Natural Capital and Intra- Generational Equity in Climate Change

Geoffrey Heal

Columbia University[1]

1 Introduction

There are two dimensions of equity that are relevant in an evaluation of the impact of climate change – inter- and intra-generational. It is the former that has been most discussed in the literature to date – all of the extensive debate about the choice of a discount rate in climate models is in effect a debate about intergenerational equity and how to model our concerns about this. And clearly this is very relevant in a climate context – emissions made today will affect generations not yet born, so that issues of intergenerational fairness are central to any discussion of climate policy. But intragenerational issues loom large too: climate change is an external cost imposed largely by rich countries on poor ones, and in addition there is evidence that in any given country it affects poor people more than rich. This dimension of climate change has not been extensively discussed.

Climate change affects our stock of natural capital – for example, the IPCC has estimated that by 2100 in the range of 30-40% of currently extant species may be driven extinct by climate-induced changes in their ecosystems. This would represent a massive transformation of the biospehere, one unprecedented in human history. Glaciers and snowfields are also likely to diminish greatly in extent, affecting water supplies to many regions. Changes like this in our natural capital could have far-reaching consequences, and these are likely to be felt more by poor than by rich countries, and more by poor than rich groups in any country (World Bank 2006). So intra-generational equity and natural capital impacts are related: the latter is likely to reinforce concerns about the former. An important question here is whether some other form of capital – human, intellectual or physical, can replace natural capital. To the extent that this is possible, it may be possible to ameliorate some of the intra-generational equity impacts of climate change.

In the notes that follow, I begin to develop some of these points, making suggestions about how they might be modeled.

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[1] Prepared for an NSF workshop on *The Damages from Climate Change*, November 2010. Author's contact details: Columbia Business School, NY 10027, geoff.heal@gmail.com, www.gsb.columbia.edu/faculty/gheal

2 Equity and Discounting

As anyone who has spent even a short time on the economics of climate change must be aware, a central issue is the choice of the pure rate of time preference (PRTP), to be distinguished clearly from the consumption discount rate (CDR). The PRTP is the δ in the expression $\int_0^\infty u(c_t)e^{-\delta t}dt$ where c_t is aggregate consumption at time t, u is a utility function showing strictly diminishing returns to consumption and we are summing discounted utility over all remaining time.

The other discount rate concept, the CDR, is the rate of change of the present value of the marginal utility of consumption, that is, the rate of change of $\frac{e^{-\delta t}du(c_t)}{dc_t}$. For the case of a single consumption good - and we will turn to the case of multiple goods later - it follows from well-known arguments going back to Ramsey [1928] (see Heal [2005] for a review) that this is equal to the PRTP plus the rate of change of consumption times the elasticity of the marginal utility of consumption:

$$\rho_t = \delta + \eta(c_t)R(c_t) \tag{1}$$

where ρ_t is the consumption discount rate applied to consumption at time t, $\eta(c_t) = -\frac{cu''}{u'} > 0$ is the elasticity of the marginal utility of consumption and $R(c_t)$ is the rate of change of consumption at time t. (Here $u' = \frac{du(c)}{dc}$ and $u'' = \frac{d}{dc}u'$.)

What do these two discount rates mean? The PRTP δ is the rate at which we discount the welfare of future people *just because they are in the future*: it is, if you like, the rate of intergenerational discrimination. Note that there are at least two reasons why we may wish to value increments of consumption going to different people differently: one is that they live at different times, which is captured by δ, and the other is that they have different income levels, which we discuss shortly.[2] A PRTP greater than zero lets us value the utility of future people less

[2]We could also value them differently for all manner of other reasons - differences in nationality, ethnicity, and proximity either physically or genetically. In general we don't do these things, at least explicitly, which to me makes it strange that we do explicitly discriminate by proximity in time.

than that of present people, *just because they live in the future rather than the present*. They are valued differently even if they have the same incomes. Doing this is making the same kind of judgment as one would make if one valued the utility of people in Asia differently from that of people in Africa, except that we are using different dimensions of the space-time continuum as the basis for differentiation.

That an increment of consumption is less important to a rich person than to a poor person has long been a staple of utilitarian arguments for income redistribution and progressive taxation (see Sen [1973]), and is almost universally accepted. This is reflected in the diminishing marginal utility of consumption, and the rate at which marginal utility falls as consumption rises is captured by $\eta(c_t)$. Equation 1 pulls together time preference and distributional judgments, or considerations based on inter- and intra-generational judgments: the rate at which the value of an increment of consumption changes over time, the CDR ρ_t, equals the PRTP δ plus the rate at which the marginal utility of consumption is falling. This latter is the rate at which consumption is increasing over time $R(c_t)$ times the elasticity of the marginal utility of consumption $\eta(c_t)$.

3 Equity and Climate Change

As we have just seen, there are two dimensions of equity that are important in the context of climate change: equity between present and future generations, the aspect that has been most extensively discussed, and equity between rich and poor countries or groups, both now and in the future – inter- and intra-generational issues. This second dimension is invisible in aggregative one-good models, which is one reason why we need a many-good model to talk seriously about climate change. The discussions below will reinforce the need for some measure of disaggregation in the analysis of the economics of climate change if we are to grapple with equity issues.

The parameter η, the elasticity of the marginal utility of consumption, summarizes our preference for equality: it determines how fast marginal utility falls as income rises. There are two ways in which this affects the case for action on climate change.

As η rises, the marginal utility of consumption falls more rapidly. If consumption is growing over time, then this means that the marginal utility of future generations falls more rapidly with larger values of η and therefore we are less concerned about benefits or costs to future generations. We are less future-oriented - the consumption discount rate ρ is higher - and so place less value on stopping climate change. So via this mechanism, *a stronger preference for equality leads to a less aggressive position on the need for action on climate change*. Preferences for equality and action on climate change are negatively linked here.

There is another offsetting effect, not visible in an aggregative model. Climate change is an external effect imposed to a significant degree by rich countries on poor countries. The great majority of the greenhouse gases currently in the atmosphere were put there by the rich countries, and the biggest losers will be the poor countries - though the rich will certainly lose as well. Because of this, *a stronger preference for equality will make us more concerned to take action to reduce climate change*.

So we have an ambiguous impact of a stronger preference for equity on our attitude towards climate change. Via the mechanism captured in the formula for the consumption discount rate, equation 1, it makes us less future oriented - provided consumption is growing. (If consumption were to fall, it would make us more future oriented, and if consumption of some goods were to rise and that of others to fall, the effect would be a priori unclear.) And via our concern for the poor countries in the world today it makes us more future-oriented.

Unfortunately, without exception analytical models capture only the first of these effects. They are aggregative one-sector models or models with no distributive weights and so their operation does not reflect the second mechanism mentioned above. This explains the really puzzling and counter-intuitive result that a greater preference for equality in Nordhaus's DICE model leads to less concern about climate change.

To capture fully the contradictory impacts of preferences for equality on climate change policy, we need a model that is disaggregated both by consumption goods and by consumers, allowing us to study the consumption of environmental as well as non-environmental goods and also the differential impacts of climate change on rich and poor nations.

3 Natural Capital and Climate Change

Return to equation (1) for the consumption discount rate. Note that if consumption were *falling* rather than *rising* over time (the latter being the universal assumption in IAMs), then the second term in the expression for ρ_t would be negative and the CDR could in principle be negative, that is the value of an increment of consumption could be rising over time rather than falling. We would not be discounting but doing the opposite, whatever that is. It is not impossible that in a world of dramatic climate change and environmental degradation, consumption might fall at some point. It is even more likely that *some aspects of consumption, or the consumption of some social groups,* would fall while other continue to rise - recognizing this requires that we treat consumption as a vector of different goods that can be affected differently by climate change. For an early recognition of this point see Fisher and Krutilla [1975], who comment that increasing scarcity of wilderness areas may drive up our valuation of them. A more detailed analysis in the context of a growth model is in Gerlagh and van der Zwaan [2002], who make the interesting point that with limited substitutability between environmental and manufactured goods and the growing scarcity of environmental goods, there is likely to be a version of Baumol's disease - an ever larger portion of income being spent on non-manufactured goods.

Let's follow this line of thought and disaggregate consumption at date t into a vector $c_t = \left(c_{1,t}, c_{2,t}, \ldots c_{n,t}\right)$ of n different goods. (We will mention briefly later the case in which thsee are the consumption levels of different countries or social groups.) Utility is increasing at a diminishing rate in all of these goods and is a concave function overall. In this case we have to change equation 1 for the consumption discount rate. Now there is a CDR for each type of consumption and we have n equations like equation 1, with a CDR for each good i equal to the PRTP plus the sum over all goods j of the elasticity of the marginal utility of consumption of good i with respect to good j times the growth rate of consumption of good j:

$$\rho_{i,t} = \delta + \eta_{ii}\left(c_t\right) R\left(c_{i,t}\right) + \sum_{j \neq i} \eta_{ij}\left(c_t\right) R\left(c_{j,t}\right) \tag{2}$$

where $\rho_{i,t}$ is the CDR on good i at date t, $R\left(c_{i,t}\right)$ is the rate of change of consumption of good i at date t, and $\eta_{ij}\left(c_t\right)$ is the elasticity of the marginal utility of good i with respect to the consumption of good j (see Heal [2005] for details: the most general framework of this type can be found in Malinvaud's classic paper [1953]). The own elasticities such as $\eta_{ii}\left(c_t\right)$ are positive numbers, but the cross elasticities $\eta_{ij}\left(c_t\right)$, $j \neq i$, are zero if the utility function is additively separable and can otherwise have either sign.

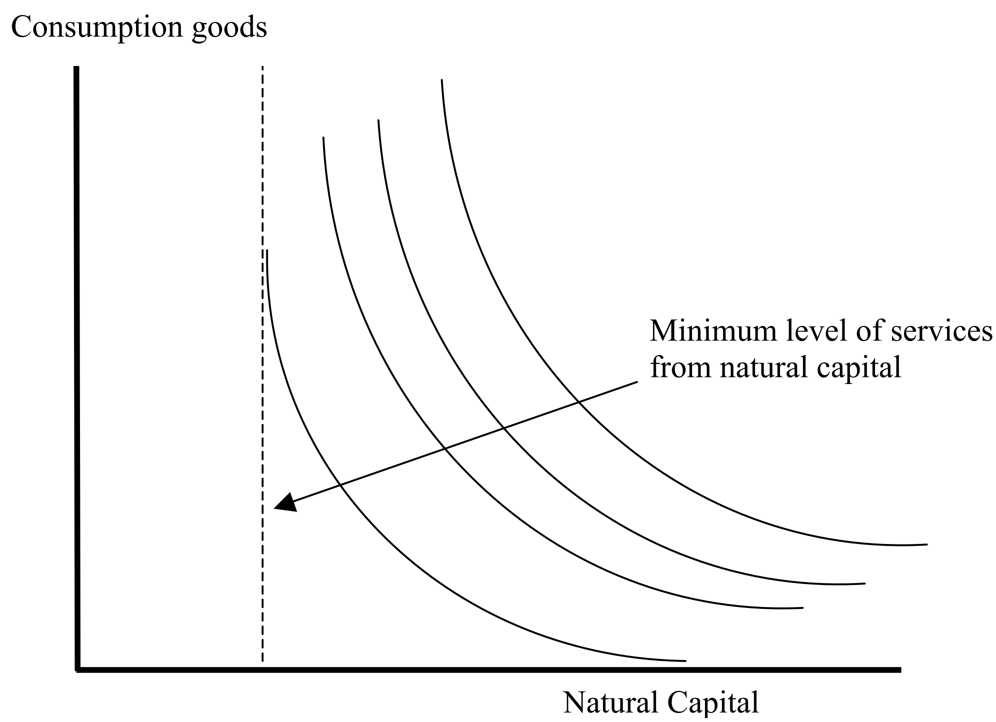
As an illustration consider the constant elasticity of substitution utility function

$$\left[\alpha c^{\sigma}+(1-\alpha)s^{\sigma}\right]^{\frac{1}{\sigma}} \quad (3)$$

Here we can think of c as produced consumption and s as natural capital, an environmental stock that produces a flow of ecosystem services. (See Barbier and Heal for a discussion of this concept [2006] and the World Bank for a detailed review of the role of natural capital in the growth process [2006].) In this case the cross elasticity of the marginal utility of consumption depends on whether c and s are substitutes or complements. For an elasticity $\sigma > 1$ they are substitutes and the cross elasticity is positive, and vice versa.

Let's test our intuitions on this. Take the case where natural capital and produced consumption are highly complementary, so that indifference curves are near to right angled and the elasticity σ is close to zero. Then the cross elasticity is negative. This means that if the stock of natural capital is rising then this reduces the consumption discount rate on the regular good. Conversely if the availability of natural capital is falling then this raises the consumption discount rate on the consumption good. These results make sense: because of the assumed complementarity, an increase in the amount of the environmental good will raise the marginal utility of the consumption good and so tend to lower the consumption discount rate, and vice versa. Of course, the own elasticity on natural capital is positive so that if the availability of this good is falling then this will tend to make its own consumption discount rate negative.

Whether produced goods and environmental services are substitutes or complements in consumption is not an issue that has been discussed in the literature, as with the few exceptions mentioned above people have worked with one-good models. There do however seem to be reasons to suppose that complementarity is the better assumption, with $\sigma < 1$. Dasgupta and Heal [1979], following Berry Heal and Salamon [1978], suggest that in production there are technological limits to the possibility of substituting produced goods for natural resources. In particular we invoke the second law of thermodynamics (Berry and Salamon are thermodynamicists) to suggest that if energy is one of the inputs to a production process, then there is a lower bound to the isoquants on the energy axis. Similarly one can argue that certain ecosystem services or products, such as water and food, are essential to survival and cannot be replaced by produced goods. There are therefore lower bounds to indifference curves along these axes, implying if the utility function is CES that $\sigma < 1$.



The figure illustrates this idea: it shows indifference curves for a two-argument utility function, consumption of produced goods and of ecosystem services, as in equation 3 above. There is a minimum level of ecosystem services needed for survival - think of this as water, air, and basic foodstuffs, all of which are ultimately produced from natural capital. For low welfare levels there is no substitutability between these and produced goods, so that indifference curves are close to right angled. At higher welfare levels where there are abundant amounts of both goods there is more scope for substitution. Taken literally, this implies that the elasticity of substitution is not constant but depends on and increases with welfare levels. This of course is not reflected in the CES function such as 3. A function with these properties is

$$\left[\alpha c^{\sigma} + (1-\alpha)(s-\varepsilon)^{\sigma}\right]^{\frac{1}{\sigma}} \tag{4}$$

which is simply the CES function we noted before, with the zero of the ecosystem service axis transformed by $\varepsilon > 0$. Utility is not defined for $s < \varepsilon$. Relative to the transformed origin $(\varepsilon, 0)$ there is still a constant elasticity of substitution σ but relative to $(0,0)$ the elasticity is not constant. For $\sigma > 1$, every indifference curve, every welfare level, can be attained with only ε of ecosystem services, whereas with $\sigma < 1$ greater welfare levels require greater levels of ecosystem services (and of consumption goods).

These ideas can be applied to modeling equity: it is generally recognized that poor countries, or poor groups within countries, are more dependent on natural capital and its services than are richer groups (World Bank [2006]). They have less capacity to substitute alternative goods for the services of natural capital and so show more complementarity between natural capital and other goods. In terms of the figure, their indifference curves are lower and closer to being right angled. This means that they have different consumption discount rates from other groups: if the stock of natural capital is falling then they will have higher consumption discount rates on the common consumption good. In this sense they will appear to be more impatient. Of course as noted above their discount rate on natural capital will be negative, so we will have the paradox of an apparently impatient group – with respect to the consumption good – being willing to invest for low returns in natural capital.

4 A Sterner Perspective

It's worth looking in more detail at the Sterner and Persson development of this point [2007]. They talk about the effect of changes in relative prices rather than consumption of produced and environmental goods, but the point is the same. If we consume both produced goods and the services of the environment, as in the utility function 3, then we can expect that with climate change environmental services will become scarce relative to produced goods and therefore their price will rise relative to that of produced goods (the " environmental Baumol disease" that Gerlagh and van der Zwaan refer to [2002]). Consequently the present value of an increment of environmental services may be rising over time, and the consumption discount rate on environmental services may thus be negative, precisely the point that we were making in equation 2 above. This could be the case even with a high PRTP, which is the main point of the Sterner and Persson paper. They also present an interesting modification of Nordhaus's DICE model to incorporate this point. They replace the standard utility function, which is an isoelastic function of aggregate consumption, by a CES function along the lines of equation 3 above, but modified to reflect a constant relative risk aversion:

$$\left[(1-\gamma)c^{1-1/\sigma}+\gamma s^{1-1/\sigma}\right]^{(1-\alpha)\sigma/(1-\sigma)}/(1-\alpha)$$

They assume that the supply of environmental services s is negatively affected by temperature according to the square of temperature, and that the share of environmental goods in consumption is about 20%, use these assumptions to calibrate the modified DICE model and and then run the model with the PRTP used by Nordhaus. Their runs show that even with such a high PRTP the presence of an environmental stock that is damaged by higher temperatures radically transforms the optimal emissions path of CO_2 and leads to a vastly more conservative policy towards climate change, with emissions both staying lower and falling faster. In fact it leads to a more aggressive reduction in greenhouse gases than recommended by the Stern Review.

5 Natural Capital and Production

I have emphasized so far that natural capital can affect human welfare directly, and needs to be thought of as an argument of the welfare function. Natural capital also affects a nation's production possibilities: I mentioned above changes in hydrology such as melting of glaciers and reduction in winter snowfields, both of which are already in evidence and are affecting agriculture in some regions. They will affect it further over the coming decades. This is quite separate from any impact that changes in temperature and precipitation may have on agriculture. Other changes in natural capital will probably affect agriculture – changes in species abundance and distribution, for example, can affect whether birds and insects pollinate crops.

6 Modeling Different Groups

I commented above that equation 2 can be given a different interpretation: instead of

$$\rho_{i,t} = \delta + \eta_{ii}(c_t) R(c_{i,t}) + \sum_{j \neq i} \eta_{ij}(c_t) R(c_{j,t}) \tag{2}$$

the subscripts i and j referring to different goods, they can be taken as referring to the amounts of a single good consumed by different groups – these could be social groups within a country or they could be different countries. I this case we hae different consumption discount rates for each group's consumption, and the elasticities now indicate how the marginal valuation of consumption by one group depends on the cosumption levels of others. Do we value on increment of consumption to the poor more if everyone else is very rich than if most others are also poor? Presumably the answer to this is yes, but these are issues that have not featured at all in the discussions to date.

7 Choosing η

The elasticity of the marginal utility of consumption plays a central role in much of outr discussion. Unfortunately this variable plays two roles in our models: it expresses our distributional preferences, which is the way we have been using it here, and it also expresses our aversion to risk. Most empirical estimates of the value of η come from studies of behavior in the face of risk, but it seems clear that these two interpretations of η are really quite different, and that our aversion to risk tells us little if anything about our preferences for income equality. Given this, we need to find a way of expressing preferences that does not conflate distributional and risk preferences. Recursive formulations such as that of Kreps and Porteus are relevant here.

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