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An Even Sterner Review

Introducing Relative Prices into the Discounting Debate

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Abstract

The Economics of Climate Change: The Stern Review has had a major influence on the policy discussion on climate change. One reason is that the report has raised the estimated cost of unmitigated climate damages by an order of magnitude compared to most earlier estimates, leading to a call for strong and urgent action on climate change. Not surprisingly, severe criticism has been levied against the report by authors who think that these results hinge mainly on the use of a discount rate that is too low. Here we discuss the Ramsey rule for the discount rates and its implications for the economics of climate change. While we find no strong objections to the discounting assumptions adopted in the *Stern Review*, our main point is that the conclusions reached in the review can be justified on other grounds than by using a low discount rate. We argue that nonmarket damages from climate change are probably underestimated and that future scarcities that will be induced by the changing composition of the economy and climate change should lead to rising relative prices for certain goods and services, raising the estimated damage of climate change and counteracting the effect of discounting. We build our analysis on earlier research (Hoel and Sterner 2007) that has shown that the Ramsey discounting formula is somewhat modified in a two-sector economy with differential growth rates. Most importantly, such a model is characterized by changing relative prices, something that has major implications for a correct valuation of future climate damages. We introduce these results into a slightly modified version of the DICE model (Nordhaus 1994) and find that taking relative prices into account can have as large an effect on economically warranted abatement levels as can a low discount rate.

Key Words: discounting, relative prices, Ramsey, climate damage

JEL Classification Numbers: H43, Q32 Q54.

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Thomas Sterner and U. Martin Persson*

Introduction

The Economics of Climate Change: 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 among scientists and, with some time lag, the general public. However, except for the United Nations' Intergovernmental Panel on Climate Change assessments, the *Stern Review* is the first major, official economic report to give climate change a prominent place among global problems. The political backing of the *Stern Review* in the United Kingdom—at its first presentation Sir Nicholas Stern was flanked by both Prime Minister Blair and Chancellor Brown—is impressive and one of the factors commanding attention.

Still, the *Stern Review* has been criticized both for the manner in which its results are presented and the methodology underlying them, especially when it comes to the discount rate used when analyzing the future economic benefits and costs of climate change.

The reason for the preoccupation with this seemingly trivial parameter is simple: since the effects 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 the extent to which emissions reductions today are warranted economically. A simple example illustrates this point. Using a discount rate of 1 percent, in 300 years the discounted value of $1,000,000 would be around $50,000. But if the discount rate were 5 percent, the discounted value of $1,000,000 would be less than 50 cents!

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Note how this difference is strongly nonlinear. 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, that is, how should we value costs that fall disproportionately upon the poor or the rich? Consequently, when it comes to analyzing climate change policy, there is little consensus in the economic literature about which value to choose for the discount rate.

Our main point in this paper is that results similar to those in the *Stern Review* can be obtained by taking into account the neglected but important fact that relative price change is an inherent aspect of economic growth—that is, stringent greenhouse gas emission cuts can be economically justified without making the assumptions about the discount rate for which Stern has been criticized. Because the rate of growth is uneven across the sectors of the economy, the composition of economic output will inevitably change over time. If output of some material goods (e.g., mobile phones) increases while access to environmental goods and services (e.g., clean water, rainfed agricultural production, or biodiversity) declines, then the relative price of these environmental amenities would be expected to rise over time. The result of these uneven growth rates in the economy would be increased economic damages stemming from climate change and, subsequently, higher levels of climate change mitigation would be warranted today.

In this paper we show that rising relative prices can have important implications for establishing an efficient level of climate change mitigation. We discuss the metric used by the *Stern Review* to present future costs and make some brief observations concerning the rate of discounting and its determinants. Our main contributions focus on an analysis of higher nonmarket damages and the effect of unbalanced growth on relative prices and the importance of these factors for the value of future climate damage. We illustrate the effect different assumptions regarding discount rates and incorporating relative price changes have on efficient levels of emission abatement using a well-established climate model, the Dynamic Integrated Model of Climate and the Economy (DICE) (Nordhaus 1994). We conclude by arguing that even more restrictive stabilization scenarios than those discussed in the *Stern Review* could be justified on economic grounds.

Presentation of Damage Estimates

One of the controversial features of the *Stern Review* is its presentation of the estimated damages from climate change. While earlier studies, such as those by Nordhaus (1993, 1994, and 2007), have estimated costs of climate change impacts on the order of 1 percent of the future GDP, the *Stern Review* boldly asserts that business-as-usual (BAU) emissions of greenhouse gases will lead to a minimum damage of 5 percent of the GDP and could be as high as 20 percent of the GDP now and forever (Stern 2006, 162–163).

This way of presenting future damages builds upon an expected utility framework developed by Mirrlees and Stern himself (1972). This relatively simple framework has apparently been quite confusing to many readers. Consider a hypothetical future with eternal growth in consumption at some fixed rate. The *Stern Review* assumes climate change will introduce costs that lower this growth, leading to a lower consumption trajectory. The cost of climate change is the difference between these two trajectories.

The question is then how to illustrate, in a simple and transparent way, this difference in future consumption. The difficulty in comparing the various welfare paths lies in the fact that the percentage difference between the two paths varies over time. The difference can be described either as a discounted sum (being a huge number, of a magnitude that will be hard to relate to) or by stating the number of years longer it will take until we attain a given level of consumption, but neither means is fully satisfactory. Stern solves this by calculating a consumption path that gives the same total discounted utility as the climate damage path but that has the same growth rate as the BAU path. Thus, this path must start at a lower level than today’s per capita consumption (e.g., X percent lower), but it will then always be exactly X percent lower.

This gives the policy maker a single figure (the X) to use as a cost equivalent. This number (between five and twenty) is described in the *Stern Review* as a “Now and Forever” reduction. The *Stern Review* does not suggest, of course, that consumption or utility will actually fall instantaneously, but the risk that it may be interpreted in this way has led to at least one writer calling this way of presenting the results “preposterous” (Tol 2006). However, Stern’s method is merely an attempt to find a single figure that is equivalent to something that actually varies over time.

Still, there may be something more than a misunderstanding here. Most economists, including Stern, appear to believe we will have much higher incomes in the future, despite climate change. 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. By presenting the damage estimates in the manner the Review does, it may seem that Stern falls for the temptation of overstating his case.

But doing so shifts focus from what we believe to be the true issue: the presumably small (but unknown) risk that climate change will actually make us significantly worse off in some respect. We believe Weitzman (2007a, b) is right to focus on what he calls the “fat tails” of the probability distribution: potentially catastrophic scenarios as a motivation for abatement. The main point in this paper is that we also need to think in what ways we will be richer in the future. If we experience growth in manufactured gadgets but deteriorating environmental quality, then the relative importance of the latter will have to be taken into account when evaluating the utility loss experienced from climatic change. We thus need to take changing prices into account.

Discussion of the Discount Rate

There are many uncertainties when it comes to the climate. There are 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 noneconomists 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 criticism 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 Dasgupta 2006; Nordhaus 2007; Weitzman 2007a; Yohe 2006).

Despite controversy, most participants in the debate about what constitutes an appropriate discount rate for estimating climate change damages acknowledge that a good starting point is the so-called Ramsey 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 the following sections we discuss each of these factors in turn, focusing on aspects that we believe have been overlooked in the discounting debate occasioned by the *Stern Review*. We attempt to clarify how the choice of parameter values affects policy advice when it comes to short-term emission abatement. For a more thorough account of arguments and counterarguments in the discounting debate we refer the interested reader to Lind and colleagues (1982), Arrow and colleagues (1996), and Portney and Weyant (1999).

The Discount Rate Used in the *Stern Review*

The *Stern Review* contains a very careful and nuanced discussion of the discount issue (Stern 2006, chapter 2), and eventually settles for a pure rate of time preference, δ, of 0.1 percent and an elasticity of marginal utility, η, of one. This results in a discount rate that is unusually low. With a per capita growth rate of 1.3 percent Stern gets a discount rate of 1.4 percent. As shown by Dasgupta (2006), Tol (2006), Nordhaus (2007), Yohe (2006), and others, and as illustrated numerically below, this is indeed one of the most important reasons for the *Stern Review*'s high damage figures. It is rightly at the center of the debate.

One way to judge discount rates is to compare the assumptions made with observable market variables, such as interest rates and savings behavior. This is the track taken by some of the critics of the *Stern Review*. Nordhaus (2007) 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 these criticisms.

First, real market complexities make it far from obvious which values the discount rate should match. The market rate used should 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 extremely long time periods. As noted by Cline (1999), this could well imply a discount rate close to zero, matching that of the historical real rate of return on treasury bills. Second, this is a criticism that, in its purest form, misses the point.

In our opinion, using an observable real market variable as a benchmark is not appropriate because 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; rather, we are providing arguments for public action that involves the provision of very complex public goods.

The Ramsey framework provides a tool for organizing our thoughts on this topic, and naturally it is of some interest to compare our numbers to the observable market or savings rates. However, the latter cannot be the sole arbiters of whether we chose appropriate numbers for δ and η, as 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 for which value judgments are an inseparable part of the answer.

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 being put on future damages and hence less abatement today. The major difference between the discount rate in the *Stern Review* and most other cost–benefit analyses of climate change is 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 Stern gives for a δ that differs from zero is the risk that future generations might not be around at all.[1] We agree with Stern and many other prominent economists and thinkers throughout time (e.g., Ramsey 1928; Pigou 1932; Rawls 1971; and Dasgupta 2006), who have argued that no such justification exists.

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. The higher the value of η, the less we care 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 damages will be valued lower. A higher value of η implies less greenhouse gas abatement today unless 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.

The idea that a rich person would have less marginal utility for money than a poor person is deeply anchored in economic theory and is empirically well founded (although the magnitude of the effect is disputed). Still, the practical implications of this are actually quite radical: already an η of unity means utility is logarithmic, and the utility of 1,000,000 is just 20 percent more

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

than the utility of 100,000. Let us assume person R is 100 times richer than person P. Then taking $1.00 from R and giving it to P would increase P's utility 100 times more than the loss of utility to R. With an η of two, P's utility 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 of actually implementing the redistribution. Still, a strongly curved utility function is quite radical and even an η of one has strong implications: it suggests high and progressive taxes as well as large transfers of development assistance to poor countries.

To account for the diminishing marginal utility of income, during the decades from 1970 to 2000 it was popular to argue that cost–benefit analysis (CBA) should use distributional weights, that is, that CBA should value cost falling on the poor higher than cost falling on the rich. As Johansson-Stenman (2005) points out, distributional weights were actually the norm as expressed in project appraisal documents such as Dasgupta, Marglin, and Sen (1972), Little and Mirrlees (1974), and Squire and van der Tak (1975). However, most CBAs today neglect the use of distributional weights. Instead it has become the norm for CBAs to focus on efficiency and to compare a dollar of costs with a dollar of gains at an exchange rate of one-to-one—no matter who is making the gains or losses—which in practice amounts to setting η equal to zero.

The use of distributional weights does have its proponents (see Drèze and Stern 1987 or Drèze 1998), but in practice they are seldom used. There is, however, one big exception where distributional weights 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, such as educational or nutritional programs for the poor, development assistance, or progressive taxation, we choose to disregard the curvature of the utility function. It is an irony that Stern is accused of having too low a value of η when he uses a value of one. Real business is often conducted as if η is zero, and most economists use zero in all other contexts.

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. The coastal dwellers of

Bangladesh, for example, all appear doomed to become environmental refugees as their lands are inundated.[2] Although the *Stern Review* does discuss the uneven distribution of climate change impacts at length, its analysis simply refers to others who have estimated 25 to 50 percent 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 tougher: by seeing equity weights not as a possible extension, but as an integral part of the analysis.

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 today to $94,000 in the year 2200. This raises 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) assume that growth would continue only until we became 10 times richer, and then income would level off. With this simple assumption, which leads to declining discount rates,[3] and using similar values for other parameters, they found that the shadow value of carbon increased substantially compared to analyses by, for example, Nordhaus (1993). That is, with lower projected growth rates in the future, short-term abatement should increase. Azar and Sterner (1996) also explicitly included distributional concerns and analyzed the effect of a high marginal elasticity of utility (and inequality aversion). Dividing the world into a rich and a poor segment, they showed that such high elasticities not only lead to large discount rates but logically also to a heightened welfare weight for the poor and thus to a high valuation of climate damages that affect the poor.

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. Nonetheless, 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

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[2] Some authors point out that future costs will be smaller than they appear due to adaptation. Thus people will, for instance, not wait passively until 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 may not be prepared to admit these future refugees in very large numbers.

[3] Declining discount rates are a convenient but ad hoc way of approaching the value of future damages. This method is officially recommended by several countries, including France. See Lebègue (2005) and also Gollier (2007).

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 forever, but this does not imply any practical hindrance for the development of, say, music or electronic communication and computation, which require trivial physical resources. An immediate corollary of this, however, is that continued economic growth over a period of centuries necessarily implies a dramatic change in the composition of the economy and thus in relative prices, an issue to which we now turn.

The Content of Growth, Substitutability, and the Role of Relative Prices

We have two central concerns with the *Stern Review*. First, we are concerned that it may not give sufficient weight to nonmarket damages; we return to this topic in connection with our numerical example. Our second concern, and the main theme of this paper, is that the effects of the changing composition of the economy and of changing relative prices are not analyzed. 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 are acknowledged and then left aside in the further analysis (Arrow et al. 1996; Nordhaus 1997; Lebegue 2005; Gollier 2007). Here we explain the use of changing relative prices in climate change policy and how the effects of changing relative prices imply that long-term 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, such as the PAGE model used by Stern and the models used by some of his critics (Nordhaus 2007; Tol 2006), lies the assumption of perfect substitutability. Perfect substitutability implies that the detrimental impacts of climate change can be balanced with increased consumption of material goods on a one-to-one basis: one dollar’s worth of climate damages, regardless of the kind, can be compensated by one dollar’s 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 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, in which consumption of some goods or services grows more slowly than others, would be expected to result in rising relative prices of that particular good or service as it becomes relatively scarcer.

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 percent, employed domestic labor 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, of course, is 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, such as access to water, biodiversity, or other essential ecosystem services, similar points can easily be made. For example, currently global agriculture is said to represent 24 percent of the global GDP (Stern 2006, 67). Thus, a 1 percent loss might be approximated as costing 2.4 percent of the global GDP. Everyday logic, however, tells us that a 50 percent loss would be worth much more than 12 percent of the global GDP, and a 100 percent loss would be worth more than 24 percent of the 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 percent of the total GDP.

Hoel and Sterner (2007 analyze a conceptual model of the economy consisting of two sectors with different growth rates.[4] It can be used to analyze an economy in which one (conventional) sector grows "forever" and the other sector (let us call it environmental services) 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.

The most important conclusion is 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 higher rather than lower values. Thus, we would argue that just as future costs should be discounted, they should also be "revalued" to reflect their expected prices in the future.

[4] We have recently found that there is a similar model in Guesnerie (2004). Lebègue (2005) and Philibert (1999) also mention changing relative prices as an important factor in connection with (and sometimes as a motivation for) lower discount rates.

Discount Rates and Relative Prices: A Numerical Illustration

To illustrate the effect different discount rates and, more importantly, changing relative prices have on the economics of climate change, we utilize DICE, a well-established cost–benefit model of climate change.[5] We amend the DICE model so that utility is not only dependent on the consumption of a material good, but also on the consumption of a nonmaterial, environmental good (for the technicalities of this, see Appendix A). We assume that today people derive a modest 10 percent of their utility from these environmental goods and services. Put in another way, this assumption implies that if environmental services were goods that actually could be purchased in the market, people would allocate 10 percent of total expenditures to this consumption.

The substitutability between market and nonmarket, or environmental, goods is expressed by the elasticity of substitution, here assumed to be 0.5. This implies that if, hypothetically, the relative price of the environmental good would increase by 1 percent, then the purchase of environmental goods would decline by 0.5 percent relative to the purchase of other goods. This means that the value share of the environmental goods in total consumption should be expected to increase with increasing scarcity, much as the value of food in the case of famines mentioned earlier.

In line with the results shown in the *Stern Review*, we assume that nonmarket impacts are equal, in economic terms, to those on material consumption. In the *Stern Review*, one can see that the inclusion of nonmarket impacts roughly doubles total loss in consumption, although these numbers are averages over a large set of scenarios (Stern 2006, 159). That is, for a temperature increase of 2.5^{o}C, the loss in material consumption is increased from 1.05 percent of the GDP, in the original DICE model, to 2.10 percent. To be able to isolate the effect of taking relative prices into account, we then run the model in two ways: one in which the nonmarket damages are included in consumption directly, as in the analyses of Stern (2006) and Nordhaus (2007), and one in which the damages are attributed to the environmental good, the relative price of which is rising over time.

The sensitivity of our results to all these assumptions—the share of environmental amenities in total consumption, the elasticity of substitution between man-made and environmental goods and services, and the nonmarket impacts—are discussed below.

[5] We use an updated version of the DICE model that Nordhaus (2007) developed in connection with his critique of the *Stern Review*. For a full description of the original model, see Nordhaus (1994) and Nordhaus and Boyer (2000).

The Impact of the Discount Rate

Figure 1 shows the emissions scenarios from the altered DICE model described above under two different assumptions regarding the discount rate: the low discount rate used in the *Stern Review* and the high discount rate used by Nordhaus. The difference in the level of emissions clearly illustrates the importance of the discounting assumptions, as discussed above and also as shown by Nordhaus (2007) and others.

In the emissions scenario utilizing the Stern discount rate, the CO_2 concentration in the atmosphere is stabilized at just less than 450 ppm at the end of this century (in line with the climate target of 450–550 ppm CO_2 equivalents endorsed by the *Stern Review*). Global mean temperature increase in the model stays almost below 2^{o}C, the climate target set by the European Union (although this does not hold if the climate sensitivity is increased). In the emissions scenario using the high discount rate, on the other hand, CO_2 concentrations reach over 600 ppm by the end of the century, and the temperature eventually increases by more than 3.5^{o}C.

The Impact of Changing Relative Prices

Figure 1 also shows the emissions scenario in a case with a high discount rate but in which the increasing relative price of the nonmarket good is taken into account. Although emission abatement is initially lower than in the Stern discounting case, abatement is tightened in the long run as the relative price of the environmental good increases, bringing emissions to even lower levels than in the Stern discounting case. The climatic effects are similar to the Stern discounting case: CO_2 concentrations reach about 450 ppm in the year 2100, and the temperature increase only slightly overshoots 2^{o}C before starting to recede again in response to the very low emissions levels.

This illustrates that taking relative prices into account can have an effect on necessary abatement that is on the same order of magnitude as changing the discount rate. There are, of course, huge uncertainties here regarding the share of utility derived from nonmarket goods, the elasticity of substitution, and the level of nonmarket impacts. The principle is, however, very important. Stern has been accused by Nordhaus (2007) and others (see for instance Dasgupta 2006; Weitzman 2007a; Yohe 2006; or Tol 2006) of producing results that hinge on low discount rates. While we do not necessarily agree that these discount rates are too low, we show that there is an alternative line of argument that builds on high discount rates and still gives similar results to those of the *Stern Review*. If we were to have both low discount rates and changing relative prices, we would find even stronger support for firm and immediate abatement measures.

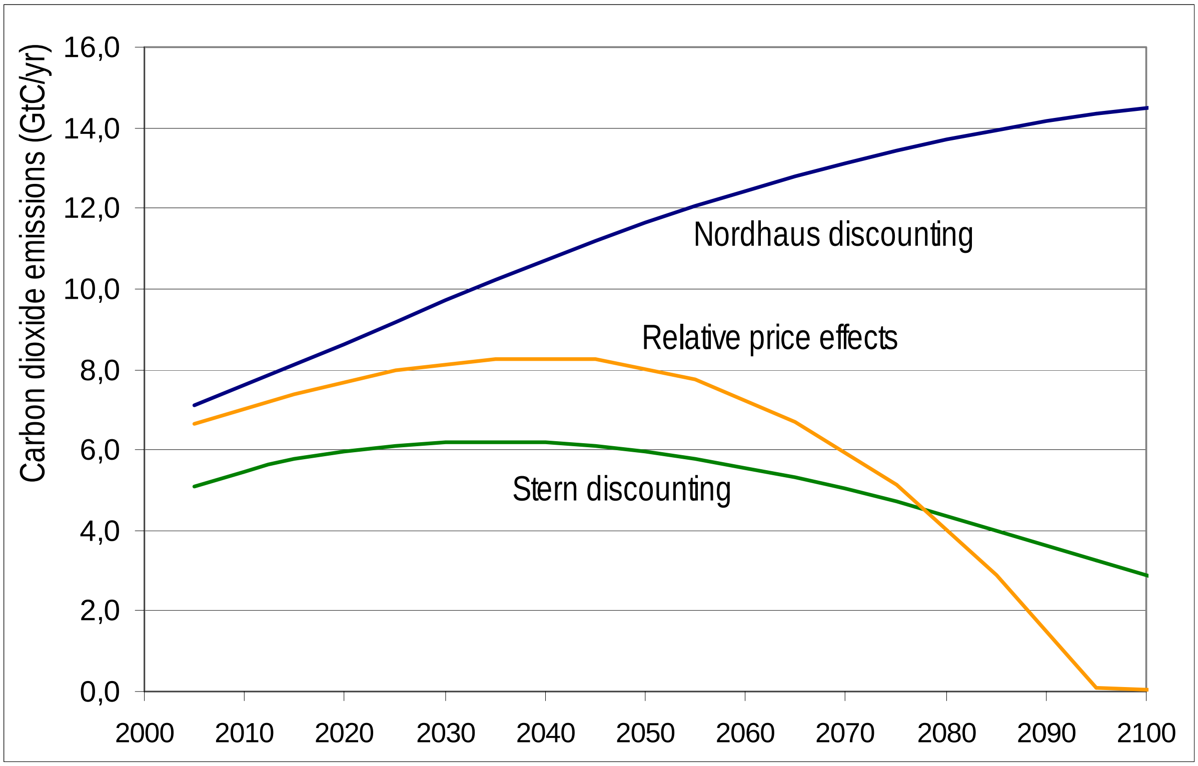

Figure 1. Optimal CO_2 Emission Paths in the Modified DICE Model

Note: The blue line (Nordhaus discounting) represents a high discount rate case; the green line (Stern discounting), the lower discount rate argued for in the *Stern Review*. The orange line (Relative price effects) represents a run with the high discount rate but in which the nonmarket impacts are attributed to the consumption of a representative environmental good whose relative price is rising over time. See text for further explanation.

To test the sensitivity of our results, we increase the share of environmental goods and services in today's consumption to 20 percent. This implies that emissions peak 10 years earlier than in our base case, at a lower level, and that emissions reach zero in year 2075. The resulting CO_2 concentration in year 2100 is 400 ppm. On the other hand, increasing the limits to substitutability between man-made and environmental goods by setting the elasticity of substitution to one implies that relative prices in this case have virtually no effect at all, with emissions being similar to the Nordhaus case. This lack of effect indicates the importance of this parameter. If substitution away from the environmental good is easy (elasticity of one or more), then the effects of changing relative prices are weakened substantially.

It is hard to give a good empirical estimate for the elasticity of substitution at this level of aggregation (our model uses only two representative goods), and particularly hard to say how it would evolve over time. In a model with many goods, the elasticity would vary considerably from one environmental good or service to another (as well as varying over time with scarcity and between individuals). The very essence of what we want to illustrate, however, is the fact that some natural ecosystem services are inherently very hard to replace.

Furthermore, if there is a range of goods and services with different elasticities of substitution, then the relevant aggregate number is likely not going to be the average of those elasticities. The goods or services with low elasticities will dominate the calculation since these will be the ones with increasing shares in utility. This goes for clean water, pollination services, and many other subtle aspects of the ecosystem that we take for granted as long as they are plentiful. As Dasgupta and Heal (1979) show, the elasticity of substitution becomes very small when one approaches thermodynamic or other minimum input levels. (See also the discussion in Gerlagh and van der Zwaan (2002) on weak vs. strong sustainability).

Finally, while we have increased the nonmarket impacts in the DICE model in this analysis, we would argue that they are still comparatively low. As discussed above, total damages in our case amount to slightly more than 2 percent of the GDP for a temperature increase of 2.5^{o}C. As noted by Manne and colleagues (1995), U.S. expenditures (which should be smaller than averted damages) on environmental protection totaled about 2 percent of the 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.

Nonmarket impacts from climate change can take many shapes: biodiversity and ecosystem loss; effects on human well-being (decreases in human amenities, loss of lives, and air pollution); and impacts from natural disasters (droughts, hurricanes, or floods) (Manne et al. 1995). Moreover, nonmarket impacts can also include socially contingent consequences such as increased migration and risk for conflicts. The *Stern Review* does a great job listing many of these, the consequences of which could become severe over the coming century. Billions of people could suffer water shortages, while equally many run the risk of being flooded; tens to hundreds of millions are at risk of hunger, diseases like malaria, and coastal flooding.

As rightly pointed out by the *Stern Review*, the patchy (at best) coverage of these impacts in the current IAMs seriously undermines the validity of their results. 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 conditioning equipment in developing countries, primarily Africa [sic!] (Warren et al. 2006). In the original DICE model, nonmarket impacts for a 2.5^{o}C warming actually amount to a small net benefit. When examining the damage estimates used in today's IAMs of climate change one can not avoid getting the feeling that the effects of climate change on human lives are trivialized.

We believe that it is exactly the nonmarket effects of climate change that are the most worrisome. If we focus on the risk for catastrophes, as Weitzman (2007b) suggests, then we believe the main effect of climate change will not be to stop growth in conventional manufacturing but to damage our ability to enjoy some vital ecosystem services.

Stern (2006) acknowledges that the steps taken in the analysis to rectify these limitations are only partial. The PAGE2002 model used adopts as a benchmark a nonmarket impact on global GDP of a 2.5°C warming of 0.7 percent, with an uncertainty span from 0–1.5 percent, but social impacts are not included. Yet social impacts, in the widest sense, have the potential to make the already serious climate damages much worse. For example, conflicts triggered by disagreements on policy, resource wars, or migration of environmental refugees could become very serious. If in the term "social impacts" we include conflict triggered by massive climate-related migration then it seems reasonable to assume a very low "substitutability" between the absence of these effects (i.e., peace) and material consumption. Thus, to give a sensible picture on the cost of climate change and the benefits of mitigation, these impacts should also be taken into account, together with their expected increase in relative prices over time.

Conclusions

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. In fact, it may be surprising that reactions have not been stronger, but this may be due to a confluence of several factors: Stern's personal stature as an economist; the recent research indicating that climate change may be faster and more severe than previously thought; and finally, strong political backing, primarily in Britain, but also seen in the clearly changing tide of opinion in the United States.

Still, there is some serious criticism that risks undermining the 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 *Stern Review* is also accused of being a political document (see, e.g., Nordhaus 2007). 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*: weighing the costs and benefits of climate change mitigation in order to provide policy makers with advice as to how to handle the problem. Although there is a lot of science and economics involved in trying to provide such advice, we have argued in the present discussion that ethics and value judgments, and thus politics, are inherent parts of the picture.

A case in point, of course, is the most widely debated issue in economic circles following the publication of the *Stern Review*: the choice of the discount rate. We thus trace the discount rate back to its basic components and discuss them in turn. Stern's choices with regard to marginal elasticity of utility and pure rate of discount are in fact low compared to many others, but we believe they are well within the realms of the defensible.

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 that also give a high social cost of carbon emissions and thus encourage large early abatement. We argue that nonmarket damages are probably underestimated and that future scarcities that will be induced by the 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 scarcer should raise the estimated damage of climate change, counteracting the effect of discounting. We refer to an earlier paper (Hoel and Sterner 2007) that shows analytically the link between discounting and relative price change in a two-sector model. By taking seriously the likely future scarcity values for nonmarket environmental assets, we get high damage figures even when using high discount rates.

We make our estimates using Nordhaus's (2007) DICE model. We show that even with Nordhaus's 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 discount rates in the *Stern Review* with rising relative prices, the conclusions would favor even higher levels of abatement. This would in fact lead us to consider some of the levels of carbon content that Stern deems unrealistic, that is, aiming for a target of less than 450 ppm CO_2 equivalents. (See Azar and colleagues (2007) for a discussion on the possibility of attaining stabilization levels of CO_2 less than 400 ppm by using bioenergy with carbon capture and storage, thereby achieving negative CO_2 emissions.)

Some of the most obvious prices that need to change dramatically are the relative prices of fossil fuels themselves (Sterner 2007). Conventional price elasticities (1 for income and –0.65

for fossil fuels), together with *Stern Review* figures of emissions falling 1 to 5 percent per year as incomes grow at 2 percent, imply real price increases of 5 to 10 percent per year! Still, we do not believe that the need for increases in energy prices comes across clearly enough in the *Stern Review*. It seems the report is banking on strong technical progress to lower the future costs of nonfossil technologies. This may indeed happen, but it would be unwise to rely too much on it. In fact, it would be a Pyrrhic victory to persuade people that climate change was important if it were done at the cost 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 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 in which more work should be done. The starting point for the *Stern Review* is that our 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, 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 seriously damage some of these nonmarket sectors; taking these changes in relative prices into account raises the future cost estimates of climate damage and acts as a motivation for stronger abatement now. Combining the low discount rate of the *Stern Review* with our increases in the relative prices associated with ecosystem damage would give support to even stronger abatement measures.

Appendix A: Incorporating Relative Prices in DICE

To allow for changes in relative prices between market and nonmarket (or environmental) goods in the DICE model, we have made two changes in Nordhaus's (2007) version of the model: we have changed the utility function equation and we have included an extra equation that determines how consumption of environmental goods changes over time in response to climatic change.

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

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

where utility, U, is dependent 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:

$$U(C) = [(1-\gamma)C^{1-1/\sigma} + \gamma E^{1-1/\sigma}]^{(1-\alpha)\sigma/(\sigma-1)}/(1-\alpha) \quad (2)$$

where utility is dependent on the consumption of two goods, C and E, where the latter represents nonmarket, or environmental, amenities. The elasticity of substitution is given by σ, and γ determines the share consumption of nonmarket 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 be affected only by rising temperatures, that is, in the absence of climate change environmental quality will neither deteriorate nor improve. We use a quadratic relationship between temperature change, $T(t)$, and nonmarket damages so that

$$E(t) = E_0 / [1+ aT(t)^2] \quad (3)$$

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 and Sterner 2005).

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