that can be logically added, subtracted, multiplied and otherwise transformed mathematically. By contrast ordinal values can only be ranked so that we can say 4 is higher than 2 but not twice 2.

to welfare but for a given level of total income, welfare is maximised when inequality is minimized.

These welfare functions are static, that is, they only aggregate across individuals at a given point in time. By contrast, most of the ethical concerns in the climate change debate involve comparisons across time. That is, how do we measure and add utility that not only accrues to person A and person B, but accrues to them at different times. Since the analysis of Stern and most other climate change analysts involves very long time horizons, the analyst has to make not just inter-temporal comparisons but inter-generational comparisons.

Many people abhor the idea of reducing happiness or satisfaction to a number and placing it in an equation. However, economists argue that as soon as one makes a decision involving trade-offs between one person and another, or one time period and the next, they are making a value judgement whether the explicitly recognise it or not. The aim of economic modelling is to make these assumptions transparent to the decision maker and society.

Calculating social welfare

Under the utilitarian framework, the optimal policy action is the policy-action pathway[4] associated with the greatest enumerated social welfare. Generally, four steps are taken to calculate the social welfare of each scenario:

(i) Consumption pathways for each scenario must be estimated.[5] Since each scenario involves a set of uncertain outcomes, these must be reduced to certainty equivalents (usually through attaching subjective probabilities to each event). So for example, for each year, the modeller makes estimates of expected global temperatures, then the subsequent effects on rainfall and other major climatic events, then the effects of this on agricultural production and other climate sensitive sectors, then the effects on the terms or trade, employment and finally on household incomes and consumption. The parameters that define the size of these knock-on effects are estimated from historic economic data.

(ii) Consumption at each point in time, and for each unit of analysis (which may be a household, country, region or the whole world), must be converted into cardinal utility units. This conversion enables us to aggregate across individuals so we can obtain a single utility measure for each point in time. One way to do this is

[4] A policy-action pathway is a particular set of government policies which are enacted at given points in time.

[5] A consumption pathway is a time series of consumption levels.

to equate a dollar of real consumption to a unit of utility. Another approach is to assume that a unit of real consumption to a rich person is worth less than a unit of real consumption to a poor person. The function converting real consumption into utility is referred to as the marginal utility of consumption.

(iii) The utilities from each point in time are reduced to a present value using the pure rate of time preference as the discounting factor. This provides us with a single welfare figure for each scenario.

(iv) Present-value welfare estimates are compared. The preferred policy-action is the one with the highest welfare estimate.

According to Stern, steps (i) to (iv) must be followed if we want to compare scenarios that involve non-marginal variations. In cases where scenarios involve a marginal variation, we do not need to evaluate the whole social welfare function, but we can apply marginal analysis using marginal formulas. However, Stern is very clear that this does not apply to the analysis of climate change where discontinuities and irreversibilities make consumption paths non-differentiable.

While there is considerable discussion in the literature about how to deal with uncertain events [step (i)], especially those which may be catastrophic or be irreversible, this paper is essentially concerned about the choice of functions and parameters for steps (ii) and (iii).

The general mathematical representation of step (ii) is:

$u_{i_t} = u(c_{i_t})$ for each household/country/region i

and $U_t = \sum_{i=1}^{n} u_{it}$ for each time period t.

where u is the level of cardinal utility associated with the level of per capita consumption c for each household/country/region i and U is total cardinal utility for all households/countries/regions at a given point in time t. The first function essentially says that utility for each entity depends on their level of consumption of goods and services and that these can be added up to give the total level of happiness or utility U for the whole of society. The shape of the function u defines how we weight the utility of rich versus poor households/countries/regions.

Step (iii) is represented as:

$$W = \int_{t=0}^{\infty} U_t \exp^{-\delta t} \, dt$$

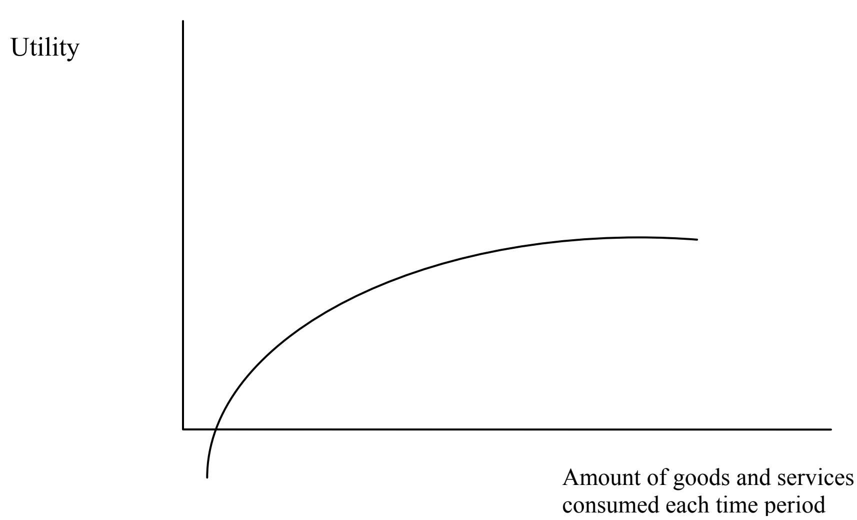
W is the present value of each *U* pathway discounted by the pure rate of time preference δ. Essentially, this says that the total stock of human happiness from now (*t=0*) to forever (∞) can be summed to a stock figure *W*, but that future happiness may not count the same as current happiness. They may count for more, but generally it is assumed that future happiness counts for less than present happiness. The degree to which the future utility counts for less is called the 'discount rate', δ *(delta)*. The expression $\exp^{-\delta t}$ is a common mathematical expression, which uses the natural number '*exp*' to represent a continuous rate of change over time (in this case *U* declines at the rate of δ per time period *t*).

Inter-temporal and inter-personal comparisons of social welfare

In principle, the shape of the *u* function and δ are not constant and can vary over consumption levels and over time. However, for the purposes of tractability, it has become conventional to assume that the *u* function adopts the mathematically elegant functional form:

$$u(c,t) = \frac{c(t)^{1-\eta}}{1-\eta} \text{ and } u(c,t) = \log c(t) \text{ if } \eta = 1 \qquad (1)$$

How much weight is given to the poor relative to the rich depends on η (*eta* called the elasticity of marginal utility of consumption). If η=1 then 10 per cent of a poor person's consumption is equivalent in utility terms to 10 per cent of a rich person's consumption. This relationship is depicted below. Utility rises as consumption rises, but at a declining rate.



If we adopt equation (1); assume that δ is constant over time; assume that there is only one household/country/region; assume that per capita consumption, *g*, grows at a constant rate over time; and assume we are only taking about marginal variations to a set of scenarios, then the actual rate at which future consumption will be discounted is ρ *(rho)* such that

$$\rho = \eta g + \delta \,.\text{[6]} \qquad (2)$$

The reason why the discount rate in equation (2) is not just δ is because we have assumed that people in the future will be richer than us (i.e. *g* is positive) and thus, since we apply a difference weighting to rich versus poor households/countries/regions, a dollar value of a future rich person's consumption is effectively discounted relative to a dollar of a current poor person's consumption.

Equation (2) has become a short hand in the social welfare literature so much so that many commentators use it to test for the common sense appeal of social welfare calculations. Note that it defines the rate of discount on future <u>consumption of goods and services</u>, ρ (in contrast to discounting of future <u>utility</u>, δ). This formula is descriptive not prescriptive. Since many people often confuse δ and ρ, this formula helps in separating the two distinct concepts. As we note above, δ is the rate at which we discount future utility, while ρ is the rate at which we discount future consumption of goods and services. The two are only synonymous under the condition that either η or g equal zero.

In equation (2), because per capita consumption is expected to rise over time, η essentially includes *inter*-personal, *intra*-personal and inter-generational dimensions. Stern chose the values δ=0.1 and η=1 (and *g*=1.3 per cent per annum), which gives a social discount rate close to the real interest rate for government bonds (i.e. ρ=1.4 per cent per annum). In the next two sections, we review the controversy of these parametric choices. The least controversial task relates to the parametric choice for *g*.[7]

[6] See Stern (2007, pp.43-46) for details. Note that the parameters are defined as percentages, that is a growth rate of 2 per cent is 2 not 0.02.

[7] However, this is not to say that it is uncontroversial – for instance, the assumption that *g* is positive quite clearly depends on the timeframe we use to justify this assumption. If we were to take our experience over the last 200 years, an assumption of 1.3 per cent growth projected into the future seems entirely reasonable. However, as pointed out by Dasgupta et al. (2000), a longer-term time horizon (say two thousand years) might lead to an estimated growth figure of 0. In this Report, we ignore this issue and assume that assumptions regarding a positive value for *g* are acceptable.

However, while Stern uses equation (1) as an illustration of the intuition of his parameters, he does not use this discounting short cut (equation 2) and recommends that the welfare calculations be derived long hand from the steps outlined in (i) to (iv) above. Equation (2) should only be used if we can be confident that there are not discontinuities on the scientific side. For reasons given above in our short summary of climate change, we cannot assume this.

A common point of confusion in the debate over the magnitude of the parameters in the social welfare function is whether people are discussing the pure time preference rate (δ) or the summary 'discount rate' ρ. As soon as one reverts to the summary measure, they are implicitly including an assumed rate of growth of consumption (=rate of growth of GDP) as well as assumed values for δ and η. This often leads to confusion over the true meaning of 'the discount rate'. In this context, we do not find the summary measure, ρ, helpful. Not only does it carry with it various assumptions about functional forms etc (as discussed above) but it also compounds the three separate variables in a way that confuses three intrinsically separate issues. In the following, we will discuss the meaning and estimation of the two main parameters – δ and η – separately.[8]

Rate of Pure Time Preference (δ)

The rate of pure time preference is essentially society's level of impatience. It denotes the extent to which we discount future utility simply because it is felt in the future. At the individual level, there is evidence to suggest that people do discount future utility. However, in an inter-generational setting such as the climate change problem, the issue is much more complex than the intra-personal issue of whether to enjoy things now or in wait for the future. How do we value the happiness of future generations vis-à-vis our own? The standard utilitarian position is that future generations' happiness should be

[8] There are others, however, who argue that the debate really needs to move beyond the discounting issue. Neumayer (2007) is representative of this line of argument. He argues that the most important issue from an ecological standpoint is that damage caused to ecosystems caused by climate change may be irreversible. Most economic analysis of climate change, however, implicitly assumes away this aspect of climate change and therefore underestimates the case for urgent and immediate action.

treated exactly the same as the current generation (i.e. δ is close to zero[9]). This debate highlights two alternative approaches – the first is essentially a normative (or prescriptive) approach since it argues that this is the way future generations *should* be treated. The alternative approach is positive (or descriptive) in that that it argues that the choice of the rate of pure time preference should be determined by how humans *actually* behave. Therefore, much of the disagreement over discount rates and their use in climate change models, boils down to whether a prescriptive or descriptive position should be adopted.

There is a long historical debate in welfare economics about the issues surrounding the issue of pure time preference and a low rate of pure time preference is consistent with the views of many pre-eminent economic scholars including Ramsey (1928), Pigou (1932), Harrod (1948), Sen (1961) and Solow (1974). More recently, Hepburn (2007) finds such impersonal consequentialism "compelling, especially when the lens is that of the global decision-maker", and DeLong (2006) believes that: "The fact that we want to apply a pure rate of time discount much greater than the risk of extinction to problems of planning for the far future is, I think, a flaw in our reasoning."

While it is hard to dismiss the prescriptive approach, there is one ethical problem with choosing a low rate of pure time preference – irrespective of the fact that future generations may be richer, it seems to imply that the current generation should saves a lot, such as over 50 per cent, to protect future generations. Take the limiting case of $\delta=0$. Koopman's (1965) argument (as restated by Arrow [1995]) is that if a current investment opportunity exists which will produce a perpetual stream of future benefits (such as investments into knowledge creation), then it should be undertaken since each unit of saving by the current generation incurs a finite loss but results in an infinite gain to future generations. Hence, so long as such investment opportunities exist, all current generations should have a 100 per cent savings level in order to maximize social welfare.

Adopting a similar stance, Arrow (1995) states that "I therefore conclude that the strong ethical requirement that all generations be treated alike, itself reasonable, contradicts a very strong intuition that it is not morally acceptable to demand excessively

[9] It is only non-zero to account for the unlikely event that the Earth may be destroyed by some catastrophe. Note also that a present value for a positive stream of utilities for an infinite time horizon produces $W=\infty$ if zero pure time preference rate is assumed. This is not very helpful for ranking different Ws.

high savings rates of any one generation, or even of every generation" (p.16). Like Koopmans (1965), then, Arrow believes in the following seemingly paradoxical views: on the one hand, he argues for neutrality between the welfare of different generations while, on the other hand, he holds that the pure rate of time preference *must be positive* since he believes that one does not have to fully comply with impersonally moral obligations. In Arrow (1995), he argues that the pure rate of time preference is 1 per cent.[10]

Other economists similarly disagree with the choice of a zero rate of pure rate of time preference, but from a descriptive position. Two different descriptive positions have been taken: the first draws on empirical or experimental estimates of the degree of people's impatience. Weitzman (2007), for example, states that low values of δ are based on the "…*a priori* philosophical principle of treating all generations equally – irrespective of preferences for present over future utility that people seem to exhibit in their everyday savings and investment behavior" (p.6). The major problem with this line of argument is that it seems to confuse the issue with the *intra*-personal dimension of the pure rate of time preference (which can be empirically verified) with the *inter*-personal, inter-generational dimension of the rate of pure time preference (which cannot be empirically verified since we can't observe the preferences of future generations).

The second descriptive position uses the principle of opportunity cost. Proponents of this view argue that public investment simply crowds out private investment and thus any diversion of (scarce) resources to mitigate CO_2e emissions should earn an equivalent marginal return to investment. Accordingly, the risk-free or default-free rate, being the minimum return on investment, reveals society's rate of pure time preference (Arrow 1995). If one accepts this logic, then δ should be about 1 per cent, this being the average treasury bill rate over the period 1889-1978 in the US.[11] However, this line of reasoning appears to confuse change in the expected growth consumption path under each scenario [step (i) above] with time preference [step (ii) above]. Crowding out has nothing to do with society's impatience. It merely alters the shape of the expected consumption path.

[10] In another publication where the conclusions of the Stern Review are critically reviewed, Arrow (2007) shows that Stern's case for urgent and immediate action on climate change holds for a number of different scenarios. As long as $\delta<8.5$, Arrow argues that the present value of mitigation provides a better outcome than the business-as-usual outcome.

[11] Quiggin (2007) claims that this average rate signifies ρ not δ.

Looked at another way, the rates on treasury bills, bank bills and other short-term default-free securities are governed by central governments short-term macroeconomic policy stance and this has nothing to do with society's rate of time preference.

Nordhaus (2007), who lies in the descriptive camp, takes a novel and different line of argument altogether. He is also unconvinced about the logic of choosing low values of δ. He argues that if we assume δ=0.1 then present decisions become extremely sensitive to uncertain events in the distant future. Hence the present generation would be forced to make decisions about highly uncertain events in the distant future even though these estimates are not accurate and would be refined over the coming decades. Nordhaus illustrates this with a simple example and suggests that policies would be identical for different dates in the future as the future is so greatly magnified. He then examines whether Stern's predicted economic losses are robust to alternative assumptions about pure time preference.

In Nordhaus' model, δ is set at 3 per cent initially but then declines to 1 per cent in 300 years. As a result, he finds that the economic losses under business-as-usual are of a much smaller magnitude than would be the case with lower values of δ and hence that carbon taxes on emissions need only be quite small. However, Nordhaus essentially takes a market-based view of the value of ρ (i.e. the weighted average cost of capital for private investment, which is around 6 per cent[12]), chooses the value of η=1 for reasons of simplicity and then "backs out" a value for δ (which, by default, must be quite high). In doing so, Nordhaus fails to provide any philosophical or economic justification of the resultant parametric choice for δ. In fact, as Quiggin (2007) points out, it is hardly surprising that Nordhaus' model predicts a "do nothing" approach since imposing values of δ=3 implies that the welfare of our great grandchildren has about one-tenth the weight of the current generation's welfare.

All values of δ have somewhat awkward interpretations. In a Technical Annex to the Postscript of the Stern Review, the point is made that an assumption of δ=1.5 (as suggested by Byatt et al. 2006) implies that the probability the human race will survive

[12] The difference between this rate and the real interest rate on government bonds is referred to as the "equity premium". The fact that this premium cannot be explained – even when risk and uncertainty are accounted for – is known as the "equity premium puzzle".

another 50 years is only 0.47. An assumption of δ=0 on the other hand, while morally straightforward, makes the calculations useless since all estimated *W* will equal infinity.

There is no easy solution to the problem of δ. Although it is a value judgement, it is difficult to defend large values of δ, and in our view the Stern Review has adopted a justifiable ethical position on this issue. However, adopting a value of zero is not an option within the utilitarian framework since all *W* equal infinity in an infinite world. Hence, the somewhat expedient ethical use of a very small δ to account for the small possibility that the world will end. Ultimately, we believe that the choice of the pure-time preference rate is essentially a philosophical issue: should we value future generations' consumption in the same way we view our own? If you believe the answer to this question is "Yes", then the rate of pure time preference must be zero (or close to it). Accordingly, if δ is zero (or close to it), then all of the action regarding discounting lies in decisions regarding η.

Elasticity of the Marginal Utility of Consumption (η)

The assumed elasticity of the marginal utility of consumption is essentially society's aversion to inequality. An assumption of η=1 – which is the assumption that Stern (2006) makes[13] – implies that the addition to social welfare from each additional unit of consumption declines as society becomes richer. In other words, a 1 per cent increase in income now is treated as having exactly the same welfare value as a 1 per cent increase at any time in the future.[14] Thus, the assumption of η=1 implies that the relationship between consumption and welfare is such that a 1 per cent reduction in consumption today would be desirable if it leads to slightly more than 1 per cent increase in the consumption of some future generation *even if future generations are richer than the current generation*. While diminishing returns is fairly standard in neoclassical economics, the choice of η=1 has come under fire primarily for its ethical implications.

Dasgupta (2007) is the chief protagonist on this issue. His concern is that η=1 simultaneously places a low weight on the welfare of the current generation relative to

[13] Stern (2006) relies on empirical evidence in Pearce and Ulph (1999) to justify this assumption.
[14] Note however that if we derive the elasticity of the marginal utility of consumption from equation (1), it is equal to 1-η.

future richer generations *and* places a low weight on the welfare of the current poor (developing nations) relative to the current rich (developed nations). Note that η has an inter-temporal dimension only if we are confident that average consumption levels will be higher in the future. Dasgupta's estimates, using the assumptions δ=0.1 and η=1, suggest that if we wanted to increase the well-being of future generations, we would need to save and invest 97.5 per cent of our global output today, which is equivalent to saying that the current generation should starve itself. An η in the range of 2–4 per cent would be more satisfactory from Dasgupta's point of view. Increasing the value of η in this context would lessen the requirement on the current generation to do something about the possible effect of climate change.

However, Sterner and Persson (2007) point out that the norm in cost-benefit analysis it to actually assume η=0, that is, that a dollar gained or lost has the same value regardless of the underlying distribution of income. Any implied values of η greater than zero is quite radical. Is it reasonable, they ask, that the only time distributional weights are called into question is when we want to argue that we should do nothing today and leave all the costs to future generations? They suggest not. In fact, they argue that Stern's choice of η is quite defensible in the scheme of things.

One might reasonably argue that rather than relying on some philosophical discussion about the pros and cons of various values of η, we simply rely on empirical estimates from experiments. But this, too, is fraught with difficulties and only produces imprecise and ambiguous estimates. In fact, an overview on the literature on this issue (which adopt both positive and normative positions) suggests that it is more reasonable to assume $0.5<\eta<4$ per cent. This of course does not help solve the problem of identifying the "true" value of η (see Gollier 2006; Cowell and Gardiner 1999; Quiggin 2007). Moreover, economists should be reminded of the work of Robbins (1935) who argued that all decisions regarding parameters such as the elasticity of the marginal utility of consumption involve value judgments. Economists should not impose such value judgments on others, but rather examine the implications of different value judgments.[15]

[15] Thanks to John Creedy for pointing this out to us (for more on this point, see Creedy 2007).

The agent-relative framework provides a philosophical justification for different values of the elasticity of the marginal utility of consumption.[16] In formal terms, the agent-relative framework means that each generation will maximize a weighted sum of its own utility plus the sum of utilities of all future generations (which receive a lower weight). Assuming that every investment is reversible (which may not apply to the climate change problem), each generation is able to determine for itself what investments are to be made. This decision can't be imposed by current generations on future generations. All each generation can do is to decide how much capital to pass on to the next generation (Arrow 1995), which leads to a game amongst successive generations.

The essence of agent-relative ethics is that the manner in which we treat others depends on their relation to us: under this framework, it is not amoral to argue that a person cares more for his spouse or child than for a complete stranger. The importance of relations to humankind has developed over time and it may be perfectly reasonable to discount the welfare of others relative to you and your immediate family. It may also be reasonable to argue that under a system of agent-relative ethics, a nation-state may choose to discount the welfare of foreigners relative to their own citizenry.

Beckerman and Hepburn (2007) make the point that these arguments assume it is reasonable to draw an analogy between how a parent and a nation-state should view their descendants. In reality, such an analogy may not exist. Whether it is moral to apply this view of welfare to the long time horizons involved in the climate change externality is however less straightforward since an agent-relative framework implies that descendents of wealthy countries will have greater weight than those from poor countries.

Conclusions

Despite its apparent simplicity, the discounting issues related to climate change are incredibly complex. As we have seen, there is a complex web of intra-personal, interpersonal and inter-temporal issues which involve difficult ethical issues. Our analysis suggests that while there is no single set of values for δ and η that produce

[16] Beckerman and Hepburn (2007) traces the agent-relative concept back to the work of David Hume (1740), but the term appears to have first been introduced into the modern economics literature by Arrow (1995).

‘correct’ or incontestable values, the range of defendable values for η is considerably broader than that for δ.

This doesn’t mean we shouldn’t debate the issues. And while the debate is often confusing, a few guiding principles can be drawn. First, there is a strong argument for believing that this is a normative issue not a positive one – we should not be asking, “*do* people discount their own future consumption?” but, “*should* we discount future generations’ consumption?” Secondly, this debate is really not an empirical one since there is no way to answer this normative question through empirical analysis. Rather, it is essentially a philosophical issue. However, while answers are necessarily subjective they should be guided by philosophical principles. The value judgements involved in selecting δ and η should not distinguish between individuals as such but may differentiate between them based on morally relevant properties such as need and circumstance. A morally sound judgement is a judgement that a disinterested spectator would take. Thirdly, a richer model is required to address the complex set of inter-personal, intra-personal and intergenerational issues raised by climate change. The good news is that there is currently work underway on exactly this issue by academics such as Karp and Tsur (2007). In the mean time, we must make do with the inadequacies inherent in the existing model.

Although this is a complicated issue, our view on the correct way to model climate change is that δ should be very small to accommodate both the very remote possibility of extinction and the necessity of the mathematics. In other words, the Stern rate of 0.1 per cent is not unreasonable. Secondly, a sensitivity analysis should be undertaken for η perhaps over the range 0.5 to 3 per cent. These guiding principles should be incorporated into any model of the effects of climate change on the Australian economy.

On a final point, it also seems unfortunate that most of the economic models of climate changes have focussed on the choice of discounting factors to the almost complete exclusion of what are probably more serious concerns – environmental irreversibilities. This includes the melting of the Siberian permafrost, changes in deep ocean currents and the permanent destruction the barrier reef and eco-systems, to name just a few (Neumayer 2007 is an exception). Typical economic cost-benefit tools are not equipped to make clear and sensible decisions when irreversible investments are involved – they implicitly assume that ‘goods’ today and ‘goods’ tomorrow are perfect substitutes from the supply side. What we are hearing from the scientific community is that it is quite probable that this is not the case. However, we simply do not know what the likelihood is of such irreversible damage to natural capital.

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