Climate Change Reviews: How Convincing are their Assumptions?

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Abstract

This essay investigates criticisms on two recent and government-commissioned climate change reviews, the British *Stern Review* (2007) and the Australian *Garnaut Review* (2008). Both reports are likely to shape British and Australian public policy on climate change mitigation. Given the breadth of the reviews, the essay focuses on specific criticisms of assumptions made about: (i) how to discount future utility; and (ii) the consumption elasticity. It is shown that the approaches taken by *Stern* and *Garnaut* have absurd implications which impact substantially on the implied cost of carbon.

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Reason and free inquiry are the only effectual agents against error.

Thomas Jefferson, 1784

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1 Introduction

It is clear the Australian public desires climate change mitigation policies from its governments. Sound arguments may be made that the major parties' perceived environmental stance was the swinging issue of the 2007 federal election. As such, this essay adopts the majority view of the Australian public: despite dissent warranting investigation (discussed in detail by Kellow, 2008) the essay proceeds on the premise that human activities cause climate change. The next step is to examine proposals for climate change mitigation, in particular to analyse advice informing the development of public policy designed to reverse offending human emissions.

To this aim, the essay reviews criticisms of the highly publicised *Stern Review* (2007) on the economics of climate change. It asks whether similar issues are applicable to the Australian *Garnaut* climate change review (2008*b*). These questions are important to understanding the reviews' arguments which ultimately shape Australian public policy and impact on Australians' standard of living.

2 Climate Change Reviews

2.1 The Stern Review

In November 2006, Nicolas Stern (2007) presented a British government commissioned review of the global impact of climate change. The *Stern Review* outlined serious economic consequences of climate change; 'the overall costs ... of climate change would be equivalent to losing at least 5% of global GDP each year, now and forever' or 20% of annual GDP 'if a wider range of risks and impacts is taken into account' (Stern, 2007, p. xv).

Advocating a global response, the *Stern Review* suggests three policy responses: (i) place a price on carbon emissions by tax, trade or regulation; (ii) fund the development of low-carbon technology; and (iii) develop a regulatory system promoting energy efficiency complemented by 'educating' individuals about their environmental responsibilities (Stern, 2007, p. viii).

2.2 The Garnaut Review

On 30 September 2008, Professor Ross Garnaut (2008*b*) submitted a similar review with an Australian flavour to the Australian federal government and the governments of the Australian States and Territories. His report had a similar tone to the *Stern Review* and describes the 'severe and costly' economic consequences of climate change (Garnaut, 2008*b*, p. xxxvii).

The *Garnaut Review* calls climate change 'a diabolical policy problem' (Garnaut, 2008*b*, p. xviii). Drawing on the classic prisoner's dilemma, he writes 'it is harder than any other issue of high importance [because] it is long-term ... [with] effective remedies ... requiring international cooperation of unprecedented dimension and complexity' (Garnaut, 2008*b*, p. xviii). Ultimately, its recommendations 'fall within four clusters' (Garnaut, 2008*b*, p. xxix): contributions to a global agreement; development of mitigation policies such as emissions trading; research and development; and ensuring an 'equitable distribution of the burden' (Garnaut, 2008*b*, p. xxxiii).

2.3 Criticism: Outline

The *Stern Review* attracted media attention because of its clear and unambiguous predictions of significant expected costs of global warming. However, its unambiguous nature has invited academic study. Tol (2008) presents a wide-ranging meta-analysis of literature estimating the social cost of carbon and shows how Stern's (2007) results represent an outlier in the climate change economics literature. Further, commenting on Stern's (2007) conclusions, Weitzman (2007, p. 704) asked: 'why is there such a big difference between what *Stern* is recommending and what most other serious analysts favour?'.

To answer this, Nordhaus (2007) focuses his criticism on the discounting assumptions made in the *Stern Review*. In a similar vein, Weitzman (2007, p. 705) writes that 'the discount rate is all important and *Stern*'s results come from choosing a very low discount rate'. Given the wide range of issues that could be investigated in analysing the *Stern* and *Garnaut* reviews, this essay focuses on the importance of discounting to the long-term nature of cost-benefit climate change analysis. As we shall see, decisions made about how to discount appreciably affect the implied cost of mitigation.

3 The Conceptual Framework

To appreciate the criticisms made of the *Stern* and *Garnaut* assumptions, the conceptual framework used needs exposition. The *Stern Review* uses the Ramsey (1928)-Cass (1965)-Koopmans (1965) model (Romer, 2006, p. 48). Implicit in the rough calculations made in the *Garnaut Review*, it appears it took the same approach (Garnaut, 2008*b*, p. 19). At the centre of the model is a decision-maker who aims to maximise a social welfare function from now into the future. Assuming constant population normalised to 1, this social welfare function is:

$$W = \int_{t=0}^{\infty} U\left[c(t)\right] e^{-\rho t} dt, \tag{1}$$

where $c(t)$ is per capita consumption, $U[\bullet]$ is the instantaneous utility function and ρ is the time discount rate. What equation (1) shows is the utility of generations from now ($t = 0$) into the indefinite future ($t = \infty$), with future utility discounted (reduced in magnitude) by ρ. To diagrammatically conceptualise equation (1), Figure 1 gives a welfare function W calculated over an arbitrary time period. Intuitively, it is the area under the time-varying utility function for a constant population normalised to 1; it 'sums' the utility of the population over time t to $t + x$.

The *Stern Review* and, implicitly, the *Garnaut Review* use a specific form of the utility function with a constant elasticity of the marginal utility of consumption:

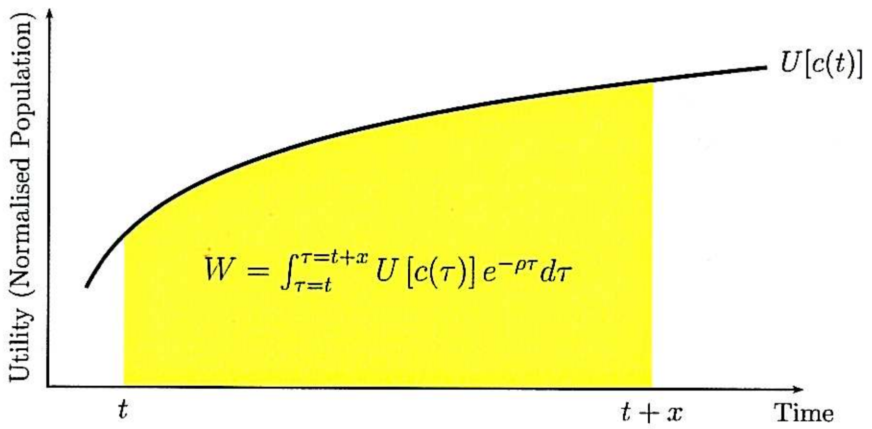
$$U\left[c(t)\right] = \frac{c(t)^{1-\theta}}{1-\theta}, \tag{2}$$

where θ is the elasticity of marginal utility of consumption with $0 < \theta < \infty$. The parameter θ defines the shape of the utility function. Optimisation of the function subject to an intertemporal budget constraint yields the 'Euler' (Romer, 2006, p. 55) or 'Ramsey' (Nordhaus, 2007, p. 691) equation:

$$c^*(t) = \frac{\dot{c}}{c} = \frac{r(t) - \rho}{\theta}. \tag{3}$$

This equation gives the time-varying optimising relationship between consumption growth $c^*(t)$, the real interest rate $r(t)$, the pure time preference parameter ρ and the elasticity of marginal utility of consumption θ. It gives the utility-maximising consumption path over time; that is, for an economy to maximise its living standards, it must satisfy (3). Equation (3) is used as a simplifying tool to analyse the reasonableness of parameter assumptions made in the *Stern* and *Garnaut* reviews.

Figure 1: Social Welfare Function, t to $t+x$



Note: This figure shows the social welfare function (1) (W) over an arbitrary time period t to $t+x$. Intuitively, it is the area under the time-varying utility function for a constant population normalised to 1. Assume $\rho = 0$ for this stylised example; ρ needs to be positive to ensure discounted utility falls to 0 as $t \rightarrow \infty$.

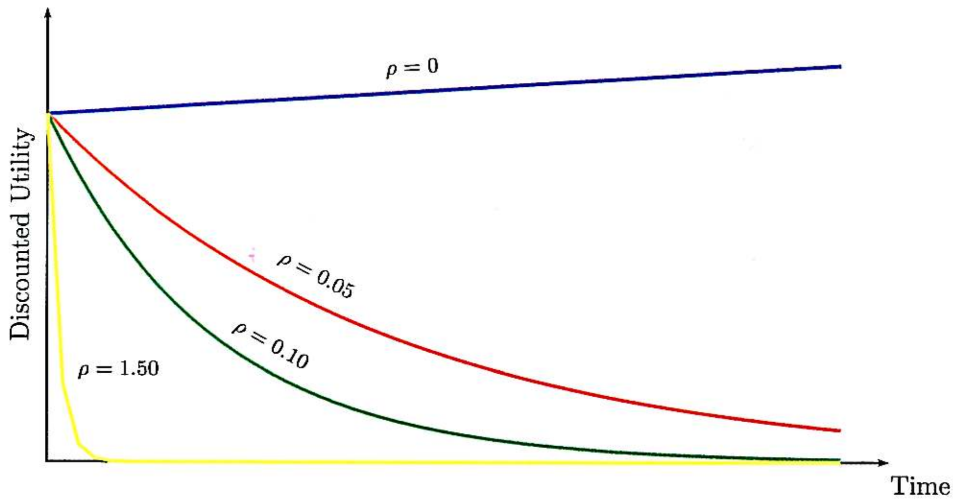
4 Parameter Assumptions

4.1 The Pure Rate of Time Preference

Here we investigate the formulation of the pure rate of time preference ρ. Conceptually, this parameter is required to discount utility because future consumption is valued less today than current consumption precisely because it lies in the future (Garnaut, 2008*a*). Therefore, the parameter ρ ensures future utility is comparable to present utility. This is required for the hypothetical decision-marker to derive the optimal consumption smoothing path embodied in the 'Euler' equation (3). To illustrate the effects of different values of ρ on the social welfare function (1), consider Figure 2. It gives four constructed social welfare functions and shows how with higher ρ discounted utility falls faster over time.

A priori ethical and philosophical questions have played a role in formulating the pure rate of time preference in the *Stern* and *Garnaut* reviews. Citing 'economists and philosophers', the *Stern Review* suggests a positive pure discount rate is only relevant to account for 'the exogenous possibility of extinction' (Stern, 2007, p. 60). Thus, *Stern* uses a time discount rate of 0.1 percent per year. In a similar vein, the *Garnaut Review* cites 'the philosopher kings of economics' including Ramsey (1928) and Sen (1961) in justifying a near-zero time discount rate of 0.05, writing that a positive time discount rate 'flies in the face of the utilitarian principle underlying

Figure 2: Social Welfare Function with Discounted Utility



Note: This figure shows the social welfare function (1) (W) with utility discounted by different values of ρ. A ln utility function is used with an arbitrary initial consumption level of 100 and growing by 1.3% per time period. The welfare functions reflect primarily the discounting function $\exp(-\rho t)$, particularly at high t.

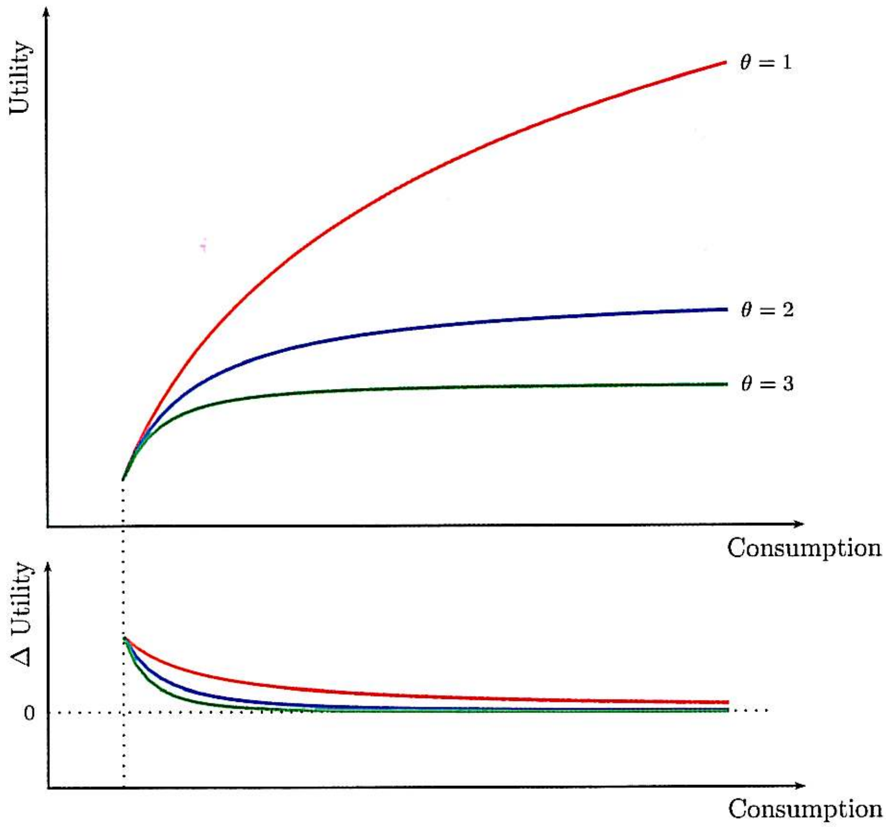
most economic analysis: that equal weight should be placed on each person.'

We thus see Stern (2007) and Garnaut (2008*b*) placing *a priori* faith in the British utilitarian tradition (analysed by Sen and Williams, 1982) without mentioning competing philosophies (for more detail on these see Nordhaus, 2007, p. 692). This calls into question the universality of the assumptions and conclusions of the *Stern* and *Garnaut* reviews and invites us to consider the warning of one of the independent founders of the conceptual framework used (Koopmans, 1965):

> The problem of optimal growth is too complicated ... for one to feel comfortable in making an entirely *a priori* choice of [a time discount rate] before one knows the implications of alternative choices.

Of more concern than the philosophical contentions, the choice of very low pure time discount rates do not reflect real-life observations. Weitzman (2007, p. 707) suggests *Stern*'s choice of a pure time preference of 0.10 cannot be reconciled with observed savings and investment behaviour indicating people prefer current to future consumption. Australia's superannuation policy supports this–individuals are forced to save to adequately fund future consumption. Tol and Yohe (2006), Dasgupta (2007) and Mendelsohn (2007) all make similar arguments against accepting a near-zero time discount rate.

Figure 3: Utility Functions Under Different Values of θ



Note: This figure shows constructed instantaneous utility functions given by equation (2) with a common starting point to illustrate the effect of different values of θ; the higher θ the quicker utility falls with greater consumption–the second pair of axes shows the change (Δ) in utility.

4.2 The Consumption Elasticity

The second component influencing the optimal time path of consumption in the 'Euler' equation is the consumption elasticity θ. The value of θ defines the shape or curvature of the utility function (equation (2)) indicating households' willingness to move consumption across time. For example, if θ is small, as consumption rises, the marginal utility of the extra consumption falls slowly. As such, households will be more willing to shift consumption into the future (Romer, 2006, p. 50). To conceptualise this, Figure 3 gives equation (2) for different values of θ. As shown, for higher values of $\theta \geq 1$ the utility function is 'flatter'. This illustrates how with more consumption, the marginal utility (the change Δ) in function (2) falls faster with higher θ.

Stern (2007) uses a marginal elasticity of consumption $\theta = 1$ in his initial report which Weitzman (2007) remarks is 'the lowest lower bound of just about any economist's best-guess range'. This observation is confirmed by Tol's (2008) meta-analysis of a wide range of climate change studies. Nordhaus (2007, p. 694) similarly criticises this assumption which he writes is 'casually discussed [by Stern (2007)] without justification'. Garnaut (2008*b*) uses two rates, $\theta = 1$ and $\theta = 2$; this apparent flexibility was perhaps pre-empting the criticism of *Stern* and Stern's (2007) *ex ante* analysis with varying values of θ in response to the criticism.

Appealing to real-world evidence, with a utility function given above in equation (2) it can be shown that the elasticity of substitution between consumption in different time points is $\frac{1}{\theta}$. In demand analysis, Powell (1992) has shown under preference independence,[1] the average elasticity of substitution between goods is approximately equal to $-\phi$ where ϕ is the 'income flexibility' parameter (Clements, 2008, n. 2, p. 492). Clements (2008) reviews a range of demand studies and shows there is strong evidence for the income flexibility $\phi = -\frac{1}{2}$. Thus, equating $\frac{1}{\theta} \approx -\phi$ implies $\theta \approx 2$. This calls into question *Stern* and *Garnaut*'s use of $\theta = 1$.

5 Consequences of Assumptions Made

The assumptions about ρ and θ have important implications not fully discussed in the *Stern* and *Garnaut* reviews. This section looks at these consequences.

5.1 The Interest Rate

The first consequence concerns the implied interest rate. In the Ramsey (1928)-Cass (1965)-Koopmans (1965) conceptual framework the real rate of return is endogenous and depends on the parameters discussed above. It is analysed by rearranging equation (3) and expressing $r(t)$ as the focus variable:

$$r(t) = \theta c^*(t) + \rho.$$

All the parameters are defined as above. As Nordhaus (2007, p. 694) shows, under the *Stern* assumptions of $\theta = 1$, $c^*(t) = 1.3$ and $\rho = 0.10$, $r(t) = 1.4$ percent per year. Under the *Garnaut* assumptions, there is some flexibility–ρ is assumed to be 0.05, $c^*(t) = 1.3$ (based on historical trends) and $\theta = 1$ or $\theta = 2$; these imply $r(t) = 1.35$ or $r(t) = 2.65$. In any event, neither implied rate of return is consistent

[1] *Note*: Preference independence applies to $W = \int U[c(t)]e^{-\rho t}dt$ over continuous time.

with observed rates of return on capital of around 6 percent per annum.

Accepting this is strange; Kevin Murphy (2008) argues that, since the discount rate on consumption should reflect opportunity costs defined by the real rate of return, the assumptions about ρ and θ should be chosen as such. Consider his pungent example: assume a real interest rate on assets of 6%. Suppose in 2008 we have to make a choice with \$1 which will yield \$20 of climate-related benefits in 100 years time; it can be invested in climate-change mitigation, yielding the \$20, or it can be invested in other assets. If the latter, the realised gain on that \$1 in 2108 is \$339. Surely, future generations would prefer the investment in general assets; they would be left with \$319, subtracting the \$20 cost of global warming.

This is a compelling illustration of why ρ and θ should be chosen such that the model used reflects real-world observations. Even if the rate of return is judged not to be the return of capital, *Stern*'s implied 1.4% $r(t)$ and *Garnaut*'s 1.35% $r(t)$ do not reflect the historical 2.1% return on (almost) riskless long-term Australian government bonds. In any event, despite Garnaut (2008*b*) attempting to 'normatively' persuade otherwise, the real return to capital is the appropriate objective comparison. As Nordhaus (2007, p. 693) writes:

> It is the real return on capital that enters into the equality between the marginal consumption cost of emissions reductions today and the discounted marginal consumption benefit of reduced climate damages in the future.

5.2 The Growth Rate of Consumption

Now suppose we take an approach where $r(t)$ is set equal to observed rates of return of around four to six percent per annum and analyse the implications for consumption growth under different values of ρ and θ (Table 1). As presented, large differences between $r(t)$ and ρ imply large consumption growth rates for low θ–intuitive because (i) individuals exploit differences in $r(t) - \rho$ and (ii) they are not adverse to future consumption (low θ).

If we attempt to reconcile the observed growth rate of consumption of around 1.3 percent per annum with the parameters θ and ρ, through the 'Euler' equation we generally require a combination of high ρ and high θ. For the *Garnaut* assumptions, under none of the $r(t)$ rates analysed in Table 1 is the implied consumption growth rate similar to the long-term observed trend.

Table 1: Implied Consumption Growth Rates for $r(t)$, ρ and θ

$\dot{c}/c = (r(t) - \rho)/\theta$

	$r(t)=4$			$r(t)=5$			$r(t)=6$		
$\rho \setminus \theta$	1	2	3	1	2	3	1	2	3
0.00	4.00	2.00	1.33	5.00	2.50	1.67	6.00	3.00	2.00
0.05	3.95	1.97	1.32	4.95	2.48	1.65	5.95	2.97	1.98
0.10	3.90	1.95	1.30	4.90	2.45	1.63	5.90	2.95	1.97
1.50	2.50	1.25	0.83	3.50	1.75	1.17	4.50	2.25	1.50
2.00	2.00	1.00	0.66	3.00	1.50	1.00	4.00	2.00	1.33

Note: Author's derivations.

5.3 The Implied Savings Rate

A further implication, noted by Dasgupta (2007) and Weitzman (2007) concerns the savings rate. Assume the permanent income hypothesis holds. Suppose there is an individual representing a 'long-lived dynasty' with wealth W comprised of (capitalised) future earnings and initial wealth and who faces a constant interest rate $\bar{r}$ (Weitzman, 2007, p. 709). Permanent income is $\bar{r}W$; optimal consumption implies the individual saves proportion s of permanent income. Thus, implied consumption growth is $c^* = s\bar{r}$. From this the 'Euler' equation (3) becomes, after rearranging for s to be the focus variable:

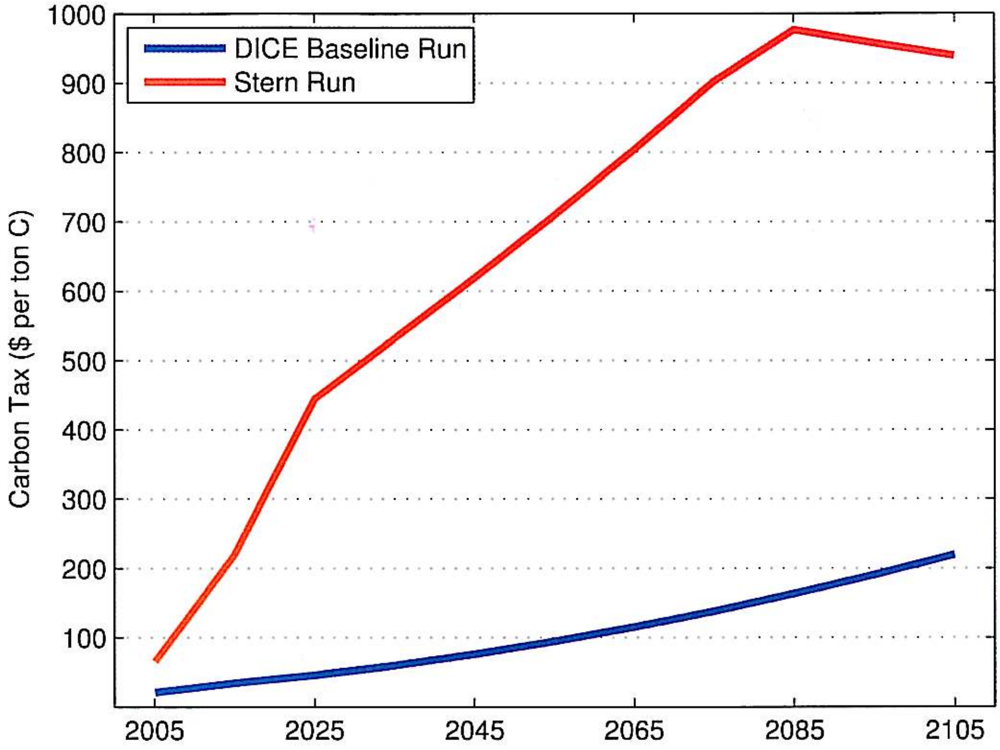
$$s = \frac{\bar{r} - \rho}{\bar{r}\theta}$$

Assuming $\rho \approx 0$ and $\theta = 1$ implies $s \approx 100$; *reductio ad absurdum* (Weitzman, 2007, p. 709)–Dasgupta (2007) calls it 'patently absurd'. Even with $\theta = 2$, allowing for Garnaut's (2008*b*) 'flexibility', with $\rho = 0.05 \approx 0$, the implied savings rate is $s = 0.5$. The highest estimates of the Australian savings rate do not put it at 50%.

5.4 The Cost of Carbon

Finally, and with important policy implications, assumptions made about θ and ρ have implications for the cost of carbon. Consider Figure 4 showing the implied cost of carbon per ton (USD) calculated by the Dynamic Integrated model of Climate and the Economy (DICE model) (DICE Model Web Site, 2008). The DICE model links scientific and economic factors of population, technological change, greenhouse gas emissions, concentrations, climate change and damages (Nordhaus, 2007, p. 697). The implied cost of carbon is equivalent to the social cost of carbon according to the model. Two runs are presented, the baseline model results using parameter assumptions $\rho = 1.5$ and $\theta = 2$ and a run using the *Stern Review* parameter assumptions

Figure 4: DICE Runs and the Optimal Tax



Note: This figure shows the DICE model (DICE Model Web Site, 2008) runs on the cost of carbon in a consumption smoothing framework. Two runs are presented; the DICE baseline run and the *Stern Review* and by analogy the *Garnaut Review* runs. The only difference in the assumptions input into the DICE model concern ρ and θ.

$\rho = 0.10$ and $\theta = 1$–similar to the *Garnaut* assumptions. All other parameters and assumptions of the model are held constant.

Under the DICE baseline run the optimal carbon tax increases smoothly to around USD200 per ton of carbon by 2100. By contrast, with the *Stern* assumptions the optimal carbon tax displays a considerably steeper gradient and peaks around USD1000 per ton of carbon in 2085. The notable conclusion of this illustrative comparison is the sensitivity of the implied cost of carbon to the assumptions about ρ and θ.

Linking this observation to the analytical exposition of the welfare function and utility function above, the social cost of carbon (and thus optimal tax) represents the discounted value of the change in the utility of consumption in terms of current consumption (Nordhaus, 2007, p. 698). That is, it is the (utility) cost today of an expected decline in future consumption due to climate change. If future consumption is highly valued (ρ low, θ low) the current social cost (tax) of carbon is magnified.

This explains why *Stern* and, implicitly any modelling analysis conducted using *Garnaut* assumptions will yield high taxes on carbon:

> [This highlights] what counts in the economics of climate change–the hidden discounting assumptions whose role tends to be obscured than informed by the big [models] (Weitzman, 2007, p. 708).

6 Conclusion

The essay outlined criticisms of important assumptions made by the prominent climate change reviews of Stern (2007) and Garnaut (2008*b*). Focussing on a specific analysis of the assumptions made about the pure rate of time preference ρ and the consumption elasticity θ, this essay illustrated how judgments made about these in the reviews can have absurd implications inconsistent with the opinion of mainstream economics and with observable evidence. This should raise concerns about the policy implications arising from the two reviews, in particular on the implied cost of carbon.

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