Work in Progress

An even Sterner Review

Introducing Relative Prices into the Discounting Debate[1]

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1 Introduction

The Stern Review (2006) has come to symbolize something of a dividing line in the evolution of the common appreciation of the climate problem. It is fair to say that during the last decade there has been a gradual but uneven increase in the perceived gravity of anthropogenic climate change, both among scientists and, with some time lag, the general public. However, save the United Nations Intergovernmental Panel on Climate Change (IPCC) assessments, the Stern Review is the first major, official report to give climate change a really prominent place among global problems. The political backing of the Stern Review in the UK is impressive. At its first presentation Sir Nicholas Stern was flanked by both Prime Minister Blair and Gordon Brown.

However, the Stern Review has been criticized on a number of accounts. The criticism has regarded both the manner in which the results are presented and the methodology underlying them, especially when it comes to the economics of discounting the future benefits and costs of climate change. For instance Nordhaus has a model DICE (Dynamic Integrated model of Climate and the Economy) which produces results suggesting climate change is not so serious and that relatively little abatement is needed. Nordhaus (2006) shows that DICE gives similar conclusions to those of the Stern Review if the rate of discounting is low suggesting that the only reason for the Stern results is the assumed discount rate which Nordhaus considers too low.

In this paper we show that results similar to those in the Stern Review can be obtained even without making the criticized assumptions concerning the discount rate. We do this by taking into account a neglected but important fact that relative price change is an inherent aspect of economic growth. As the rate of growth is uneven across the sectors of the economy - the composition of economic output will inevitably change over time. Output of mobile telephones may grow fast while glaciers and coral reefs decline and therefore relative prices will change.

We show that this has important implications for the efficient level of climate change mitigation. We present the results of some simulations using the same standard climate model,

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DICE in order to illustrate the impact that changes in relative prices can have on calculations of future climate-change damages. We conclude by arguing that greenhouse gas stabilization scenarios that are even more stringent than those discussed or suggested in the Stern Review could be justified.

There are many uncertainties when it comes to the climate. We are all used to hearing about the uncertainties related to cloud formation, feedback from methane in melting permafrost and ecosystem responses to rapid change, to mention just a few. Hence it may come as a surprise to some non-economists that the main source of uncertainty in estimates of the economic consequences of climate change is something else: *the discount rate*. In fact, much of the critique of the Stern Review has focused not on the climate science embodied in the report or its assessment of the costs and benefits of climate change mitigation, but on the low discount rate used in the analysis and how this drives the central results of the Review (see e.g., Dasgupta (2006), Nordhaus (2006), Weitzman (2006), Yohe,(2006))

The reason for the preoccupation with this seemingly trivial parameter is simple: since the impacts of climate change will mostly be felt in the future (because emissions of greenhouse gases are rising and because of the inertia of the climate system), the rate at which we discount the future will have a huge impact on what constitutes the efficient level of emissions reduction today. A simple example illustrates this point. The discounted value of one million dollars three hundred years hence is around fifty thousand $ today, using a discount rate of 1 percent, but if the discount rate were 5% it would be less than 50 cents! Note how this difference is strongly non-linear – in this example the value is changed by a factor of 100,000 when the discount rate is changed by a factor of 5.

Although a relatively simple concept in economics, the discount rate debate cuts to the core of many fundamental questions regarding global environmental change: how much weight should we put on the welfare of future versus current generations?, Will growth continue so that future generations are all richer than we are today? How important is the distribution of impacts (i.e., how should we value costs that disproportionably fall upon the poor or the rich)? Consequently, when it comes to analysing climate change policy, the economics literature is far from a consensus on which value to choose for the discount rate. Nor is the academic debate on discounting that has followed the Stern Review a new one.

In section 2 we discuss the metric used by the Stern Review to present future costs. In section 3, we make some brief observations concerning the rate of discounting and its determinants. [2] Our aim here is to raise issues that we feel have been overlooked in the debate following the release of the Stern Review and that could have large implications for how seriously we regard global warming.

Section 4 introduces our main contribution: the effect of unbalanced growth on relative prices and the importance of these factors for the value of future climate damage. If, in the future, we have much more (of some) material goods but much less access to environmental goods and services, then the relative price of these environmental amenities will rise, and hence the value of climate damage will be higher. Section 5 concludes.

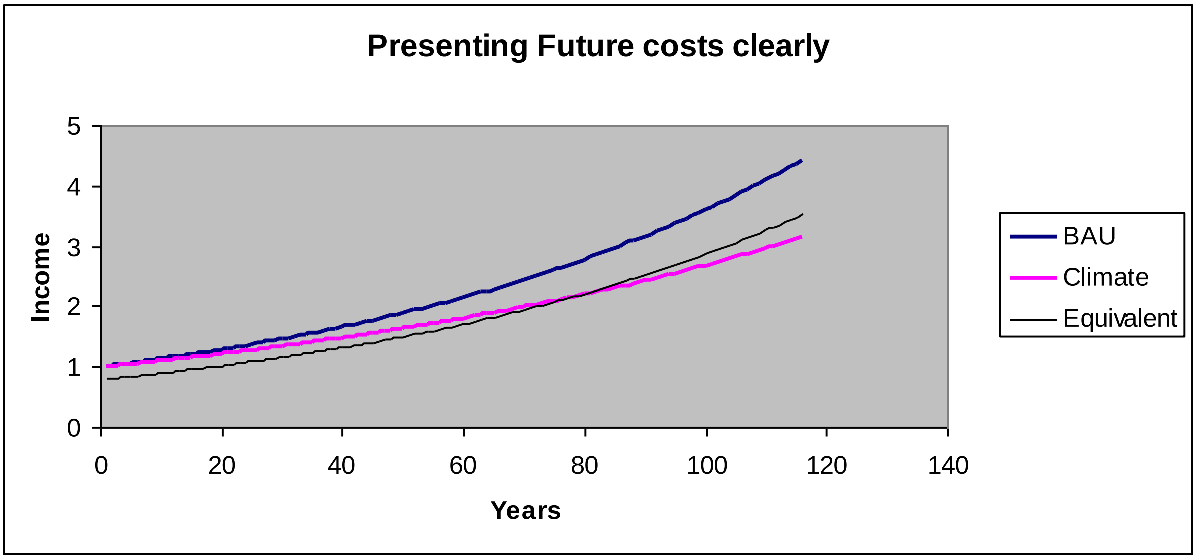
[2] For a good account of arguments and counter-arguments in the discounting debate we refer the interested reader to, e.g., Lind et al., 1982, Arrow et al., 1996, and Portney & Weyant, 1999.

2 Presentation of Damage estimates

One of the features of the Stern Review that has stirred controversy concerns the way it presents the estimated damages from climate change. While earlier studies (citations?) have estimated costs of climate change impacts on the order of 1% of future GDP, the Stern Review boldly asserts that business-as-usual (BAU) emissions of greenhouse gases will lead to a minimum damage of 5% of GDP, and could be as high as 20% of GDP, *now and forever* (pp. 162-163).

This way of presenting future damages builds upon an expected utility framework developed by Mirrlees and Stern himself (1972). Although this approach is much respected in the profession, it may be confusing to the uninitiated. We can illustrate the concept of an expected utility framework by depicting scenarios for growth in future per capita income or utility (see Figure 1). An underlying assumption is eternal growth at a fixed rate as in the top line marked “BAU.” This line shows expected (business as usual) development over time in the absence of any climate change. The Stern Review then assumes that climate change will introduce costs whose net effect is equivalent to a lowering of growth for the next 200 years to the line marked “Climate” after which no further damage is assumed, which means that the BAU growth rate resumes.

Figure 1



The cost of climate change is given by the difference between the “climate” and BAU trajectories. This difference can be described as a discounted sum, or by stating the number of years longer it will take till we attain a given income or utility level but neither means is fully satisfactory.

The difficulty in comparing the various welfare paths lies in the fact that the percentage difference between the two paths varies over time. Stern solves this problem by introducing a third scenario (marked “Equivalent” in figure 1), which has a total discounted income or utility equal to that of the Climate path, but the same growth rate as the BAU path. Thus, this path must start at a lower level than today, e.g., x% lower but will then always be exactly x% lower, This gives the policy maker a single figure (x%) to use as a cost equivalent. This number (between 5 and 20%) is described in the Stern Review as a "Now and Forever" reduction.[3]

Most economists appear to believe we will have much higher incomes in the future but the risk of being only 11 times – instead of 13 times - as rich in the year 2200 is unlikely to get many people upset about climate change. Instead it seems that many people think the true issue lies in the presumably small (but unknown) risk that climate change will actually make us <u>significantly</u> worse off. In this respect, we agree strongly with Weitzman (2007) who focuses on what he calls the fat tails of the probability distribution: the potentially catastrophic scenarios that motivate abatement as a reasonable insurance premium. Thus we should be thinking in terms of the precautionary principle rather than cost benefit or expected utility.

3 Discussion of the discount rate

Most participants in the debate about what constitutes an appropriate discount rate for estimating climate damages acknowledge that a good starting point is the so called Ramsey[4] rule. The Ramsey rule holds that the discount rate should be set equal to the sum of two factors, the pure rate of time preference, δ, and the product of the growth rate of income, g, and the elasticity of the marginal utility for money, η. The first component, δ, implies discounting of future utility *per se*, while the second implies discounting the value of future consumption goods based on the notion that we will be richer in the future and that the rich gain less welfare than the poor from a given quantity of money.

In this section we will discuss each of these factors in turn, focusing on aspects that we feel have been overlooked in the discounting debate that has followed publication of the Stern Review. We will attempt to clarify how the choice of parameter values affects policy advice when it comes to short term emission abatement.

3.1 The discount rate used in the Stern Review

The Stern Review contains a very careful and nuanced discussion of the discount issue (Stern chapter XXXXXXXX), and eventually settles for a pure rate of time preference, δ, of 0.1% and an elasticity of marginal utility, η, of 1. This results in discount rates that are unusually low. With a growth rate of 2.5% we get a discount rate of 2.6%, Using the Stern Review's assumption of an average per capita growth rate of 1.3% we get a discount rate of 1.4%). As shown by Dasgupta (2006), Tol (2006), Nordhaus (2006), Yohe (2006) and others, this is indeed one of the most important reasons for the Stern Review's high damage figures. Rightly it is at the centre of the debate.

How are we to judge individual discount rates? One way to go about is to compare the assumptions made with observable market variables, e.g., interest rates and savings

[3] Note that this number will be highly sensitive to the discount rate, since a higher discount rate (or rather a higher pure rate of time preference) will imply less weight being put on the welfare of the future generations that will bear the brunt of climate change. Note also that the expression is clearly misleading if the reader interprets it as an actual *fall* in utility "now" which Tol (2006) appears to do when he calls it "preposterous."

[4] This rule is very elegantly explained by Sir Partha Dasgupta, the Frank Ramsey professor of Economics in Cambridge, in Dasgupta (2006) so we will refer to his text and merely summarize here, see also Arrow et al., 1996.

behaviour. This is the track taken by some of the critics of the Stern review's low discount rate. Nordhaus (2006) notes that the resulting discount rate numbers do not match the observed market rate of interest. Similarly Dasgupta (2006) argues that the values of δ and η assumed by Stern would not be compatible with observed savings rates. There are two major problems with this line of critique.

First of all, real market complexities make it far from obvious which values the discount rate should match. The market rate used should of course be a risk-free rate and presumably we should use an average over a very long time period since we are going to use the rate over very long time periods. As noted by Cline (1999), this could well imply using a discount rate close to zero, matching that of the historical real rate of return on treasury bills. We would also argue that there are stylized facts, other than current interest and savings rates that we can consider for guidance as to appropriate numbers, such as the structure of our tax systems or the size of our foreign aid budgets (see below).

Secondly, and more importantly, in our mind this is a critique that, in its purest form, misses the point. In our opinion, using observable real market variables as a benchmark is not appropriate, since we are searching for a number on which to base *ethical* or *normative* judgments. We are not simply observing the market as we do in positive or empirical studies, we are providing arguments for public action which involve the provision of very complex public goods.

The Ramsey framework provides a tool for organising our thoughts on this topic and naturally it is of some interest to compare our numbers to the observable market or savings rates, but the latter cannot be a sole arbiter of whether or not we chose appropriate numbers for δ and η – since then there would be no point in taking the trouble to attempt this ethical exercise – and there would be no independence of the normative from the positive. As Hume (1740) concluded long ago: one cannot derive an *ought* from an *is*.

The disagreement over the discount rate is not merely a case of *scientific* uncertainty, that can be logically or empirically resolved, but a question where value judgements are an inseparable part of the answer. To answer the question of what *should* be done about climate change, the Stern review assumptions can not be said to be more wrong nor right than those of his critics.

3.2 The size of δ - how much should we care about future generations?

The pure rate of time preference, δ, measures the extent to which we discount future welfare *per se.* The effect of δ on our estimate of optimal abatement is straightforward: a higher value implies less weight on future damages and hence less abatement. The major difference between the discount rate in the Stern review and most other cost-benefit analyses of climate change, is the fact that Stern uses a very low pure rate of time preference. This implies that Stern takes a very egalitarian view on intergenerational distribution. In fact, the only reason why Stern uses a δ that differs from zero is the risk that future generations might not be around at all.[5]

[5] The pure rate of time preference of 0.1% used in the Stern review is compatible with a risk of extinction humanity of about 10% per century, or 65% per millennium. In this light we must see 0.1% as a fairly high number. The reader should be warned that there is a risk delta be treated in a way that makes it endogenous: those who believe in a high value will in fact suggest policies (of doing nothing much) that make extinction more likely!

While one can construct hypothetical examples that result in seemingly absurd conclusions using a low pure rate of time preference (see, e.g., Nordhaus, 2006, in his critique of the Stern Review's discount rate), it is equally simple to construct a hypothetical example showing the opposite.[6] We would argue that intuition is a poor guide when it comes to (often far-fetched) examples of trade-offs being made over many centuries to come.

Instead we feel that one should, as the Stern review does, arrive at a value for δ based on first principle, i.e., by arguing whether valuing the utility of future generations less than the current one is ethically defensible or not, save for the risk that future generations might not exist. We agree with Stern and many other prominent economists and thinkers throughout time (e.g., Ramsey, Pigou, Rawls and Dasgupta), who have argued that no such justification exists.

3.3 The size of η – how curved is the utility function?

The marginal elasticity of utility to income, η, measures the curvature of the utility function. A high value for η implies that we will care less for a dollar more of consumption the richer we become. Since we expect that we will be richer in the future, when climate damages will be felt, a higher η implies that the damages will be valued lower. A higher value for η implies less greenhouse gas abatement today unless, for some reason we will not be richer but *poorer* in the future then the logic implies that a higher η gives higher damage values and more abatement would be warranted.

In order to properly discuss the curvature of the utility function – which is one of the most contentious of variables here – we make a small digression into welfare theory, cost-benefit analysis and the debate on policies for a more even income distribution. The idea that a rich person would have less marginal utility for money is an old idea and very popular among the more mathematically oriented of the radical economists since it provides a strong rationale for redistribution. Already an η of unity means utility is logarithmic and the utility of a million is just 20% more than the utility of a hundred thousand. To most people this is quite a radical, non-materialistic view of the World. Let us assume person R is a hundred times richer than person P. Then taking one dollar from R and giving to P would increase P's utility a hundred times more than the loss to R. With an η of 2 it would be 10 000 times more!

If η is large and if we assume a utilitarian Social Welfare Function (which is the simple sum of the individual utilities), then aggregate welfare would be much higher in an economy with an even income distribution. This does not automatically imply that redistribution of wealth is desirable since we must consider problems related to incentive effects and rule of law. Still, a strongly curved utility function is quite radical and even an η of 1 has strong implications. If η was so high it suggests we would expect to see high and progressive taxes as well as large transfers of development assistance to poor countries[7].

Recognizing the limits of directly redistributive policies, another line of thought that was popular in the 1970-90s was that cost benefit analysis (CBA) should use distributional weights. As Johansson-Stenman (2005) points out, the idea of distributional weights was actually the norm as expressed in project appraisal documents such as Dasgupta, Marglin and Sen (1972), Little and Mirrlees (1974) or Squire and van der Tak (1975). However, most

[6] The cost of Armageddon in 2600 would be 10 cents with a discount rate of .

[7] When it comes to international development cooperation, there are again, a serious of intervening factors such as doubts about the efficacy of aid.

CBAs neglect the use of distributional weights. Instead it has become the norm for CBA "to focus on efficiency". One of the arguments for this is that redistribution issues could be more effectively taken care of by direct redistribution policies. As we just discussed above – such policies are however difficult and only applied in a limited number of so-called welfare states.

The actual practice in CBA is thus to compare a dollar of costs with a dollar of gains at the exchange rate 1:1 whoever is making the gains or losses – which amounts to setting $\eta = 0$. Part of the reason for this may paradoxically be that the earlier debate set η to very high levels. Empirical estimates of η are often based on individual behaviour with respect to risk in experiments or in insurance markets and suggest values of η of 2 (see also Dasgupta 1998). As we saw above, even an η of 1 has radical consequences - an η of 2 makes the utility of the rich completely irrelevant and thus it is easy to imagine the dilemma for someone doing an actual real-life CBA: gains or costs to the rich and powerful should basically be ignored.

The use of distributional weights does have its proponents – see for instance Dréze and Stern (1987) himself or Drèze (1998). Johansson-Stenman (2005) shows conditions under which such weights should be used, also in the presence of optimal income taxation – but in practice they are seldom used. There is however one big exception, one where they turn up with another name: discounting! By setting η higher than zero, distributional weights are in fact used for future generations. Is it reasonable that the only time we use welfare weights is when we want to argue that we should do nothing today but leave the costs to future generations? This happens to be a case when the use of the curved utility function is in our interest. In all other cases, educational or nutritional programs for the poor, development assistance or progressive taxation, we choose to disregard the curvature of the utility function.

If we use the discount rate to lower the estimates of the costs that our descendents will face with the argument that they will be so much richer and the utility function is so curved, we should logically give extra weight to any low income people affected – such as the coastal dwellers of Bangladesh who all appear doomed to become environmental refugees as their lands are inundated[8].

While much emphasis is put on the uneven distribution of climate change impacts in the Stern Review, in its analysis, the Review simply refers to others who have estimated 25-50% increases in damage costs if equity weights are used. This is one of the points where we think the Stern Review could have been a bit Sterner: by seeing equity weights, not as a possible extension, but as an integral part of the analysis.

It is an irony that Stern is accused of having too low a value of η when he uses a value of one for discounting. Real business is often conducted as if η was zero and most economists use zero in all other contexts but now some suggest a value of two or more for the distant future.

3.4 The Rate of growth

The final factor in the Ramsey formula is the growth rate of the economy. In Stern's case, per capita consumption is projected to grow from 7 600 \$ to 94 000 \$ in the year 2200. This raises

[8] Some authors point out that future costs will be smaller than they appear due to adaptation. Thus people will, for instance, not wait passively till they are inundated. We do not doubt that the people of coastal Bangladesh will want to move – we do however have concerns that other countries will be prepared to admit these future refugees in very large numbers.

a number of fascinating issues: Can growth go on for so long? What about the material and ecological sustainability of this growth? To account for the idea that growth cannot "go on forever", Azar and Sterner (1996) assumed that growth would only continue until we became ten times richer and then income would level off. With this simple assumption – and using similar values of other parameters – they found that the shadow value of carbon increased very substantially compared to analyses by for instance Nordhaus.

However, the "Malthusian" notion that the economy has limits to growth is quite discredited. The counterargument is that there are no bounds to human imagination. However we should not let this point pass too easily. Clearly there is some logic to the fact that the planet is finite and on any finite surface, eternal exponential growth must represent a problem. The reconciliation of these two notions lies in the insight that the argument against growth only applies to certain aspects of *physical* activity: The steel, cement and oil industries cannot grow for ever – but this does not imply any practical hindrance for the development of say music or electronic communication and computation which require quite trivial physical resources. An immediate corollary of this is however that continued economic growth over a period of centuries necessarily implies a dramatic change also in the *composition of the economy* and thus in *relative prices*, an issue to which we now turn.

4 The content of growth, substitutability and the role of relative prices

Our central concern with the Stern Review – where we think it could well have been a little Sterner – is that the effect of changing composition of the economy and of changing relative prices is not analysed. The mechanism of changing relative prices is brought up on several occasions in the text, but it never enters the analysis. Stern is not alone in this, in most discussions on discounting and climate change policy, the advent of changing relative prices and the effect this could have on real discount rates is acknowledged and then left aside in the further analysis (see e.g., Arrow et al., 1996; Nordhaus, 1997). In this section, we explain and motivate the use of changing relative prices and then illustrate their use in the DICE model to show that they imply that long run damages from climate change should be taken much more seriously.

Implicit in all integrated assessment models (IAMs) used in the analysis of climate change policy – the PAGE model used by Stern and the models used by some of his critics (e.g., Nordhaus, 2006; Tol, 2006) – lies the assumption of *perfect substitutability*. Perfect substitutability implies that detriments of climate change impacts can be balanced with increased consumption of material goods on a one to one basis: one dollar worth of climate damages, regardless of the kind, can be compensated by a dollar worth of material consumption, so that despite climate impacts we will be richer and enjoy a higher level of welfare in the future. However, if there are limits to the substitutability between, e.g., consumption of material goods and environmental services then we need to take into account the content of future growth in our analysis of climate change. An unbalanced growth, where consumption of some goods or services grows slower should be expected to giving rising relative prices of that particular good or service, as it becomes relatively more scarce.

This effect of increasing scarcity on relative prices can be quite drastic, as illustrated by the following example: One or two centuries ago, a share of the population – say 5% - employed domestic labour such as maids. In spite of increasing average incomes – the number of people who have a maid has not gone up! The reason for this is of course that the price of maids has gone up at about the same speed (if not faster) than average income.

When it comes to environmental amenities similar points can easily be made. Without entering into details of climate change, suppose that climate change leads to a loss in water, food products or some other good or ecosystem service that is really quite essential. Clearly such a loss would be accompanied by changing relative prices. For example, currently global agriculture is said to represent 24% of global GDP (Stern Review, pp. 67). A 1% loss might be approximated as costing 2.4% of global GDP. Everyday logic, however, tells us that a 50% loss would be worth much more than 12% of global GDP and a 100% loss would be worth more than 24% of GDP! *The mechanism behind this would be escalating food prices*: As food became more and more scarce, its relative price would rise so fast that the dwindling food supplies would crowd out everything else and approach 100% of total GDP.

In a recent paper, Hoel and Sterner (2006) analyze a conceptual model of the economy consisting of two sectors with different growth rates. It can be used to analyse an economy where one (conventional) sector grows "forever" and the other (let us call it environmental services) sector is constant – or maybe even declining due to pollution. The model shows that the environmental sector can see its share of the economy grow in value terms in spite of becoming physically smaller in comparison to the growing sector, due to rising relative prices.

Moreover, the discount rates themselves are affected due to the changing composition of the economy. The model derives a generalisation of the Ramsey Rule which is too complicated to discuss in a non-technical paper without formulae. Suffice is to say that discount rate depends on the elasticity of substitution between the environmental and the conventional consumption good as well as on the two growth rates, and, just as in the original Ramsey formula discussed above, the elasticity of marginal utility and the pure rate of time preference. When the sectors have the same growth rate the discount rate is the same as the conventional Ramsey rule.

The most important conclusion is however that, when valuing damage to the environmental sector, discounting should be supplemented with changes in relative prices that may well more than counteract the effect of discounting so that the net effect is instead higher rather than lower values. Thus, we would argue that just like future costs should be discounted they should also be "revalued" to reflect their expected prices in the future.

As mentioned above, there is in fact no disagreement on this principle in the literature. Still, this effect is not incorporated into models to provide policy makers with advice on optimal levels CO_2 emissions and taxes. One reason for this is that an attempt to take the relative prices of environmental services into account implies venturing into the unchartered territory of non-market impacts of climate change and the extent to which these are substitutable with increasing material welfare. It implies trying to find answers to questions such as: how do we value biodiversity, what is the value of human lives or human health impacts, how large is the cost of being forced to migrate due to sea-level rise?

4.1 Taking relative prices into account – a numerical illustration

Stern has been criticized of assuring high damage numbers by using low discount rates. While we do not necessarily disagree with these rates, the main point of this article is to show that there are other reasonable assumptions not made by Stern, which would also have given a high social cost of carbon and thus large early abatement. By taking seriously the likely rise in future scarcity for (non-market) environmental assets we get high damage figures even using Nordhaus' discount assumptions.

Although there are numerous problems in trying to monetize non-market damages of climate change and account for changes in relative prices of environmental services, excluding these impacts from the analysis is not a valid response. Adhering to the maxim that it is better to be approximately right than precisely wrong, we attempt to include the effects of relative price changes in a well-established integrated assessment model of climate change and climate policy, DICE (Nordhaus, 1994; Nordhaus & Boyer, 1999). DICE is a highly stylized Ramsey growth model of the world economy that incorporates the economic costs and benefits of greenhouse gas mitigation through a simple climate model, tracking the causal chain from emissions to changes in the global temperature and consequent damages. We use a recently updated version of the DICE model, one that Nordhaus uses to illustrate his critique of the low discount rate used in the Stern review (Nordhaus, 2006).

4.2 Calibration of our model

We amend the DICE model by changing the utility function from one only depending on consumption of (one representative) market good, to a constant elasticity of substitution (CES) function of two goods, the market good and a non-market environmental amenity (see Appendix A for details). In doing this we need to make some heroic assumptions regarding (1) the contribution of consumption of environmental amenities to current total consumption or utility, (2) the elasticity of substitution between the two goods, and (3) the damages to the environmental consumption from climate change. While there are some estimates of the latter in the literature, for the former two we have to resort to quite speculative assumptions. We do however provide an analysis of the sensitivity of our results to these central parameters.

1. The level of environmental consumption

How large a share of people's utility is derived from what we have broadly referred to as environmental amenities in the discussion above? Or, put in another way, if the environmental services were goods that could be purchased in the market, how large a share of total consumption would they account for? As a starting point we will assume a fairly modest share of environmental services in current consumption of 10%.

2. The elasticity of substitution between market and non-market (environmental) goods

The elasticity of substitution between market and non-market, or environmental, goods determines to which degree environmental goods are substitutable in peoples consumption. We assume an elasticity of 0.5, implying that if, hypothetically, the relative price of the environmental good would increase by 1%, then the purchase of environmental goods would decline by 0.5% relative to the purchase of other goods. This means that the value share of the environmental goods "consumed"[9] would increase with increasing scarcity much as the value of food in the case of famines mentioned earlier. We have also tested a range of other values as part of our sensitivity analysis.

3. Estimates of non-market impacts from climate change

[9] The reader should remember this is an analogy since most of these goods will be public goods.

Manne et al. (1995) provides a neat taxonomy of the damages from global climate change. Under non-market impacts they list biodiversity and ecosystem loss, effects on human well-being (human amenity, loss of lives, air pollution and migration), and impacts from natural disasters (i.e., extreme weather events, droughts, hurricanes or floods). The coverage of these impacts in the IAMs in the literature is patchy at best and uncertainties are of course huge.

Nordhaus and Boyer (1999) includes non-market impacts in the form of effects on human health, leisure activities and loss of ecosystems and human settlements. For a benchmark warming of 2.5°C they estimate total global damages of 0.1, -0.29, and 0.17 % of gross world product, respectively. In sum this gives a very small net non-market *benefit* from a 2.5°C warming. The PAGE2002 model used in the Stern review adopts as a benchmark a non-market impact on global GDP for a 2.5°C warming of 0.7%, with an uncertainty span from 0-1.5%. The assumption underlying these numbers are not discussed in the Stern review or in other descriptions of the model (e.g., Hope, 2006).

These estimates of small or even positive non-market impacts from a 2.5°C warming stand in stark contrast to the estimates that such a warming by year 2080 could put an additional 300 million people at risk of water shortage, an additional 250 million at risk of malaria, and an additional 50 million at risk of hunger and flooding, respectively (Parry et al., 2001). The same holds for the Stern review's assessment that a 2°C warming could lead to the extinction of 15-40% of all terrestrial species and destruction of most of the world's coral reefs.

When examining the damage estimates used in today's integrated assessment models of climate change one can not avoid getting the feeling that the effects of climate change on human lives are trivialized[10]. As noted by Manne et al. (1995), US expenditures on environmental protection totaled about 2% of GDP in 1995. That we, as suggested by current IAMs, should be willing to spend much less on climate protection, one of the biggest environmental problems facing humanity, seems implausible.

However, in order to keep the focus in the modeling exercise on the impact of relative prices, rather than amplified damage estimates, we assume a willingness-to-pay of 2% of gross world product at present for avoiding non-market impacts from a 2.5°C warming, with a quadratic relationship between temperature and damage. Although this is an estimate only slightly above than the highest in the current IAM literature, it does represent an increase in total damages from climate change compared to Nordahaus´ assumptions[11] and we will illustrate the effect this alone has on efficient carbon policies below.

4.3 Results of our numerical illustration

Figure 2 displays the resulting emission scenario from our base case simulation when including relative price changes of environmental amenities in DICE, using the assumptions discussed above. Note that this simulation uses Nordhaus' high discount rate, with a pure rate of time preference set equal to 3% in 2005 and the declining, in order to keep focus on the effect of relative price changes.

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[10] As an illustrative example, the largest contribution to global impacts from climate change in the FUND model (Tol, 1999) comes from the extra cost of installing air condition equipment in developing countries, primarily Africa (sic!) (Warren et al., 2006)

[11] Note, however, that since the non-market part of the original DICE damage function is roughly zero for a 2.5°C warming, this addition does not imply any double-counting of damage costs.

For comparison we also show the results from the runs that do not include the effect of changing relative prices: a run with Nordhaus' standard settings (used in his 2006 paper on the Stern review), a run with higher non-market impacts, corresponding to the assumptions above, to be able to isolate the effect relative price changes has on the results, and a run using the Stern reviews assumptions regarding discount rates (cf. Nordhaus, 2006).

As can be seen, taking changes in relative prices into account in the analysis can have almost as large an effect on efficient emission levels as, like the Stern review, using a low discount rate. Although our higher assumptions regarding non-market impacts have a non-negligible impact on efficient abatement levels in the model, the largest part of the reduction of emissions is due to the introduction of changing relative prices in the model. In the base case the relative price of the environmental, non-market, good increases from 0.11 in 2005 to over six by the end of this century, and the value share of the environmental amenity in total utility increases from 10% to 46%.

In the base case, global carbon emissions start out at 6.2 billion tons of carbon (GtC) in year 2005, way below real emission levels that year and corresponding to an abatement level of more than 18% below "business-as-usual" emissions in the model[12]. The social cost of carbon, being equivalent to the carbon tax needed to reach the displayed emission level, is almost 65$/tC in 2005, reaching over 400$/tC by mid century. This can be compared with the estimated social cost of carbon in the original DICE version, 15$/tC in 2005, or the Stern reviews values starting at 90-110 $/tC, when CO_2 concentrations are stabilized at 450-550 ppm[13]. Worth noting is also that the temperature increase resulting from this emission scenario at all times stays below 2°C, the climate target support by, among others, the EU.

[12] Note that these models do not include energy system inertia and costs of adjustment which explains why the starting values can vary so heavily between the various scenarios.
[13] The social cost of carbon is dependant on the emission scenario since, e.g., if no mitigation actions are taken, climate change will of course be more severe and impacts of a given ton of emission today will be higher. The Stern review also reports the social cost of carbon for a business-as-usual emission scenario of around 310 $/tC. However, because of the higher discount rate used in this analysis and by Nordhaus (2006), the social cost of carbon is less dependant on future emissions.

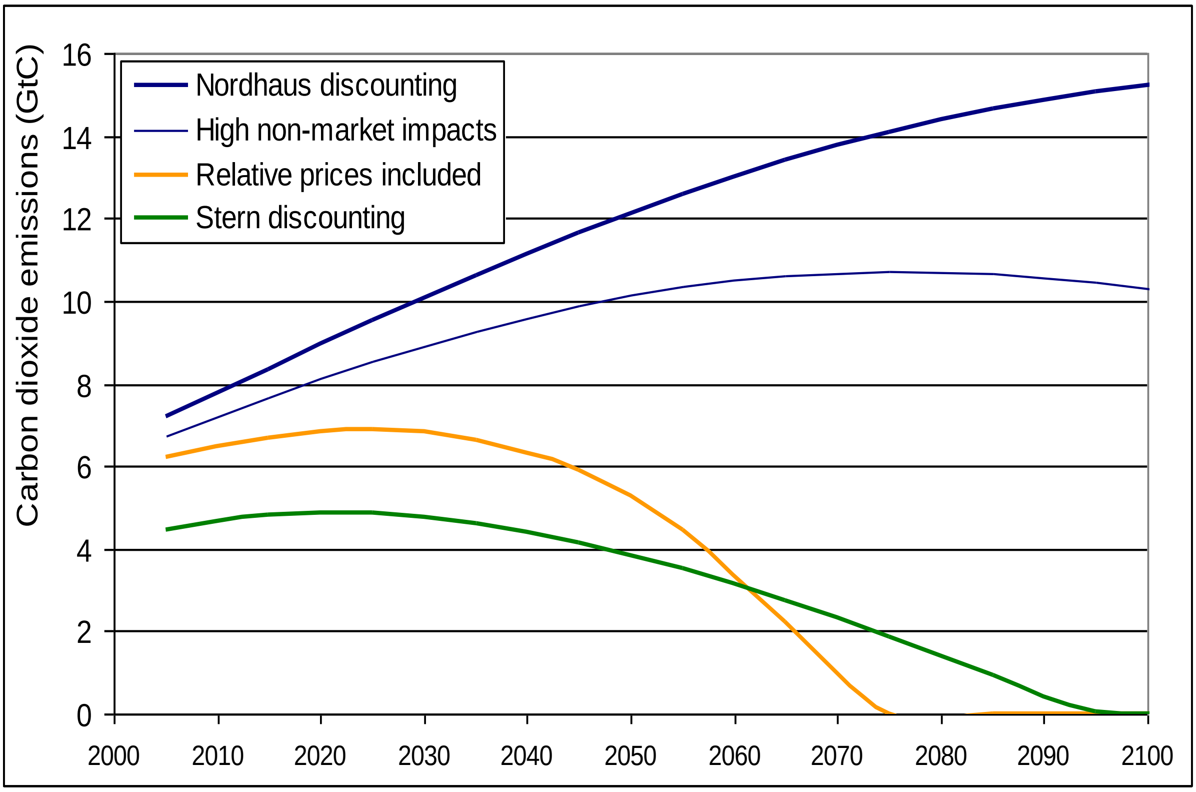

Figure 2: *Optimal carbon dioxide emission paths in the DICE model for four different cases: the original model (Nordhaus discounting), the original model with high non-market impacts(High non-market impacts), the original model with low discount rate (Stern discounting) and a run where the changes in relative prices between market and non-market (environmental) goods is taken into account (Relative prices included). See text for explanation.*

To test how sensitive these results are with respect to our assumptions regarding the value share of environmental amenity in current consumption and the elasticity of substitution between environmental and man-made goods, we ran the model with many different values for these parameters. As expected a lower level of substitutability or a larger share of environmental amenities in current utility implies a higher social cost of carbon and consequently lower emissions. Although a wide range of results can be obtained depending on parameter values, our base case result is in no way an outlier in terms of how radical its conclusions are. On the other hand, increasing the elasticity of substitution to one effectively reduces our social cost of carbon to about half – which is still however very high compared to Nordhaus (2006). STÄMMER DETTA?

It should also be noted that combining a low discount rate, as in the Stern Review, with our assumptions concerning relative prices, makes the optimal social cost of carbon even higher[14]. The reason for this is obvious: if we care as much for future generation's utility as present ones, and future generations will be less well off than the present one when it comes to the consumption of essential environmental services, then large cuts in current emissions are called for, even at a relatively high cost in terms of material consumption today!

[14] Our results in fact skyrocket to a level where abatement reaches 100% at all times for levels of substitutability between environmental and material goods up to 0.7 and for value shares of environmental consumption down to 2%.

To summarize, we have shown that including the effect of changing relative prices between environmental and man-made goods in an integrated assessment model can have a profound effect on the results. If the Stern review would have taking this into account in their analysis the resulting conclusions would most likely have been even sterner.

5 Discussion & conclusion

The Stern Review represents a radical departure from earlier estimates of the economic significance of climate change damages. The significance of climate change is seemingly increased by an order of magnitude. It is thus natural that it is being hotly debated. It is maybe surprising that the reactions have not been even stronger, but this may be due to a confluence of several factors: Sterns personal stature as an economist; the recent research indicating that climate change may be faster and more severe than previously thought and finally the strong political backing – primarily in Britain, but also the clearly changing tide of opinion in the USA.

Still there is serious criticism that risks undermining the important message of the Stern Review. The report is accused of having caused some misunderstandings through its unusual and drastic manner of presentation of the costs. While there may be some truth to this, we feel that this criticism is exaggerated.

The report is also accused of being a political document (see, e.g., Nordhaus, 2006). While we would not disagree with this statement, we would argue that this is also true for other exercises trying to perform the same task as the Stern Review[15]: weighing costs and benefits of climate change mitigation in order to provide policy makers with some advice as to how to handle the problem. Although there is a lot of science and economics involved in trying to do this, we hope to have shown in this review that ethics, value judgements, and thus politics, is an inherit part of the picture.

A case in point is of course the most widely debated issue in economic circles following the review: the choice of the discount rate. We thus trace the discount rate back to its basic components and discuss them in turn. The choices as concern marginal elasticity of utility and pure rate of discount are in fact low compared to many others but we feel they are well within the realms of the defensible.

More importantly we argue that even without these assumptions, there are other factors that would raise the estimates of aggregate costs. First we argue that non-market damages are underestimated and secondly: future scarcities that will be induced by changing composition of the economy and climate change should lead to rising prices (or willingness to pay) for certain goods and services. Price escalation of resources that become more scarce should raise the estimated damage of climate change, counteracting the effect of discounting. We refer to an earlier paper that shows analytically the link between discounting and relative price change in a two sector model.

We illustrate this argument by using Nordhaus' DICE model to simulate a number of scenarios. We show that even with Nordhaus' conventional assumptions of a fairly high rate of discount, large-scale abatement would be socially profitable if the escalation of prices for scarce environmental services were taken into account. If we were to combine the low

[15] A difference though, is of course the fact that the Stern Review has not been peer reviewed.

discount rates in the Stern Review with rising relative prices, the conclusions would be in favour of even higher levels of abatement. This would in fact lead us to consider even some of the levels of carbon content that Stern deems unrealistic, i.e., aiming for a target below 450 ppm CO_2-equivalents[16].

One of the most obvious prices that needs to change dramatically are the relative prices of fossil fuels themselves. With conventional price elasticities (1 for income and -.65 for fossil fuels) and Stern Review figures of emissions falling 1-5% per year as incomes grow at 2% imply real price increases of 5-10% per year! Still, we do not feel that the need for increases in energy prices comes across clearly enough in the Stern report. It seems the report is banking on strong technical progress to lower future costs of non-fossil technologies. This may indeed happen but it would be unwise to rely too much on it – in fact it would be a Phyrrean victory to persuade people that climate change was important if it were done at the price of making them believe that fossil fuel and energy prices do not need to rise very much. The rising price of fossil fuels is the most important mechanism in bringing about the research and implementation of other technologies needed.

In a more thorough evaluation changes in relative prices should be broken down and assessed separately for the various sectors such as agriculture and water. These and some other ecosystem services have particular importance for the very poor. With the assumptions discussed concerning the curvature of the utility function, damages suffered by the poor are particularly important for welfare. This is yet another area where more work should be done. The starting point for the report is that our average incomes will rise on average some 13 times in the reference scenario. But we need to understand better how this growth will be distributed and in particular what growth the poorest will have – with and without climate change.

Although these would be interesting extensions[17], we end by coming back to the main issues raised in this paper: Society in the future will not only be a lot richer but very different in other aspects. An integral part of increasing income must be that growth is uneven and that some of the sectors that decline or do not grow will see a strong tendency to rising prices. Climate change is likely to damage some of these non-market sectors and taking these changes in relative price into account raises the future cost estimates of climate damage and acts as a motivation for stronger abatement now.

[16] See, e.g., Azar et al. (2007) for a discussion on the possibility of attaining stabilization levels of CO_2 below 400 ppm by using bioenergy with carbon capture and storage, thereby achieving negative CO2 emissions.
[17] The issues raised by this analysis also illustrates the limits of cost-benefit calculation for this type of problem. The economy in the year 2100 and beyond will be so different from ours – not only depending on climate change, but primarily because of growth and technical change – that virtually nothing remains on which to anchor the analysis, neither incomes, preferences, nor prices. Consequently we suggest that an alternative way of seeing the issue is to focus on the worst outcomes and use the precautionary principle as a means of motivating abatement as a form of insurance premium.

Appendix A: Incorporating relative prices in DICE

To allow for changes in relative prices between market, or man-made, and non-market, or environmental, goods in the DICE model we have made two changes in the original model: we have changed the utility function equation and we have included an extra equation that determines how consumption of the environmental good changes over time, in response to climatic change.

The original DICE model maximizes total discounted utility using a *constant relative risk aversion* (CRRA) function

$$U(C) = C^{1-\alpha} / (1-\alpha)$$

where utility, U, is dependant on per capita consumption, C, and the elasticity of marginal utility of consumption, α. To include the effect of changing relative prices in the DICE model we replaced the one aggregate consumption good in this function with a constant elasticity of substitution (CES) kernel while keeping the overall CRRA properties:

$$U(C) = [(1-\gamma)C^{1-1/\sigma} + \gamma E^{1-1/\sigma}]^{(1-\alpha)\sigma/(\sigma-1)}/(1-\alpha)$$

where utility is dependant on the consumption of two goods, C and E, where the latter represents non-market, or environmental, amenities. The elasticity of substitution is given by σ and γ determines the share consumption of non-market goods in the utility function. As before the elasticity of marginal utility of consumption is given by α.

We assume that the consumption of environmental amenities will only be affected by the rising temperatures, i.e., in absence of climate change the environmental quality will neither deteriorate, nor improve. We use a quadratic relationship between temperature change, T(t), and non-market damages so that

$$E(t) = E_0 / [1+ aT(t)^2],$$

where a is a constant and E_0 is the level of consumption of environmental amenities in year 2005. By normalizing the latter to the level of material consumption in 2005, the choice of γ will determine the share of environmental amenities in initial utility (see Hoel & Sterner, 2005). By choosing another level of E in 2005 and changing γ so that the share of environmental amenities in utility is constant, the same modeling results are obtained. This leaves three new parameter values in the model to be determined, γ, σ, and a. The assumptions regarding these values are explained in the text.

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