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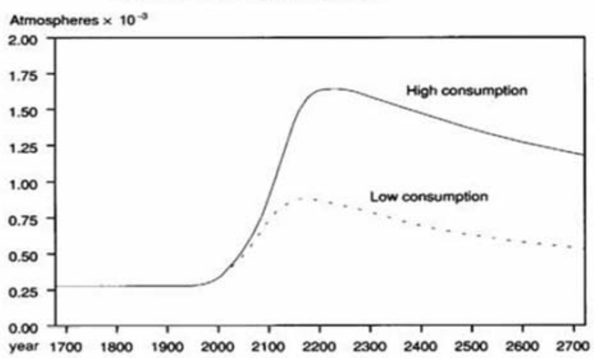
In my view, this report shifts the state of the debate and moves the burden of proof toward those economists who judge that very little should be done to stop global warming because abatement costs exceed benefits of damage avoided. I think it is high time for such a shift. I will argue that the most important reason the new report comes to the conclusion that aggressive action is highly beneficial in economic terms is that it adopts a near-zero rate of "pure time preference," the rate at which the future is discounted solely because of impatience rather than because of rising incomes. This was the approach I proposed in my 1992 book on *The Economics of Global Warming*, and I am delighted to see that the Stern team has also adopted this view. In broad terms I agree with the Stern Report's findings, although I will suggest some important qualifications.

My Earlier Results

The Stern Review results are similar to those I identified in my 1992 book, even though I used a much simpler model.

Figure 2.2 Atmospheric carbon dioxide concentrations under alternative fossil fuel consumption scenarios



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In that analysis I introduced a 300 year time horizon for the analysis, because that is the time it takes for carbon dioxide concentrations to begin falling again from mixing back into the deep ocean, according to oceanographer Eric Sundquist. This meant that I got much higher atmospheric concentrations and far higher eventual warming than the standard 3° C for a doubling of atmospheric carbon dioxide over preindustrial levels. Indeed, my basic estimates of damage avoided by abatement were close to what the Stern Review has obtained: a central estimate of 5 %of GDP by the late 23rd century to a high estimate of nearly 20 percent. I concluded that, with some risk aversion, the benefits of damage avoided would exceed the abatement costs of cutting global emissions from their 1990 rate of about 6 billion tons of carbon equivalent (or about 24 billion tons of carbon dioxide) to a ceiling of 4 billion tons indefinitely. That was a cutback of about 80 %by 2100 from the business as usual baseline. I reached similar conclusions in my more recent paper for the Copenhagen Consensus. The optimal emissions cutbacks from baseline were about 40 %in the first decade, eventually rising to 60 percent. The optimal carbon tax started out at about $150 per ton of carbon, or about 45 cents per gallon of gasoline and $90 per ton of coal, and rose much higher – but in retrospect was probably overstated because of the high abatement costs in the version of Nordhaus' DICE model that I used in that study.

The Discount Rate

By now it seems clear that the central reason for the much more aggressive abatement found desirable in my results, and now the Stern Review results, than in many optimization models is the discount rate chosen to compare costs and benefits over time. The classic statement of the discount rate for such purposes is that by Frank Ramsey in his 1928 growth model.

Social rate of time preference (SRTP)

$$SRTP = \delta + g\eta$$

δ = pure time preference
(impatience)

g = per capita growth

η = (-) elasticity of marginal utility

The social rate of time preference equals the rate of pure time preference, delta in the Stern Review, plus the growth rate of per capita income, g, times the so-called elasticity of marginal utility, eta in the Stern Review. The discount rate on these time scales is crucial. Discounting at 5 percent, for example, $1 million damage 200 years in the future is worth paying only $58 to avoid today. Discounting at 1.5 % one would be willing to pay $51,000.

I agree with the Stern Review that because there is no capital market that extends out one to two centuries, it is necessary to identify the discount parameters from first principles. I set the rate of pure time preference at zero, following Ramsey who called zero pure time preference the only ethical value for comparisons against future generations that cannot take part in decisions today. This is sharply different from the 3% rate of pure time preference that Bill Nordhaus has used, and he and I have agreed to disagree on this issue for nearly two decades now. I set the elasticity of marginal utility at 1.5, a value I derived from the literature but will discuss further. I projected long-term per capita income growth at 1% annually. This meant that the rate of time preference on consumption was 1.5 percent, a rate close to the historic average for the risk-free rate on treasury bills, which is the rate at which households can safely transfer consumption across time. I also applied a shadow price of capital to all investment in future output, to capture the difference between the rate of return on capital and the social rate of time preference – the approach of the social cost benefit literature pioneered by Arrow, Bradford, and Feldstein. After taking account of shadow pricing of investment effects, the overall effective discount rate was in the range of 1.5 to 2%.

Although the Stern Review uses a lower value for eta, it has a higher average growth rate, 1.3 percent, whereas I used 1 percent. The end result is that at 1.4% annually (or somewhat higher in initial years when growth is higher), the Review's discount rate is about the same as mine, although the Stern Review does not shadow price capital so its overall effective discount rate is somewhat further below mine.

The central difference in my results and now those in the Stern Review in contrast to many Integrated Assessment Models of global warming is the adoption of a zero or near zero value for pure time preference, or impatience (delta). The Stern Review sets delta at 0.1%, almost zero but with a small allowance for humanity's self-implosion. Without this 0.1%, the Review's use of an infinite time horizon simply explodes. The time horizon is the first place I would like to register a qualifier to the Review's results.

Welfare Equations – Stern Report

$$W = \sum_{t=1}^{2200} N(t) \ln C(t) e^{-\delta t} + \left(\frac{N_T \ln C_T}{\delta} + \frac{N_T g}{\delta^2}\right) e^{-\delta T}$$

$$W = \sum_{t=1}^{2200} N(t)\left(\frac{C_{BGE}^{1-\eta}}{1-\eta} + gt\right) e^{-\delta t} + \left(\frac{N(t)\left(\frac{(C_{BGE} + 200g)^{1-\eta}}{1-\eta}\right)}{\delta - g(1-\eta)}\right) e^{-\delta T}$$

This equation shows the calculation of the present discounted value of the future welfare in the Review. Consider the top panel, which shows welfare when the elasticity of marginal utility equals unity and utility rises with the logarithm of consumption. The first term is the discounted value of future welfare from now to 200 years from now. The second term is the value of all welfare thereafter. If you put this equation on a spreadsheet, you will find that 93% of all future welfare occurs after the year 2200. That explains the biggest paradox in the Stern Review. It states first that damage rises gradually and only reaches the 5 to 20% of GDP range by 2200. But then it says that the damages are equivalent to 5 to 20% of GDP "now and forever." What is really happening is that the first century disappears into insignificance and the "now and forever" is almost entirely what happens after 2200.

In contrast, I based my analysis on a 300 year horizon, because after that concentrations could begin to fall once again and there should be a partial decline in the cumulative warming. So the first qualification of the Stern Review is that it probably should not have extrapolated the damage rate of 2200 into the infinite future, because that probably overstates the future baseline damages. Even if there are irreversibilities that could leave some damages high despite an eventual partial decline in temperatures – such as melting of the Greenland ice sheet – the relative weight of distant future damages may be overstated. Moreover, at the most fundamental level, it becomes increasingly fanciful to think about effects on the scale of say 3000 years from now, which is still a long way from infinity! Discounting at only 0.1 % pure time preference, $1 million at 3000 years from today is still worth $50,000 today.

It is the combination of a near zero rate of pure time preference with an elasticity of marginal utility of unity, however, that generates truly explosive welfare effects with an infinite horizon. Consider the bottom panel of the figure. This panel shows the Balanced Growth Equivalent level of consumption, C_{BGE}, that generates the same total present value of welfare as the top panel equation. Once again the contribution of the first two hundred years is the first term, and the contribution of everything after that out to infinity is the second term. If you look at the denominator of the second term, you will see the term delta, or pure time preference, which is close to zero; and the growth rate "g" multiplied by one minus the elasticity of marginal utility, eta. In effect the second term is capitalizing the post-2200 future by dividing by the effective overall discount rate, which subtracts off the utility effect of the growth rate in the denominater as the way of taking account of an ever-rising level of consumption. As eta approximates unity, the denominator of the second term approaches nothing but delta, which in turn is close to zero, and division by zero causes the value to explode toward infinity. However, if eta is on the order of 1.3 to 1.5, this denominator in the second term soars from 0.1% to the range of 0.4 to 0.6%, cutting the capitalized contribution of post-2200 welfare to one-fourth to one-sixth the previous amount. As a result, using an elasticity of marginal utility in the range of 1.3 to 1.5 will greatly reduce the extent to which the future benefit of damage avoided may be exaggerated by using an infinite horizon.

In short, the combination of near-zero pure time preference with an infinite horizon probably balloons the value of damage avoided unreasonably. Instead of the benefits being 5 to 20 % of GDP now and forever and the costs of abatement being only 1% of GDP, the benefits could be considerably smaller if the horizon is limited to three centuries or even five to ten centuries. Of course, with such a large gap between the benefit of damage avoided and the estimated costs of abatement, the Stern Review has considerable cushion for reducing the damage estimates and still finding a favorable benefit-cost ratio for aggressive action.

I would argue that if the time horizon is to be extended to infinity, there should not only be more explicit attention to lower damages after 2300 because of partial reversal of global warming, but also that it is important to apply a somewhat higher elasticity of marginal utility than the value of unity used in the Review. All this being said, I would note that with the recent work by Meinshausen and others suggesting that even 2.5°C global warming would be likely to cause dissolution of the Greenland ice sheet and sea level rise of 7 meters on a time scale of 1,000 years, and in view of recent concerns that this melting could occur faster than previously thought, it may indeed make sense to extend the horizon to at least a few hundred years beyond my 300 year horizon – as long as this is done with a somewhat higher elasticity of marginal utility than used in the Stern Review in combination with the near zero rate of pure time preference.

How Rapidly Does Marginal Utility Drop Off?

It would be a mistake, however, to go to the opposite extreme and increase eta to the range of 3 to 4, as suggested by Partha Das Gupta. The value of 1.5 that I use is based in part on the econometric literature in finance, which measures this parameter as what is called the constant rate of relative risk aversion. Whereas Das Gupta agrees with Stern and with me that pure time preference should be set at delta equals zero, he argues that unity is too regressive a value for the elasticity of marginal utility, eta; and by implication the value of 1.5 that I use is also too low. If you think about it, the value of unity used by Stern is the same value that is in the bible for this parameter. The biblical tithe means that society's loss in private utility when a rich man gives up 10 %of his large income is just the same as the loss in private utility when a poor man gives up 10 %of his income. That is exactly what a value of eta = 1 means, and today we would call this a flat tax, and would call it regressive. Progressive tax systems set tax rates higher for the rich, implying that society presently thinks that marginal utility drops off somewhat faster than implied by the biblical tithe. Das Gupta thinks the progressivity should set eta at 3 or 4 instead of unity.

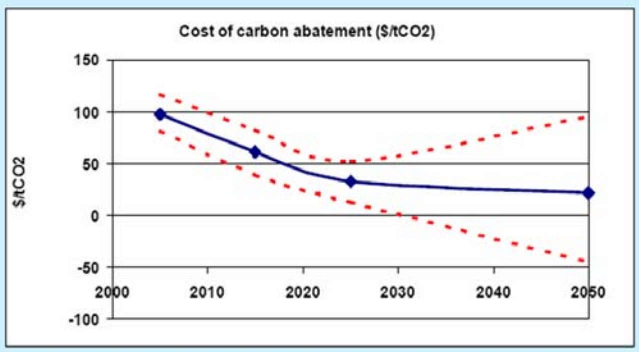
To examine his argument, I have done a back of the envelope calculation to see what our present tax structure implies about the elasticity of marginal utility. As a stylized fact, suppose a family earning $23,000 pays 15 %tax (payroll, employer and employee), while a family earning $667,000 pays a tax of 40 percent. It turns out that the parameter value for eta that makes the social welfare burden of tax payment equal for the two families is 1.35 – slightly smaller than the value 1.5 that I used. If instead the parameter were set as high as 3, then the tax that would have to be levied on the family earning $667,000 would be an average tax rate of 95 percent. Even at eta =2 the average tax rate for the rich family would have to be 84 percent, to make the social welfare burden of tax identical for the rich and poor family. So I would submit that the value of eta of 1.5 that I used is much closer to how society behaves than the range of 3 to 4 suggested by das Gupta.

When to Act?

The Stern Review seems to argue that there should be an immediate move to a carbon tax of $85 per ton of carbon dioxide, or $312 per ton of carbon.

Average cost of reducing fossil fuel emissions

Figure 9.5 Average cost of reducing fossil fuel emissions to 18 $GtCO_2$ in 2050*



*The red lines give uncertainty bounds around the central estimate. These have been calculated using Monte Carlo analysis. For each technology, the full range of possible costs (typically ± 30% for new technologies, ±20% for established ones) is specified. Similarly, future oil prices are specified as probability distributions ranging from $20 to over $80 per barrel, as are gas prices (£2-6/GJ), coal prices and future energy demands (to allow for the uncertain rate of uptake of energy efficiency). This produces a probability distribution that is the basis for the ranges given.

It then sees the carbon tax falling to half by 2018 and stabilizing at a plateau of about $120 per ton of carbon by 2025. This profile is the opposite of most optimal carbon tax paths, which tend to start lower and then increase. The result is driven by the imperative of keeping atmospheric concentrations below about 500 parts per million, and the eventual decline reflects improving technological opportunities. The initial tax is about twice the initial optimal tax I estimated in my Copenhagen Consensus paper, though the eventual tax is far lower because of more optimistic abatement cost estimates with future technological breakthroughs. My sense is that the political economy of making clear a strong commitment so the private sector takes the carbon price seriously requires at minimum a carbon tax of some $50 per ton of carbon in the near term, and a clear indication that the tax is headed to well over $100 per ton within a decade. It seems quite possible that such a path could largely accomplish what the Stern Review seeks without being so disruptive up front that the effort fails in the face of strong resistance.

Conclusion

My most basic evaluation of the Review, however, is that it is very much on the right track. It is high time that the center of gravity in economic analyses of global warming shift toward recognition that with appropriate discount rates the benefits of aggressive action warrant the costs of abatement. Increasingly, moreover, economists seem likely to move toward recognizing the dangers of uncertainties in the so-called “fat tails” of the probability distributions of damages, as emphasized by Martin Weitzman in his seminar here at Yale earlier this week, and correspondingly begin to endorse aggressive action as a reasonably priced insurance policy against potential disasters. The insurance policy approach complements what I think is already a correct, if arguably overstated, positive benefit-cost profile for aggressive abatement as identified in the Stern Review.