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SELECTING A DISCOUNT RATE FOR EVALUATING WATER DISTRIBUTION PROJECTS – THE SUSTAINABILITY CONTROVERSY

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Abstract

Water distribution systems produce greenhouse gases during the manufacture, transport and installation of pipes and also particularly as a result of pumping when electricity is derived from the burning of fossil fuels. Typically in a life cycle analysis for the planning of new water distribution system infrastructure, that involves pumping, a present value analysis is carried out to convert annual operating costs for pumping into their present values. The way in which time preferences are incorporated into the calculations strongly affects the outcomes in terms of both costs and associated greenhouse gases. Many water utilities around the world use a discount rate equal to the interest rate or the current cost of capital of between 6 and 8%. Over the last 5 years or so the United Kingdom has been using a discount rate for evaluating projects of 3.5% and declining to 1% between 30 and 301 years. The Stern Review: The Economics of Climate Change has recently recommended that a very low discount rate of 1.4% be used for evaluating projects that lead to the production of greenhouse gases. The Stern Review predicts that dire consequences will occur if the concentration of CO_2-equivelent greenhouse gases in the atmosphere exceeds 550 ppm and recommends that immediate drastic and decisive action be taken to progressively cut emissions by 3% per annum over the next century. This paper explores the different options for discount rates proposed for present value analysis by various economists and also considers the arguments for and against using the standard 6 to 8% or a significantly lower or a time declining discount rate that is based on societal preferences. The implications on the design of water distribution systems are assessed.

1. INTRODUCTION

Sustainability of urban infrastructure systems is starting to attract significant attention (Lundie et al. 2004). Over the last 20 years there has been a debate amongst economists about the use of a discount rate in the present value analysis of greenhouse gas related projects. One camp of economists stridently adhere to using the cost of capital (usually in the range of 6 to 8%) as the discount rate for the evaluation of projects. Other economists have suggested using a social discount rate ranging from zero, or a constant value that is lower than the cost of capital or a declining discount rate over time. Weitzman (2007) suggests that "*The idea behind analyzing climate change projects by converting future costs and benefits into present discounted values is that society has alternative investment opportunities, whose proxy rate of return is the discount rate, representing alternative capital-accumulation opportunities throughout the rest of the economy that would compensate us for the economic losses suffered from climate change.*"

A very significant milestone in the sustainability and greenhouse gas debate was *The Stern Report: The Economics of Climate Change* (2006). Gordon Brown, then UK Chancellor of the Exchequer, commissioned the *Stern Review* in July 2005. Sir Nicholas Stern was Head of the Government Economic Service in the UK and Adviser to the British government on the economics of climate change (Carter et al. 2006). More than 20 officials under the direction of Sir Nicholas plus a number of consultants worked on the review. Jensen and Webster (2007) conclude that Stern has two messages: first, global warming is

occurring; and, second, it is being induced by emissions of carbon dioxide (CO_2), methane and other 'greenhouse' gases. The main economic message from the *Stern Review* is that climate change will seriously curtail economic growth (Jensen and Webster 2007). The noted Stanford University Professor Emeritus of Economics and Nobel laureate, Arrow (2007) described Sir Nicholas Stern as "a top-flight economist." Arrow agrees with the Stern Report argument that huge future costs of global warming can be avoided by incurring relatively modest costs today (Arrow 2007).

The objective of this paper is to explore some of the arguments posed about the discount rate and then to explore the implications for evaluating water distribution system projects that involve pumping. The question also arises as to whether intergenerational equity is achieved for the selection of a particular discount rate. Is it fair to pass onto future generations both the extra costs and the additional greenhouse emissions? Many of the arguments put in this paper are based on Weitzman's paper (2007) which I believe provides compelling arguments for taking action on climate change via a reduction of the discount rate used for present value analysis.

2. FUTURE IMPACTS OF CLIMATE CHANGE

According to the evidence presented in the *Stern Review*, CO_2 concentration levels have gone from 280 parts per million (ppm) at the time of the industrial revolution to 380 ppm today. When consideration is taken of other greenhouse gases emitted by human activity, the level of CO_2 equivalent (CO_2-e) concentration is 430 ppm and rising at 2.3 ppm per year. The level of CO_2-e concentration is higher than at any time over the last 800,000 years (Jensen and Webster 2007). *The Stern Review* predicts that dire consequences will occur if the concentration of CO_2-equivalent greenhouse gases in the atmosphere exceeds 550 ppm and recommends that immediate drastic and decisive action be taken to progressively cut emissions by 3% per annum over the next century. This would make temperatures a hundred years from now higher with an expected temperature rise of $E[\Delta T] \approx 2°C$ and would (hopefully) stabilise future temperatures permanently thereafter at $\Delta T \approx 3°C$ (Weitzman 2007). To achieve such reductions of emissions, *The Stern Review* recommended that a very low discount rate of 1.4% be used for evaluating projects that lead to the production of greenhouse gases. Since the early 1990s there have been a number of economists who have proposed similar ideas to Stern proposing that either low discount rates or a declining discount with time should be used in life cycle analysis of projects associated with greenhouse gases. In fact, Weitzman (2007) points out that "*this important dispute about what interest rate to use for discounting costs and benefits of mitigating greenhouse warming duplicates the same debate about the same subject more than a decade ago between William R. Cline and Nordhaus, two early pioneers of modeling the economic effects of climate change.*"

The main finding of the *Stern Review* was that the cost of continued greenhouse gas emissions at the current rate is large enough (equivalent to 5–20 per cent of global Gross Domestic Product (GDP) per year, now and forever) to warrant substantial and immediate action to move the globe to a low carbon position (Jensen and Webster 2007). Stern estimates that the cost of mitigating policies should be limited to around 1 per cent of global GDP. Stern argues, there exists the distinct possibility of serious and perhaps irreversible damage to ecosystems, societies and economies. Arrow (2007) suggests that "we are much better off reducing carbon dioxide emissions substantially than risking the consequences of failing to act, even if, unlike Stern, one heavily discounts uncertainty and the future." Weitzman (2007) states "*the Stern Review comes down very strongly on the side of undertaking decisive—and expensive—measures starting now to reduce CO_2 and other greenhouse gas emissions because (and this quote captures well the tone of urgency about moving quickly to avoid catastrophic possibilities that is evident throughout the report): "Our actions over the coming few decades could create risks of major disruption*

to economic and social activity, later in this century and in the next, on a scale similar to those associated with the great wars and economic depression of the first half of the 20th century" (p. xv)."

The *Stern Review* adopts an international perspective on climate change—Jensen and Webster (2007) suggests that it argues correctly that it is a global problem which requires a global solution. The *Stern Review* argues that climate change is a market failure with some atypical characteristics. Jensen and Webster (2007) describe the characteristics as: (i) climate change being a large (in fact very large) externality, (ii) impacts in the future depend on stocks of CO_2-e emissions in the atmosphere rather than flows of CO_2-e and (iii) the size and timing of environmental impacts of global warming are uncertain.

Weitzman (2007) lists a number of threshold-crossing possible disasters associated with abrupt large-scale irreversible changes in the climate system that are associated with detrimental effects of global warming (as described by the *Stern Review*). These include:

- collapse of Greenland and West Antarctic ice sheets (There is considerable uncertainty of the temperature at which this would occur.)
- weakening or even reversal of thermohaline circulations that might radically affect such things as the Gulf Stream and European climate
- runaway climate-sensitivity amplification of global warming due to positive-reinforcing multiplier feedbacks (including, but not limited to, loss of polar albedo, weakened carbon sinks and rapid releases of methane from the thawing of arctic permafrost)
- sea level dynamics, drowned coastlines of unknown magnitude
- very different and possibly extreme weather patterns including droughts and floods
- ecosystem destruction
- mass species extinctions
- big changes in worldwide precipitation patterns and distribution of fresh water
- tropical crop failures
- large-scale migrations of human populations
- humidity-nourished contagious diseases

Such rare disasters are far out in the right tail of the probability distributions for very high temperature increases ΔT by 2105. Weitzman (2007) suggests that the cost of the disasters above from high-ΔT scenarios more properly constitutes uncertainty than risk, because the scale and probability of these disasters are both unknown. He says it is very difficult to estimate tail probabilities of high-ΔT outcomes as the rarer the event the more unsure is the estimate of its probability. There is little doubt that the worst-case scenarios of global-warming catastrophes are genuinely frightening.

Jensen and Webster (2007) refer to "a common, but unproven, view among scientists that many changes will be sudden (discontinuous) rather than incremental." Jensen and Webster (2007) suggest that there is no data to calculate the probabilities for unprecedented events (and catastrophes) which might occur if temperatures rise more than 2 degrees Celsius. The question arises as to how much insurance we need to buy to offset a small change of a ruinous catastrophe that is difficult to compensate for by ordinary savings (Weitzman 2007). Weitzman (2007) also suggests that "*investors are disproportionately afraid of rare disaster - people are willing to pay high premiums for relatively safe stores of value that might represent "catastrophe insurance" against out-of-sample or newly evolved rare disasters*." In addition, Jensen and Webster (2007) suggest that these long time horizons bring into play the ethically complex interpersonal intergenerational comparisons instead of the more straight forward intrapersonal intertemporal comparisons that are usually made.

Jensen and Webster (2007) also point out that "Since there is no parallel global government there is no obvious authority to correct the externality through the usual channels. Every country has an incentive to free ride." Based on point (ii) above, the damage by greenhouse gases being done today is a result of

accumulations over the last 100 years. The same will be true over the next century. Jensen and Webster (2007) concluded that it is the very long time lags in both the damage caused by CO_2-e emissions and policies to mitigate climate change that make discounting and investment decisions so dramatic. Finally, Jensen and Webster (2007) conclude that The *Stern Review*'s models predict that a conservative impact of 'business-as-usual' climate change will be an ongoing 5 per cent annual loss of Gross Domestic Product (GDP) compared with a 'no-climate-change' world. This impact may be as high as 20 per cent if catastrophic climatic events and non-market impacts are incorporated. Weitzman (2007) summarises the central question of the *Stern Review* as "*is it worthwhile to sacrifice costs C = 1 percent of GDP now to remove damages D = 5 percent of GDP a century from now?*"

3. PRESENT VALUE ANALYSIS

The focus of this paper is to explore the implications of using discount rates that are possibly significantly lower than the cost of capital for the evaluation of the design and operation of water distribution systems. This is particularly important in the consideration of the design of new systems that involve pumping. The usual present valuation analysis approach considers the trade-off between capital cost and a series of annual operating costs (due to the purchase of electricity) over the lifetime of the project. Every cost–benefit analysis is an exercise in subjective uncertainty (Weitzman 2007).

Weitzman (2007) says of the *Stern Review* that it consistently leans towards assumptions and formulations that emphasise optimistically low expected costs of climate change mitigation and pessimistically high expected damages from greenhouse warming—relative to most other studies of the economics of climate change. However, he also believes that far more crucially, the key assumption that drives the strong conclusions of the *Stern Review* "*is the mundane fact that a very low interest rate is postulated, with which distant-future benefits and costs are then discounted.*" Thus the selection of the discount rate becomes central to consideration of measures to evaluate the reduction of greenhouse gases into the future. In addition, Weitzman (2007) suggests "*that the biggest uncertainty of all in the economics of climate change is the uncertainty about which interest rate to use for discounting. ... it needs to be more widely appreciated by economists at large.*" An interesting view of a high interest rate is give by Weitzman (2007): "*the higher the interest rate the stronger the desire to move toward getting more pleasure now at the expense of postponing more pain until later.*"

Translation of a future cost or benefit back to a present value depends on the discount rate and the time in the future that is being considered. The present value (PV) of a future payment can be calculated using the following exponential discounting equation (Wu 2008a):

$$PV_t = \frac{C}{(1+i)^t} \tag{1}$$

where, C is the payment on a given future date; t is the number of periods and i is the discount rate. Similarly, the present value of a stream of costs with a specified number of fixed periodic payments can be expressed as:

$$PV = C \sum_{n=1}^{t} \left[\frac{1}{(1+i)^n} \right] \tag{2}$$

where, C is the periodic payment that occurs at the end of each period; n is the number of periods and i is the discount rate. The selection of the value of the discount rate has a significant impact on the result of

present value analysis, and is therefore extremely important. The higher the discount rate, the smaller the present value of a future sum, which means that more weight is placed on the costs and benefits at present in comparison to the costs and benefits in the future (Bazelon and Smetter, 2001). This means that ''*however small the cost today of preventing some catastrophic economic or environmental event in the future, if this catastrophe is sufficiently distant in time, the calculus of benefit-cost analysis will recommend against mitigative measures today.*'' (Lind, 1990 as quoted by Rambaud and Torrecillas 2005). In contrast, lower discount rates will lead people to choose programs with higher net benefits in the distant future (Rambaud and Torecillas 2005).

Rambaud and Torecillas (2005) suggest that for private projects, market interest rates or investment rates of return are usually used as the discount rate. In contrast they also suggest that for public projects different criteria be considered including:

- adoption of a social cost–benefit analysis, and then a social discount rate
- consideration of social benefits as profits in long-term public projects, e.g. increase in the quality of life
- consideration that these costs and benefits are not equally distributed between generations

There are a range of discount rates used by Governments as given in Rambaud and Torrecillas (2005) in Table 1. Weitzman (1994, 1998) argued in favour of ''a social rate of return that is not only lower than the private rate of return, but that is expected to decline systematically over time.'' The UK was the first government to recommend a declining discount rate in 2003. Time declining discount rates are supported by Rambaud and Torrecillas (2005) for the following reasons: 1) uncertainty about the future 2) future fairness and 3) observed individual choice.

Table 1 Discount rates used in different government agencies (from Rambaud and Torrecillas 2005)

AMERICAN GOVERNMENT AGENCIES AND ORGANISATIONS	**DISCOUNT RATE**
Office of Management and Budget	10%
Bureau of Land Management	10%
U.S. Fish and Wildlife Service	7.8% (nominal rate)
U.S. Forest Service	4%
Congressional Budget Office	2%
Government Accounting Office	The average cost of Treasury debt
Municipal Governments	3%
OTHER NON AMERICAN GOVERNMENTS	
English Government	3.5%, for time periods beyond 30 years the discount rate declines
Dutch agencies	8% (nominal); 4% (real rate)

Source: Ferraro (2001) and Her Majesty's Treasury (2003)

The dramatic effect of varying the discount rate is demonstrated in Table 2 for a series of annual costs of $100,000 per annum over the next 100 years. Even though the interest rate of 1.4% appears to be close to zero (compared with 8%) there is still a 46% reduction in the present value of the operating actual costs in Table 1 when an interest rate of 1.4% is used rather than a zero percent interest rate. The reduction in the value of future costs is very significant for the 8% discount rate, being only 12% of the total costs. For the 8% discount rate, the $100,000 cost in the 50^{th} year is reduced to about 2% of its original value ($2,132) while this cost in the 100^{th} year is reduced to only $45. Note there is not a lot of difference between the results of the discounted present value for the 6% and 8% discount rates.

Table 2. Present value of a stream of annual costs for various discount rates

Year	Cost	i = zero%	i = 1.4%	i = 6%	i = 8%
0	$ -	$ -	$ -	$ -	$ -
1	$ 100,000	$ 100,000	$98,619	$94,340	$92,593
2	$ 100,000	$ 100,000	$97,258	$89,000	$85,734
3	$ 100,000	$ 100,000	$95,915	$83,962	$79,383
4	$ 100,000	$ 100,000	$94,591	$79,209	$73,503
5	$ 100,000	$ 100,000	$93,285	$74,726	$68,058
6	$ 100,000	$ 100,000	$91,997	$70,496	$63,017
7	$ 100,000	$ 100,000	$90,727	$66,506	$58,349
8	$ 100,000	$ 100,000	$89,474	$62,741	$54,027
9	$ 100,000	$ 100,000	$88,239	$59,190	$50,025
10	$ 100,000	$ 100,000	$87,020	$55,839	$46,319
11	$ 100,000	$ 100,000	$85,819	$52,679	$42,888
12	$ 100,000	$ 100,000	$84,634	$49,697	$39,711
13	$ 100,000	$ 100,000	$83,465	$46,884	$36,770
14	$ 100,000	$ 100,000	$82,313	$44,230	$34,046
15	$ 100,000	$ 100,000	$81,177	$41,727	$31,524
16	$ 100,000	$ 100,000	$80,056	$39,365	$29,189
17	$ 100,000	$ 100,000	$78,950	$37,136	$27,027
18	$ 100,000	$ 100,000	$77,860	$35,034	$25,025
19	$ 100,000	$ 100,000	$76,785	$33,051	$23,171
20	$ 100,000	$ 100,000	$75,725	$31,180	$21,455
21	$ 100,000	$ 100,000	$74,680	$29,416	$19,866
22	$ 100,000	$ 100,000	$73,649	$27,751	$18,394
23	$ 100,000	$ 100,000	$72,632	$26,180	$17,032
24	$ 100,000	$ 100,000	$71,629	$24,698	$15,770
25	$ 100,000	$ 100,000	$70,640	$23,300	$14,602
26	$ 100,000	$ 100,000	$69,665	$21,981	$13,520
27	$ 100,000	$ 100,000	$68,703	$20,737	$12,519
28	$ 100,000	$ 100,000	$67,754	$19,563	$11,591
29	$ 100,000	$ 100,000	$66,819	$18,456	$10,733
30	$ 100,000	$ 100,000	$65,896	$17,411	$9,938
31	$ 100,000	$ 100,000	$64,987	$16,425	$9,202
32	$ 100,000	$ 100,000	$64,089	$15,496	$8,520
33	$ 100,000	$ 100,000	$63,204	$14,619	$7,889
34	$ 100,000	$ 100,000	$62,332	$13,791	$7,305
35	$ 100,000	$ 100,000	$61,471	$13,011	$6,763
36	$ 100,000	$ 100,000	$60,622	$12,274	$6,262
37	$ 100,000	$ 100,000	$59,785	$11,579	$5,799
38	$ 100,000	$ 100,000	$58,960	$10,924	$5,369
39	$ 100,000	$ 100,000	$58,146	$10,306	$4,971
40	$ 100,000	$ 100,000	$57,343	$9,722	$4,603
41	$ 100,000	$ 100,000	$56,551	$9,172	$4,262
42	$ 100,000	$ 100,000	$55,771	$8,653	$3,946
43	$ 100,000	$ 100,000	$55,001	$8,163	$3,654
44	$ 100,000	$ 100,000	$54,241	$7,701	$3,383
45	$ 100,000	$ 100,000	$53,492	$7,265	$3,133
46	$ 100,000	$ 100,000	$52,754	$6,854	$2,901
47	$ 100,000	$ 100,000	$52,025	$6,466	$2,686
48	$ 100,000	$ 100,000	$51,307	$6,100	$2,487
49	$ 100,000	$ 100,000	$50,599	$5,755	$2,303

50	$ 100,000	$ 100,000	$49,900	$5,429	$2,132
51	$ 100,000	$ 100,000	$49,211	$5,122	$1,974
52	$ 100,000	$ 100,000	$48,532	$4,832	$1,828
53	$ 100,000	$ 100,000	$47,862	$4,558	$1,693
54	$ 100,000	$ 100,000	$47,201	$4,300	$1,567
55	$ 100,000	$ 100,000	$46,549	$4,057	$1,451
56	$ 100,000	$ 100,000	$45,907	$3,827	$1,344
57	$ 100,000	$ 100,000	$45,273	$3,610	$1,244
58	$ 100,000	$ 100,000	$44,648	$3,406	$1,152
59	$ 100,000	$ 100,000	$44,031	$3,213	$1,067
60	$ 100,000	$ 100,000	$43,423	$3,031	$988
61	$ 100,000	$ 100,000	$42,824	$2,860	$914
62	$ 100,000	$ 100,000	$42,232	$2,698	$847
63	$ 100,000	$ 100,000	$41,649	$2,545	$784
64	$ 100,000	$ 100,000	$41,074	$2,401	$726
65	$ 100,000	$ 100,000	$40,507	$2,265	$672
66	$ 100,000	$ 100,000	$39,948	$2,137	$622
67	$ 100,000	$ 100,000	$39,396	$2,016	$576
68	$ 100,000	$ 100,000	$38,853	$1,902	$534
69	$ 100,000	$ 100,000	$38,316	$1,794	$494
70	$ 100,000	$ 100,000	$37,787	$1,693	$457
71	$ 100,000	$ 100,000	$37,265	$1,597	$424
72	$ 100,000	$ 100,000	$36,751	$1,507	$392
73	$ 100,000	$ 100,000	$36,243	$1,421	$363
74	$ 100,000	$ 100,000	$35,743	$1,341	$336
75	$ 100,000	$ 100,000	$35,250	$1,265	$311
76	$ 100,000	$ 100,000	$34,763	$1,193	$288
77	$ 100,000	$ 100,000	$34,283	$1,126	$267
78	$ 100,000	$ 100,000	$33,810	$1,062	$247
79	$ 100,000	$ 100,000	$33,343	$1,002	$229
80	$ 100,000	$ 100,000	$32,882	$945	$212
81	$ 100,000	$ 100,000	$32,428	$892	$196
82	$ 100,000	$ 100,000	$31,981	$841	$182
83	$ 100,000	$ 100,000	$31,539	$794	$168
84	$ 100,000	$ 100,000	$31,104	$749	$156
85	$ 100,000	$ 100,000	$30,674	$706	$144
86	$ 100,000	$ 100,000	$30,251	$666	$134
87	$ 100,000	$ 100,000	$29,833	$629	$124
88	$ 100,000	$ 100,000	$29,421	$593	$114
89	$ 100,000	$ 100,000	$29,015	$559	$106
90	$ 100,000	$ 100,000	$28,614	$528	$98
91	$ 100,000	$ 100,000	$28,219	$498	$91
92	$ 100,000	$ 100,000	$27,830	$470	$84
93	$ 100,000	$ 100,000	$27,445	$443	$78
94	$ 100,000	$ 100,000	$27,067	$418	$72
95	$ 100,000	$ 100,000	$26,693	$394	$67
96	$ 100,000	$ 100,000	$26,324	$372	$62
97	$ 100,000	$ 100,000	$25,961	$351	$57
98	$ 100,000	$ 100,000	$25,602	$331	$53
99	$ 100,000	$ 100,000	$25,249	$312	$49
100	$ 100,000	$ 100,000	$24,900	$295	$45
PV TOTAL		**$ 10,000,000**	**$ 5,364,265**	**$1,661,755**	**$ 1,249,432**
% of TOTAL COST		**100%**	**54%**	**17%**	**12%**

4. MAKEUP OF THE DISCOUNT FACTOR

A more formal presentation of the basic elements that make up the discount rate is given by Weitzman (p. 706). He states that interest rate, like any other price, is the outcome of a dynamic general-equilibrium interaction of tastes with technology. The equation of Frank Ramsey (1928) is stated by Weitzman as:

$$r = \delta + \eta\, g \qquad (3)$$

where r is the interest rate, δ is the rate of pure time preference, g is the per capita growth rate of consumption, and η is the elasticity of marginal utility, or, equivalently, the coefficient of relative risk aversion. Weitzman (2007) states that "*the parameters δ and η capture two critical aspects of "tastes" (or "preferences") while the reduced-form representation of "technology" is the growth rate of consumption g.*" Weitzman (2007) also describes the *Stern Review*'s preferred base-case parameter values of δ = 0.1 percent p.a., g = 1.3 percent p.a., η = 1.0, such that *Stern*'s discount rate from Eq. 3 is r = 1.4 percent. Weitzman (2007) suggests that "*the Stern Review predetermines the outcome in favor of strong immediate action to curtail greenhouse gas emissions by creating a very low value of r ≈ 1.4 percent via the indirect route of picking point-estimate parameter values δ ≈ 0 and η ≈ 1."* The appropriateness of the choices of these parameters is at the heart of the controversy related to the Stern Report. The *Stern Review* (as quoted by Weitzman 2007) puts it directly: "*The risks of outcomes much worse than expected are very real and they could be catastrophic. Policy on climate change is in large measure about reducing these risks. .... Such a modeling framework has to take account of ethical judgements on the distribution of income and how to treat future generations.*" The "ethical judgements" in the above quote about "how to treat future generations" is *Stern*-speak for picking $\delta = 0$, while the "ethical judgements on the distribution of income" is *Stern*-speak for picking $\eta = 1.0$ (Weitzman 2007). Weitzman (2007) suggests that it would have been better for the *Stern Review* "*to go directly through the front door with the legitimate concern that there is a chance, whose subjective probability is small but diffuse (thereby resulting in a dangerously thickened left tail of comprehensive consumption growth rates), that global warming may eventually cause disastrous temperatures and environmental catastrophes.*"

Furthermore, Weitzman (2007) comments on Stern's selection of the values in Eq. 3 in that he states that "*Stern follows a decidedly minority paternalistic view (which, however, includes a handful of distinguished economists) that for social discounting selects the lowest conceivable value δ ≈ 0 according to 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.*" (my underlining).

Also "*In a similar spirit of choosing extreme taste parameters, Stern selects as its base-case coefficient of relative risk aversion the value η = 1.0 that is the lowest lower bound of just about any economist's best-guess range.* Weitzman (2007) concludes about Stern's parameter selection that he ultimately finds such an extreme stance on the values of δ and η "*unconvincing when super-strong policy advice is so dependent upon non-conventional assumptions that go so strongly against mainstream economics.*" Jensen and Webster (2007) put it in another way "*Stern's assumption of η = 1.0 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 a 1 per cent increase in the consumption of some future generation even if future generations are richer than the current generation."*

Weitzman (2007) points out that the Ramsey deterministic formula of Eq. 3, does not distinguish among rates of return on various assets and that r is just the economy-wide rate of return on capital or, more succinctly, the interest rate. He points out that "*there are many rates of return out there and they differ considerably.*" Weitzman (2007) formally introduces uncertainty into the Ramsey model to distinguish

between "*rates of return on capital from two fundamentally different sorts of investments: a risky economywide rate of return applicable to investments that have payoff characteristics parallel to the economy itself and a risk free rate of return applicable to investments whose payoffs are orthogonal to the economy as a whole.*" Weitzman (2007) frames the issue as being one where the question as to which rate of return to choose for discounting a project comes down to the extent to which the payoffs from the project are proportional (use a risky economy-wide interest rate) to or independent (use a risk free interest rate) from returns to investments for the economy as a whole. Weitzman (2007) concludes that there is an economic rationale by which greenhouse-warming damages are as much uncorrelated as they are correlated with aggregate economic activity. Using this equally correlated/equally uncorrelated argument as a basis he derives an interest rate of 1.7% (which is close to the *Stern* interest rate). Weitzman (2007) says "*In this case investments for mitigating global climate change become attractive as an insurance policy that secures food supplies, preserves coastal areas, and maintains natural environments in a world where future aggregate growth rates are uncertain."* An alternative view on the choice of discount rate (as detailed by Weitzman 2007) has been put in the past by Robert Lind who, in a comprehensive summary of an influential book he edited in 1984 entitled *Discounting for Time and Risk in Energy Policy,* concluded that "*unless there is substantial evidence to the contrary, the returns associated with public projects should be assumed to be highly correlated with returns to the economy as a whole*." (p. 77)

5. THE CASE FOR A LOWER DISCOUNT RATE

As alluded to the previous section, Weitzman (2007) comprehensively reviews the *Stern Review*, its analysis methods and its conclusions. He concentrates on trying to distill the Review down to what he thinks is its analytical essence as a piece of applied cost–benefit analysis. As mentioned in the previous section Weitzman (2007) raised skepticism in relation to the formal analysis in the *Stern Review* that leads to the conclusion that a low discount rate needs to be used. Weitzman (2007) also says that he believes that "*we are actually a lot less sure about what discount rate should be used for discounting climate change than is currently acknowledged.*" Furthermore he analyzes the issue raised in the *Stern Review* of the importance of avoiding possible large uncertainties that are difficult to quantify. Weitzman (2007) suggests that the *Stern Review* may have used the wrong methods but had come up with the right answer regarding the use of a low discount rate for economic analysis. He concludes that: "*The basic issue here is that spending money to slow global warming should perhaps not be conceptualized primarily as being about consumption smoothing as much as being about how much insurance to buy to offset the small change of a ruinous catastrophe that is difficult to compensate by ordinary savings."* Taking the more traditional view of economists rather than the Stern view, a more gradual reduction of the CO_2-trajectory CO_2-e would leave concentrations a century from now at > 600 ppm and $E[\Delta T] \approx 2.5°C$—with temperatures expected to continue rising to well above $E[\Delta T] \approx 3°C$ after year 2105 (Weitzman 2007, Stern 2006). This appears to be too great a risk.

Weitzman (2007) argues that "*standard approaches to climate change (even those that purport to treat uncertainty) fail to account fully for the implications of large consequences with small probabilities and that structural parameter uncertainty that manifests itself in the thick tails of reduced-form probability distributions—not risk—is what likely matters most.*" Probabilities in the tails are in the unknown territory of subjective uncertainty. Estimates of the probability distributions are diffuse because the frequencies of rare events in the tails cannot easily be defined by previous experiences, past observations, or computer simulations (Weitzman 2007).

Weitzman (2007) suggests that the most worrying aspect of Eq. 3 is the omission of uncertainty considerations. Weitzman (2007) posed the following argument. Consider that we are not sure as to whether Stern is correct or his critics are regarding the discount rate that should be used for discounting

costs and benefits a hundred years or so from now. Interest rates under uncertainty do not aggregate arithmetically. A 50% chance of $r = 6\%$ and a 50% chance of $r = 1.4\%$ does not lead to an average of $r = 3.7\%$. The discount factors need to be averaged rather than the discount rates. A 50% chance of a discount factor of e^{-6} a century hence and a 50% chance of a discount factor of $e^{-1.4}$ a century hence make an expected discount factor of $(0.5e^{-6} + 0.5e^{-1.4})$ a century hence, which, is equivalent to an *effective* interest rate of $r = 2$ percent (Weitzman 2007). Thus the result is a discount factor that is in fact a lot closer to the *Stern* value of 1.4% and is not anywhere near the arithmetic average of $r = 3.7$ percent. Finally Weitzman (2007) concludes that "*The moral of this story is that the Stern value may end up being more right than wrong when full accounting is made for the uncertainty of the discount rate itself .... and that over such long periods we should be using interest rates at the lower end of the spectrum of possible values.*"

Arrow (2007) states that a straightforward calculation shows that mitigation is better than business as usual -- that is, the present value of the benefits exceeds the present value of the costs -- for any social rate of time preference less than 8.5 percent. No estimate of the pure rate of time preference, even by those who believe in relatively strong discounting of the future, has ever approached 8.5 percent. Trying to forecast costs and benefits of climate change scenarios a hundred years or so from now is more the art of inspired guesstimating by analogy than a science (Weitzman 2007).

6. THE ARGUMENT FOR BUSINESS AS USUAL

The analysis presented in the Stern Report has been criticised by a number of economists (for example Dasgupta 2007, Nordhaus 2006) who believe that market interest rates should be used as the discount rate in the life cycle analysis of projects that involve both capital costs and operating costs. Such a strong call by the *Stern Review* to immediate decisive action in reducing greenhouse gas emissions is at odds with what most other economic analyses of climate change have concluded (Weitzman 2007). "*The majority view of most other economic analysts is to pursue a more gradualist course by starting with greenhouse gas emissions reductions at far lower levels than what the Stern Review advocates for the near future, but which after that ramp up considerably over time.*" (Weitzman 2007). Weitzman (2007) also says there is no escaping the impact of higher interest rates on undoing the *Review*'s extreme policy conclusions.

Carter et al. (2006) and Byatt et al. (2006) are critical of both the science and economics portrayed in the *Stern Review* and suggest that "*In dealing with the economic aspects which form its main concern, it develops a closely constructed argument of its own.*" Stern's estimate of the damage caused by greenhouse gas emissions is also larger than most previous estimates, and as a result it is perhaps not surprising that the *Stern Review* attracted considerable criticism. (Jensen and Webster 2007).

7. THE RECOMMENDATION FOR WATER DISTRIBUTION SYSTEM DESIGN

Consider the use of a discount rate of say 6% or 8% over a design life of say 100 years (demonstrated in Table 2 previously). From year 40 onwards of a project's life the costs or benefits end up being so heavily discounted that they play little role in the present value analysis of a project. Thus, for the use of this level of interest rate there is a tendency to build water distribution systems with small pipes and large pumps to minimise the initial capital cost because the operating costs are reduced significantly due to discounting. The disadvantage is that future generations are burdened with the operating costs due to pumping the friction head loss component of the pumping head. The associated disbenefit is the extra greenhouse gases produced due to the additional pumping head that needs to be overcome.

The water industry needs to contribute its fair share to reduction of greenhouse gas emissions. For pumping systems use of a discount rate lower than the cost of capital is suggested (for example the value proposed by *Stern Review* of 1.4%). This will minimise friction losses in pumping systems. The downside will be the slightly higher initial capital cost but the upside will be reduced pumping costs into the future and, more importantly, reduced greenhouse gas emissions due to pumping. Weitzman (2007) suggests that there is "a fair recognition of the truth that we are genuinely uncertain about what interest rate should be used to discount costs and benefits of climate changes a century from now." He believes that we should "*bring discount rates down from conventional values r of 6 to 7 percent to much lower values of perhaps r of 2 to 4 percent, which would create a more intermediate sense of urgency somewhere between what the Stern Review is advocating and the more modest measures to slow global warming advocated by many of its critics.*" (Weitzman 2007).

When water distribution system projects are evaluated it is recommended that a sensitivity analysis for a range of discount rates based on a multi-objective optimisation analysis should be used to assess the impact of value of the discount rate and the subsequent resulting designs (Wu et al. 2008a, 2008b, 2008b). This will provide the decision maker with the tradeoff between cost and greenhouse gases associated with a particular project. In addition the impact of selecting various discount rates for the present value analysis will be apparent.

Another important aspect in the evaluation of projects is carbon pricing. This is also an important conclusion from the *Stern Review* as noted by Weitzman (2007) as "*the pricing of carbon, implemented through tax, trading, or regulation," is "required for an effective global response" (p. xvii)*." Weitzman (2007) also notes that "*The Stern Review stresses that clear long-term carbon price signals are needed for efficient investment into low-carbon emission technologies … and investments in very long-term projects need as much certainty as is possible*." Furthermore Weitzman (2007) states that he believes "*the Stern Review deserves credit for effectively raising the level of public discourse—by increasing general awareness that climate change is a serious issue which should be taken seriously, by arguing cogently for what is effectively a global carbon tax as an essential component of any reasonable solution*."

8. SUMMARY AND CONCLUSIONS

The possible outcomes of significant global warming over the next century due to climate change is extremely uncertain. One thing that is certain is that the concentration of CO_2-equivalent gases in the Earth's atmosphere has been increasing dramatically over the last century and continues to grow at alarming rates. Climate change models are predicting a temperature rise of between 2 and 6 degrees Celsius unless action is taken to reduce emissions. The *Stern Review* has raised the level of debate in relation to how quickly we need to act and what parameters we should be using for analysis of projects with greenhouse gas implications.

This paper has considered the impact of the selection of the discount rate for present value analysis of water distribution system projects that involve pumping. Present value analysis is used to bring a future stream of pumping operating costs over the design life of the project back to a present value to be added to the capital cost. Selection of the size of large pipes are traded off against the cost of pumping the friction head component of the pumping head. Based on the arguments of Stern (2006) and Weitzman (2007) it is recommended that discount rates that are lower than the cost of capital should be used for present value analysis of water distribution system projects.

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