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ETHICS, EQUITY AND THE ECONOMICS OF CLIMATE CHANGE PAPER 2: ECONOMICS AND POLITICS

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Both intertemporal and intratemporal equity are central to the examination of policy towards climate change. However, many discussions of intertemporal issues have been marred by serious analytical errors, particularly in applying standard approaches to discounting; the errors arise, in part, from paying insufficient attention to the magnitude of potential damages, and in part from overlooking problems with market information. Some of the philosophical concepts and principles of Paper 1 are applied to the analytics and ethics of pure-time discounting and infinite-horizon models, providing helpful insights into orderings of welfare streams and obligations towards future generations. Such principles give little support for the idea of discrimination by date of birth. Intratemporal issues are central to problematic and slow-moving international discussions and are the second focus of this paper. A way forward is to cast the policy issues and analyses in a way that keeps equity issues central and embeds them in the challenge of fostering the dynamic transition to the low-carbon economy in both developed and developing countries. This avoids the trap of seeing issues primarily in terms of burden-sharing and zero-sum games – that leads to inaction and the most inequitable outcome of all.

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INTRODUCTION

Equity and distributional issues, both inter- and intratemporal, loom large in discussions of national and international policy towards climate change. They are the focus of this paper. All too often equity criteria are invoked in an arbitrary way, with little or no attempt to anchor them in ethical principles or link them to the basics of public economics. Any application of principles must also be tailored to the fundamentals of the problem at hand, which in the case of climate change are shaped by the science. Accordingly, this paper builds on the foundation of its predecessor in this two-part series which examined the science and ethics (Stern 2014), and takes that discussion forward to examine issues of equity, examining the economics and politics of the key policy issues.

Part 1 of this second paper concerns primarily intertemporal issues and the appropriate analytical frameworks, including discounting. Many of the key decisions concerning climate change relate actions we may take now to possible consequences in the future. Some of these consequences will be far into the future and many or most of them will be uncertain. How should we evaluate such consequences, relative to costs or benefits today, when many of these consequences are difficult to understand and could occur in a diverse range of possible circumstances?

In this context we examine and illustrate the limitations of standard approaches to discounting, and draw attention to a collection of serious analytical errors which have arisen in the literature on climate change, and which continue to arise, as a result of applying such approaches in an unconsidered way. All too often, intertemporal social valuations are derived from an exogenously imposed set of discount rates. This is a basic error in this context, arising from misunderstanding the scale of the risks indicated by the science and often from ignoring the basic principles of shadow prices and marginal valuations: these are not marginal changes, thus marginal valuations are endogenous to our decisions.

These errors are often compounded by ignoring key market failures, and mis-specification of the ethical questions, in an attempt to base exogenously imposed discount rates on markets. It is argued here that we can expect little serious guidance from market rates for a whole series of basic reasons. These include: the scale of risk could make the future look very different from the past and result in economic decline; the decisions at issue are collective and long-term not individual and short- or medium-term; markets have gross imperfections, particularly in relation to risk; and, the problem cannot sensibly be examined in a one-good consumption framework, because lives are at stake and the physical environment is critical.

Similarly, attempting to infer social values from 'inverse optimum' analyses of public decisions is undermined by the need to model the

constraints and incentive structures which are assumed to be perceived by the 'optimizers'. The answers which emerge in such analyses are very sensitive to the assumptions on those perceptions. Given that the exogenous/market route is fatally flawed in this context and that the social-inverse optimum problem gives results that are so sensitive to assumptions, we must return to basic ethical discussions if we are to inform the social values behind intertemporal discounting.

In Part 2 we examine distribution and equity across people and countries, and thus intratemporal issues. This discussion takes us directly to challenges which are central to international policy discussions. These discussions have seen a number of suggestions for formulaic approaches to equity in relation to group or country allocations of, quotas for, or rights to 'carbon space'. These usually have weak foundations scientifically, ethically and economically. Further, there are deep political difficulties which have strong ethical and economic dimensions: various attempts to create 'formulae for equity' tend to point to 'allocations of emissions rights or permits', which would give large resource transfers to poor countries relative to current conditions. Whilst the ethical case for large transfers does indeed seem strong, rich countries are most unlikely to accept the arguments for so doing.

It would make little ethical, political or practical sense, however, to abandon an attempt to embody ethics in policy, because of the difficulties of a particular formulaic approach and the intransigence of rich countries. If we do not face seriously and constructively the equity and ethical issues that are integral to climate change in international discussions and policy making, we risk deadlock and weak action. That could yield arguably the most inequitable outcome of all – it is poor people who are hit earliest and hardest by climate change.

There is a way forward: reframing interpersonal and cross-country questions in terms of 'equitable access to sustainable development', language used in the 2010 Cancún agreement of the United Nations Framework Convention on Climate Change (UNFCCC). This approach ensures equity issues remain central and embeds them in the idea of rich country support for fostering the dynamic and attractive transition to the low-carbon economy in both their own countries and as a driver of growth and poverty reduction in the developing world. The approach frames the questions in an analysis which reflects the role and nature of the necessary economic change, involving learning and innovation, and shows the potential for shared and recognizable mutual gain. It contrasts with the language of 'burden-sharing' which frames the problem, misleadingly, in a static way and with similarities to a zero-sum game.

Policies for sustainable development and overcoming poverty require breaking the link between production and consumption activities on

the one hand and emissions on the other. Essentially, as argued in Paper 1, we need a new energy-industrial revolution. Getting decisions on action on the necessary scale requires clarity on five key issues and propositions: first, the scale of emissions reductions; second, that a dynamic and radical economic transformation is required; third, that it will have many attractive features beyond reducing climate risk; fourth, that it is a sustainable growth story with great potential for overcoming poverty; fifth, substantial investment and new technologies are required. Such a picture of the required response, including its radical nature and the importance of the dynamics of learning and transition, is a crucial part of the whole challenge of putting the science, ethics and economics together. Describing the severe consequences of inaction or business-as-usual is, of course, a fundamental part of the ethical and policy analysis; but understanding, discussion and agreement fare much better if this is accompanied by a description of the alternative paths and why they look so much more attractive, over and above the radical reductions in climate risks they can deliver. The alternative paths do indeed appear to be cleaner, quieter, safer, more secure and more biodiverse.

The framing of the ethical discussion and its conclusions can profoundly influence the way in which political, economic and social issues are understood or perceived. Reasoned ethical argument, its foundations, and the way it is conducted are vital to policy making, not just conceptually, but also practically. Philosophy without understanding the basics of economic analysis does not get us far. But, if economists are to engage seriously with policy on climate change, there is no alternative to serious engagement with the ethical issues. This is an ethical discussion that could have profound implications for action.

PART 1. ECONOMICS AND ETHICS OF INTERTEMPORAL VALUES AND DISCOUNTING

1.1 Discounting and the big picture

Many of the decisions concerning climate change relate actions we may take now to possible consequences in the future. Some of these consequences will be far into the future and many or most of them will be uncertain. How should we evaluate such consequences, many of which are difficult to understand and could occur in a diverse range of possible circumstances, relative to costs or benefits which take place now? This sounds like the 'familiar' problem in the economic appraisal of projects of discounting an incremental benefit of one unit of some numeraire good in the future relative to one unit of that good now. If this were a set of issues involving fairly minor changes and the assumption of one good were not misleading then I would not raise queries about language. In this context,

however, I think it is 'intertemporal values and valuations' that we should use rather than 'discounting'.

To insist on the term discounting in this context runs the risk of shoe-horning this part of the economics and ethics of climate change into a very narrow form. Indeed sometimes it appears that some imagine that policy analysis on climate change can be reduced to a discussion about a single number, 'the discount rate', a concept still narrower than discounting.

Let us begin by defining the relevant concepts and then place them in the context of the scale of risk, and of necessary change, and the arguments for action. The rate of fall of the discount factor for a given good at time t is the discount rate for that good at that time; where the discount factor is the relative value of a unit of the good at some date in the future, t, to a unit of that good now. The discount rate or factor will usually depend on both the good and the time being considered. The value of an extra unit of a good is generally assessed by looking at the impact on a social welfare function of the availability of an extra unit of that good. This is essentially the definition of a shadow price – see, e.g. Drèze and Stern (1987, 1990) for a detailed formal discussion. The impact on social welfare is the full general equilibrium effect of an extra overall availability of the good (in other words, where functions are differentiable, the Lagrange multiplier on the resource balance constraint for the good). It will depend on the functioning of the economy, including who gains and who loses from the extra availability, and the social weightings attached to those gains and losses – distribution matters to the determination of shadow prices. Shadow prices can be very different for different availabilities of goods, different times, different model structures and different distributional weightings.

The concepts have great usefulness and we do not have to fall into the common errors described below. But all too many economists and others have fallen and do fall into analytical traps they barely recognize. This is yet another example of the dangers in the economics and ethics of climate change of focusing on standard narrow formulations and losing sight of the big issues at stake. We have to look in a careful way, using all the economics we can muster, into intertemporal values in imperfect and uncertain economies where the range of possible circumstances is very large and future levels and distributions of well-being are strongly influenced by the decisions we take now. The Economics 101 treatment of intertemporal issues using models with perfect markets and one good at each point of time just does not cut the mustard.

In my view, the key choices in policy for climate change are the strategic ones amongst radically different emissions paths. In Paper 1 I argued that, based on an understanding of the consequences of different emissions paths in terms of the management of risk, there was a powerful case for strong and urgent reductions of emissions flows, with an aim

of radically reducing probabilities of temperature increases of 4 °C and above and the great dangers they bring. Could those strategic choices be reached or guided by describing shadow prices, discount factors and the like, starting from where we are and gradually making investments guided by those prices? I would suggest that such a process guided by marginal signals would be very unlikely to generate change at the pace necessary.

Formally speaking, in models of maximization, with 'well-behaved' functional forms (appropriate continuities and convexities which allow marginal conditions to fully characterize an optimum) there is a duality between prices and quantities. At a maximum or optimum, the set of shadow prices associated with the optimum would imply that any perturbation from that optimum would make a loss if evaluated at those prices. In this sense the shadow prices guide us to an optimum, and each optimum has an associated set of shadow prices. If functional forms and model structures are sufficiently 'well-behaved', at a point away from the optimum, if choices are guided by shadow prices associated with that point, then the incremental decisions will move us towards the optimum. This is the familiar 'duality' between prices and qualities in well-behaved models.

However, this context is much more difficult than that, not only technically (probably there are many 'badly behaved' relationships),[1] but also in the scale of the risks involved, the scale and nature of necessary change and the dangers of delay. The scale of the possible consequences involved, the uncertainties and the timescales make an approach based on shadow prices and integration or summation over a sequence of small changes extremely difficult to carry through and potentially very misleading. Issues of this scale and temporal sensitivity cannot be convincingly represented as the integral of a collection of marginal changes in a static model or in a framework where the clock is conceptually stopped whilst the tatonnement process edging towards some optimum takes place. We have a complicated dynamic process, with major and disruptive change, with learning and discovery, and where risk is of the essence.

The sensible way forward, in my view, is a strategic analysis of possible actions and consequences along the lines described. Implementation will indeed require a strong reliance on markets, entrepreneurship and private investment but the strategy has to be drawn

[1] Many discontinuities and non-convexities are likely to arise in this context. It is probably still more difficult than that – it is hard to know what functions and spaces may be at issue. See Drèze and Stern (1987, 1990) for the relationship between shadow prices and the theory of reform: this follows a tradition of Meade, Guesnerie and others (see references in those papers).

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on a bigger scale. This is a familiar mathematical and practical point. Mathematically, prices and marginal valuations will depend on the overall path. Practically, investors will find decisions very difficult if they cannot have some confidence in the overall policy direction of travel.

From this point of view an intense focus on discount factors and rates, particularly if made the central issue, can divert attention from the big strategic issues. The discount factors and rates will matter to investment programmes, public and private. They will be important to implementation and to the calculation of important social costs, including that of carbon. But we must be careful to avoid missing the 'forest' of the big decisions by looking only at the 'trees' of valuing marginal increments. This is surely a case where the scale and risks are such that we should start with an examination of the overall strategy and see marginal valuations, shadow prices, within that strategic framework. Both intertemporal and intratemporal values will influence that strategic framework but they are also endogenous to it.[2]

Unfortunately, in discussions in economics of ethics and climate change, the role of discounting is not only over-done, it is badly done. The misleading formulations and mistakes matter not only to the diversion from the big picture but also in influencing the important role that discounting should play within the implementation of a strategy. The mistakes are closely linked to the attempts to shoe-horn the very non-standard set of issues in economics and ethics that are raised by climate change, into the standard framework of marginal adjustments. The misleading formulations and mistakes matter not only to the subject of climate change but also more generally, for example, in framing long-run decisions on infrastructure and on the environment. The rest of Part 1 of the paper is devoted to some of the detail.

1.2 Many goods, many people, many states of nature, many discount rates and many mistakes

In order to explain and illustrate the limitations of standard approaches to discounting in this context, and the many mistakes which have arisen in relation to climate change, let me look at two propositions, each of which is crassly misleading or false in this context. First, 'the question of discounting and intertemporal values is basically the same question as the choice of the discount rate, or hurdle rate of return, against which all investment projects should be assessed'. Second, 'we can learn most or all of what we need to know for intertemporal valuations and the choice of discount rate in this context from capital markets'.

[2] And see Weitzman (1974) on starting with quantities or prices in problems of risk.

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First, it should be clear from the definition of discount factors and rates (depending as they do on the good in question and on the time being considered) and from the magnitude of potential change that anyone who speaks of 'the discount rate' in the context of climate change, in the sense that there is one rate, constant over time, which should be applied to all investment projects, including investing in reducing emissions, should go to the bottom of the class. It should be clear that to formulate the question in this way is to make a collection of serious errors. The detail of an appropriate treatment of the issues and the nature and implications of the common errors is important.

Let us start with the formal definitions of a discount factor and rate as given above. If the discount factor for good i at time t is λ_{it}, then the discount rate, ρ_{it} at time t, is the rate of fall of λ_{it}, i.e. it measures how fast the discount factor is falling. In other words $\rho_{it}\Delta t$ measures how much less (proportionally) a unit of good i is valued at $t+\Delta t$, relative to good i at time t. In discrete time, if ρ_{it} were 0.1 per period, a unit of good i at time $t+1$ would be 10% less valuable than at time t.

$$\rho_{it} \equiv -\dot{\lambda}_{it}/\lambda_{it} \tag{1}$$

As we have emphasized, 'the discount rate' depends on i and t. Equation (1) is sometimes said to define the 'own' discount rate for good i.[3] When uncertainty is introduced, an index for the 'state of nature' will be necessary, too; alternatively we can interpret goods in different states of nature as different so that the index i carries that information (an umbrella when it is raining is deemed a different good from when it is dry).

How are own discount rates for goods i and j related? This is clear from (2), remembering that λ and ν depend on t,

$$\rho_{jt} - \rho_{it} = \dot{v}_{ij}/v_{ij} \text{ where } v_{ij} \equiv \lambda_{it}/\lambda_{jt} \tag{2}$$

Thus the difference between the discount rates for goods i and j at time t is equal to the rate at which the relative valuation, or relative discount factors, or relative shadow prices[4] (we use the terms interchangeably for this discussion) are changing.

This type of argument has been familiar in economic theory for at least 60 years (see, e.g. Malinvaud 1953, on heterogeneous capital goods) and was generally recognized in the cost-benefit analysis literature of the 1960s, 70s and 80s, in the phrase 'the discount rate depends on the choice

[3] See, e.g. Bliss (1975).

[4] A formal definition of the shadow price of good i at time t is the increment to social welfare arising from an extra unit of good i becoming available at time t. It will be relative shadow prices that matter to decisions. This definition of the notion needs some aggregate concept of social welfare or an objective function. See Drèze and Stern (1987, 1990). A shadow price will depend both on the functioning of the model and the distributional and other values embodied in the concept of social welfare.

of numeraire'.[5] In other words, if good i is chosen for numeraire we will see a different array of discount rates from those which would arise if good j is chosen as numeraire. The choice of numeraire should not affect decision-making but it will affect the expression of the social accounting.

We would expect λ_{it} to be influenced by the relative scarcity of i at that time. For example, if i were environmental services it is possible that they would become more scarce putting 'upward pressure' on λ over time. It would also be influenced by overall standards of living. If life was getting better the overall λ levels might fall over time, but if conditions were getting worse they might rise.

Similar remarks apply when we recognize that incremental consumption may not have the same social value for different groups. Indeed, it is reasonable to argue that consumption increments for different groups will have different social marginal values, unless it is assumed directly that they are all deemed to have the same value (which would seem arbitrary since the supporting ethical judgements are unclear); or unless it can be assumed that an optimum set of lump-sum transfers is in place that sets the social marginal valuations to be the same, as a condition of optimality. The availability of such a set of lump-sum transfers is thoroughly implausible for the usual information/incentive reasons which are standard in modern public economics (see, e.g. Mirrlees 1971, 1997). Many would argue that a lower social marginal valuation should be applied to an increment to someone who is better off (e.g. under utilitarian or Bergson–Samuelson objectives).[6] The social value of good i, made available at time t, to household h, is $\lambda_{it}\mu^{ht}$ where μ^{ht} is the social marginal valuation of income to household h in time period t, or the welfare weight for h at time t. It would generally vary across households.

Narrow cost-benefit analysis, using standard marginal techniques, of small investment projects, which cause minor deviations from a given growth path can be a very useful way of discriminating in a practical and reasoned way between different opportunities. However, in the context of climate change, we have seen that there are real possibilities that some (high-carbon) attempted investment or growth strategies could lead to immense change in the world's economic and social circumstances, including the possibility of rapid decline, wholesale destruction of the environment, radical change in income distribution, and the movement of people on a scale which could result in major, widespread and extended

[5] See, e.g. Little and Mirrlees (1974) or Stern (1972a).

[6] The concept of the social marginal valuation of income must in any case be used with care since, if market and shadow prices differ anywhere in the system, the marginal propensity to pay shadow taxes out of income (where shadow taxes are the difference between market prices and shadow prices) should influence the marginal conditions for optimum lump-sum taxes, or indeed for second-best optimum taxes. These issues are discussed formally at some length in Drèze and Stern (1987, 1990).

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conflict and loss of life. In such a context, it could hardly be argued convincingly that discount rates could be treated as constant over time for at least four important reasons. First, they would surely be sensitive to possible future income levels, particularly to possible decline, an outcome which could be associated with higher discount factors in the future and negative discount rates. Second, environmental services might collapse on key dimensions, thus it is difficult or impossible to make a case that the relative shadow price of such services and consumption goods remains constant – discount rates will vary across goods – see equation (2). Third, if world income distribution is radically affected, e.g. the poorest are hit earliest and hardest by climate change, it cannot be argued that benefits or costs are likely to be spread in a fairly broad and stable way, and one which is similar for benefits, for costs and for the raising of resources: these are the kind of arguments necessary if income distribution issues are put to one side. Fourth, widespread loss of life would require going outside the standard formulations of a fixed number of individuals and the evaluation of consequences only in terms of changes or goods accruing to those individuals.

Thus many attempts at presenting action on climate change as just another project to be compared with other possible projects, such as building water infrastructure in poor countries, fighting malaria and so on (e.g. Lomborg 2009) are hopelessly flawed because they take no serious account in their method of cost-benefit analysis (CBA) of the potential radical global changes involved in unmanaged climate change and their implications for intertemporal valuation.

Such simple-minded cost-benefit comparisons also usually treat such projects as separate stand-alone projects with no interactions. Water issues, diseases and health, and climate change are intimately inter-linked and it is a basic mistake in CBA to treat inter-linked projects as separate when one is attempting to evaluate them. Such attempts to shoe-horn a profoundly non-marginal and system-wide set of issues into a narrow marginal framework, and in the process overlook the inter-linkage of projects, appear to involve an ignorance of the basics of the theory and practice of cost-benefit analysis. Careful analyses of consequences should indeed be at the heart of strategic decisions but the narrow forms of CBA sometimes used or proposed ride roughshod over the science concerning scale and interlinkage, the economics in terms of the basic theory of evaluation, and the philosophy relating the underlying ethical issues.

It is interesting to note that towards the end of one of his papers on discounting, which is largely based on approaches involving simple social welfare functions and marginal effects, Partha Dasgupta, who has written interestingly and wisely on the principles of project evaluation, concludes that the possible vast scale of losses makes such narrow cost-benefit analyses of very limited value (Dasgupta 2008). I agree with him, but this

does suggest that focusing heavily or primarily on such approaches risks being diversionary for the analysis of intertemporal values and valuations in this context.

Let me now move from general formulations of underlying principles to a very particular structure which focuses on a one-good growth model. It involves a narrow approach to ethics and uncertainty and a highly aggregated approach to both consumers and goods. Thus, I do not wish to argue that it should occupy centre stage in a discussion of discounting for climate change. However, because it is so prominent in discussion of intertemporal ethics, it is important to set it out explicitly so that the problems applying it in this context can themselves be made explicit. We shall see that notwithstanding its narrowness, the approach will also have some usefulness in analysing parametric formulations of approaches to intertemporal values and that it can illuminate some of the issues around pure-time discounting in infinite horizon models. A core part of this story will be the Ramsey analysis or rule for optimum allocation between consumption and investment.

Many formulations of overall objectives in the modelling of intertemporal choices at the national level, in standard micro, general equilibrium or growth theory, use a simplified objective expressed as the maximization of the mathematical expectation of the integral of some function of aggregate consumption (see for example equation (3)).

$$\text{(3)} \qquad \mathrm{E} \int \sum_{h} u(C_{ht}, N_{ht}, t) dt$$

The expectation operator E ranges over the space of possible outcomes, the integral is over time, and the summation is over individuals (or, in many examples in the literature, fairly aggregated sub-groups in the population), u is a social utility function, C_{ht} is the total consumption (usually one-good but could be a vector) of group h at time t, and N_{ht} is the population of group h at time t. It is often assumed that C_{ht} is equally distributed amongst group h with consumption per head in the group c_{ht} (although other within-group distribution rules are possible).

Whilst this formulation is fairly flexible in terms of the issues it covers, it does embody two important and narrow assumptions: it represents attitudes to risk by working with the expectation of social utility $u(\ )$, and second, it treats consumption at different points in time as separable.[7] The vector c_{ht} could be interpreted as allowing for the role of environmental services but all too often is in terms of one dimension only: aggregate consumption. Whilst not embodied in (3) itself, applications often treat the probability distribution of outcomes at different times as independent. That is implausible because if climate turns out, for example, worse than

[7] And it assumes an exogenously given structure and time profile of population.

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expected[8] then the same may be more likely to be true of later periods. Further, some damages may be irreversible or long-lasting. See Stern (2013) for an elaboration of this idea.

In order to express in a simple way some of the common discussions of discounting based on this approach, let us further simplify the formulation of the social objective (3), as in equation (4):

$$\mathrm{E} \int N_t u(c_t) e^{-\delta t} dt \tag{4}$$

Now we have just one good, there are N_t households at a time t, with equal consumption c_t,[9] and 'pure-time discounting' at a constant rate δ. Pure-time discounting here involves a discount factor, $e^{-\delta t}$, on future utility and attaches a lower weight to future generations or future utility of consumption entirely on the grounds that they are in the future: we shall shortly examine some of the suggested arguments for so doing. It can be understood as discounting the lives, and thus utilities, of those born later simply on the grounds of date of birth, irrespective of what their consumption might be; it is quite explicitly discrimination by date of birth.

In this framework the discount factor at time t is:

$$\lambda_t = u'(c_t) e^{-\delta t} \tag{5}$$

Then λ_t is the marginal valuation of an overall extra unit of total consumption (distributed equally so that everyone at t gets an extra $1/N_t$); it is the partial derivative of (4) with respect to C_t We take λ_0 equal to one. Then λ_t can be seen as the shadow price of a unit of consumption in time t. In a simple optimum growth model the optimality condition for the allocation between consumption and investment is that λ_t should be equal to the value of an extra unit of investment or capital.

The social discount rate, ρ_t, at time t, is then the rate of fall of λ_t, that is:

$$\rho_t = -\frac{1}{u'} \frac{d}{dt} u' + \delta \tag{6}$$

This may be interpreted as the social discount rate – the rate at which the shadow value of a unit of consumption falls. Optimality, or the *Ramsey rule*, would require that this should be equal to the social rate of return on investment or the rate at which the shadow value of an extra unit of investment falls; in simple cases this will be equal to the social marginal product of capital. The intuition is that on the margin the return to

[8] For example, because climate-sensitivity turned out bigger than expected.
[9] It is possible to tell a story of a fixed income distribution but we keep it simple.

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allocating a unit of output to consumption or to investment should be the same.[10]

If $u(c)$ takes the special isoelastic form, i.e. $u' = c^{-\eta}$, this becomes:

$$\rho_t = \eta g_t + \delta \quad \text{where} \quad g_t \equiv \dot{c}/c \text{ at time } t. \tag{7}$$

Thus the social discount rate is equal to the elasticity of the marginal utility of income, times the growth rate, plus the pure-time discount rate.

The Ramsey formulation has been widely used, although the narrowness of the assumptions used to derive it often get insufficient attention. We should recognize, and this has all too often been overlooked or assumed away, that there are circumstances, with substantial probabilities, where g_t may be negative. Thus, as we have observed already, even in this narrow and often misleading framework we are quite likely to find negative discount rates.

The Ramsey formulation was presented and discussed in Appendix 2A of *The Stern Review*. That appendix also contained warnings about the unreliability of many of the simplifying assumptions: including that of one-good in relation to the important environmental services; uncertainty about future consumption; the possibility of decline for some individuals; endogenous population, and so on. These warnings appear to have been overlooked by many (see, e.g. Weitzman 2007a; Nordhaus 2008; International Monetary Fund (IMF) 2012: ch. 4). On the other hand, the Ramsey formulation has some usefulness in crystallizing some discussions of distributional judgements and some issues around infinite horizons, as we shall see below.

1.3 Attempts to base discounting on markets

The above discussion has already gone much of the way to explaining why it makes little sense in this context to try to derive implied social values for policy on climate change from market observations of rates of interest or return. Such attempts generally involve a whole series of mistakes. I set them out explicitly here because it is remarkable how tempting such a procedure has sometimes appeared to be (see, e.g. Weitzman 2007a; Nordhaus 2008; IMF 2012: ch. 4) in the context of climate change. I should note, however, that both Bill Nordhaus and Marty Weitzman are changing their approach in the light of an enhanced focus

[10] In formal analysis of necessary conditions for optimal growth following Pontryagin or Lagrangean methods, the Ramsey rule plays the role of the differential equation for shadow prices. The capital accumulation condition (consumption plus investment is equal to output) gives the differential equation on quantities. The transversality condition on long-run value of capital is discussed below. For a discussion of sufficient conditions for optimum growth, see Stern (1972b).

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on just how big the effects of climate change could be (see, e.g. Nordhaus 2011; Weitzman 2011).

Interestingly, 6% has occasionally seemed a popular[11] choice for 'discount rates': supporting arguments, which are mistaken as we shall argue, are sometimes based on medium- to long-term returns in rich countries (primarily USA) on risky financial assets such as shares. Assuming such a rate were to be applied over 50 and 100 years it would mean a unit of benefit being valued 50 years from now 18 times lower than now and, for 100 years, 339 times lower than now. It comes close to saying 'forget about issues concerning 100 years or more from now' – an ethical conclusion which is so strong that its validity requires examination. That is why it is so important to show how mistaken this approach can be.

The assertion that discount rates appropriate for application to long-run climate issues can be derived directly from observed market rates of interest or return can include some or all of the following errors. Some derive from implicit underlying modelling assumptions concerning the nature of growth or decline across many dimensions of goods and people, and others basic problems with the functioning and existence of markets.

Problems arising from underlying modelling assumptions

- Extrapolations from past rates of return involve the assumption that the past circumstances, including economic growth rates, for which those rates of return had applied will continue in a fairly similar manner into the medium- and long-term future. That assumption cannot be remotely plausible when the analysis of choice over climate change must cover the real possibility that in some circumstances the effects will be so severe (as described in Paper 1) as to generate great damage to livelihoods, severe dislocation for many, major conflict and substantial loss of life. In circumstances where future generations may be substantially worse off than ourselves there would be a powerful case (and see below) for discount factors (for the associated consumption good) less than one (extra units at some time in the future are seen as more valuable than now) and thus, over some periods for negative discount rates.
- The possible devastation of the natural environment by climate change indicates the possibility that the discount rate with environmental services as the numeraire could be negative. If we have postulated a high discount rate, possibly market derived and however mistaken that may be, with aggregate consumption as numeraire we must allow the possibility of a rapidly increasing

[11] For example, Weitzman (in 2007a) argued for 6% as consistent with a 'trio of twos'. Growth rate at 2%, pure-time discount rate at 2% and $\eta = 2$ – see equation (7).

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relative price of environmental goods, potentially at a rate much faster than the discounting. In practice this increasing relative price is likely to be forgotten.

- There is a potential for sharp deterioration in the distribution of income as a result of climate change – with the poorest being hit earliest and hardest. Thus taking a numeraire for discounting as aggregate consumption, whilst ignoring changes in income distribution, is likely to be misleading. Whilst relative welfare weights μ^{ht} might, or might not, be specified in the model for $t = 0$, their changes may well be overlooked.

Problems arising from functioning of markets

- Capital markets, particularly for the long term, have a whole host of familiar imperfections concerned with asymmetric information (including moral hazard and adverse selection), market manipulation, limited ability to carry risk by different parties, and so on. In these circumstances, the standard arguments that they reveal relevant marginal rates of transformation or substitution over time are weak.
- There is no substantial financial or other market that applies to collective decision-making over a century or two. Markets deal mostly with individual decisions over relatively short-term scales; the high end of timescales is perhaps 2 or 3 decades for mortgages or 4 or 5 decades for pensions. Thus the markets which might (if we forgot about the many other serious problems with the argument) give us guidance are not there.

Suppose we obstinately persisted in an attempt to derive discount rates for social evaluation in this context, notwithstanding these serious errors or problems, what would we find if we tried to get as close as we could to a relevant discount rate? Whilst I think it provides only limited guidance for the reasons already described, the closest one we could find in the markets would probably be the 'riskless' real rates on long-run government bonds. These are the longest-term amongst the options which might be available to individuals. Note that it is the riskless rate (nothing, of course, is completely riskless) that is relevant here since in most of the specific formulations in terms of an overall societal objective (see below and equation (3) above), risk is usually handled separately by taking expectations. Such rates for the UK and USA have generally been around 1.5% or so over 50 years, hugely different from 6% (see, e.g. data and analysis in Barclays 2011). Interestingly Weitzman (2007b) points out that the reason this may be so far below the long-run 6% on shares is the substantial riskiness in the shares, particularly in terms of 'weight in

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tails'; this is an important argument, interesting in its own right, but which appears to implicitly accept a riskless rate around 1.5%.

A common and longstanding line of argument on discounting in project appraisal is to use 'the opportunity cost of funds'. This is based on rates of return to investment on the grounds that, through the production process, a unit of investment can be turned to $(1 + r)$ next period if r is the rate of return. In this argument the discount factor would be $1/(1 + r)$ and the discount rate r.

This is clearly to use 'free investible funds' as the numeraire in defining the discount factor (see, e.g. Little and Mirrlees 1974). For a recent discussion in this context, see Posner and Weisbach (2010) or Gollier (2012). Investment is not an obviously useful numeraire for this context of possible long-term dislocation and where the questions at issue refer to major damage to individuals. One way of expressing the approach implicit in adopting this numeraire and 'hurdle rate' would be to say that we can make 'standard investments' reap the returns that market rates indicate, and 'buy-down' any climate damage resulting from climate inaction.

However, this line of argument suffers from many of the same problems described above. Long-term rates of return on investment might be negative in an environment where capital goods could be destroyed or where the investment process itself could have strong negative externalities in the damage it might cause. Shorter-term market rates might be poor guides to these longer-term, and possibly negative, rates. Further, the future prices of 'buying-down' environmental damage may be much higher than we anticipate now.

A recent high-profile paper by Arrow *et al*. (2013) recommends declining discount rates (DDR) for the USA, a procedure adopted in practice by the UK and France, in the context of long-term projects, including climate change and environmental issues. It also contrasts the discount rates based on using consumption and investment as numeraire. It treats the problem in large measure as one of uncertainty over discount rates. The broad conclusion of DDR is a step in a sensible direction. In bringing in uncertainty over discount rates, they contrast a 1% rate, such as we might see in long-term bond markets, and 7% market rates of return on (risky) private investment. They argue that if the two rates are equally likely then an equivalent path of year-to-year discount rates giving the same expected net present value would show DDR.

All this is broadly sensible as far as it goes, and set as it is in the context of crude aggregate public discount rates. But it does not go far enough and it does not start from the right theoretical foundations. On the former, the major uncertainty is over *outcomes*; future generations could be worse off. The paper argues correctly that the reason for standard approaches to discounting is that future generations are likely to be better

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off but then it fails to bring in properly the key uncertainties which are over future standards of living. On the second, they do not start from the original basics of the theory of shadow prices on which discounting is based. Thus, in their discourse, they lose the key points about multiple goods and changes in their shadow values, and fail to identify properly the issues around choosing consumption or investment as numeraire as described above. In this case I would suggest that choosing consumption as the numeraire is more helpful as the issues concern potentially dramatic effects on consumption and livelihoods and the focus should be these. It is more natural to choose investment as the numeraire in contexts where decisions focus on the allocation of investment within a public budget.

1.4 Attempting to specify or infer distributional values

Let us return to the narrow framework of the one-good model and the expression for the social discount rate in equations (6) and (7). In particular, in that context we discuss possible ethical approaches to the specification of the 'parameters' η and δ in (7). The formulation captures some issues of distributional judgements and pure-time preference in a clear and stark way; it is widely adopted and it is important to see how discussion over the choice of η and δ might be articulated and which arguments might be robust. Further, whilst the discount rate formula (7) does depend on the particular, and rather narrow, model structure, the principles and issues it embodies are more general. Pure-time discounting is discrimination by date of birth, and is a much more general notion than a particular form in the analysis preceding (7). Similarly, social values arise from discussions of the role of relative consumption, income or wealth in valuing relative increments to different people which are more general than, but reflected in, discussions of the particular isoelastic form embodied in (7).

For each of η and δ, 'thought experiments' can be useful. We take η first in this section and δ in the next. If I were to take η as 2, then I would value an extra unit to person A, who has consumption one-fifth that of B, 25 times as much as an extra unit to B; if η were 1 then 5 times as much (see the specification of the isoelastic form of utility following equation (6)).[12] Such thought experiments are sometimes expressed in terms of a 'leaky bucket' and this is a metaphor widely used in both economics and philosophy (e.g. Okun 1975; Stern 1977; Atkinson and Brandolini 2010, in economics; Page 2007; Broome 2009, in philosophy). In the example for B

[12] The isoelastic form (and only this form) has the feature that these relative marginal valuations depend only on relative incomes. Some, such as Serge Kolm, have questioned this feature on the grounds that we might worry little about distribution of income amongst the rich, even if some of the rich were a good deal richer than the others. See, e.g. Kolm (1969) 'The optimum production of social justice'.

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with consumption 5 times of A we could ask whether we would make a marginal transfer from B to A even if four-fifths of it were lost on the way. If the answer is 'yes' then η is larger than 1. Such a discussion can directly inform a choice of η.

There have been various attempts to try to assemble evidence from some public or collective decisions involving distributional judgements in such a way as to throw light on what η might summarize the values behind such decisions. To infer values from decisions in a formal way we have to consider an 'inverse optimum' problem: for an observed decision, we ask what values (here η) in the objective function would be consistent with that decision. A great difficulty with this approach is that, for it to be usefully informative on the implied ethical position, we have to have a plausible description of what is in the mind, or collective minds, of the decision-maker(s). And in the latter case we have to argue that the decision of a collective, community or nation can be plausibly modelled as if it were a single optimizer.

When we model policy problems as if they involve maximization of some objective, we specify the constraints and incentive structures assumed or perceived by the policy maker. For example, we have to make assumptions in discussing the setting of taxes, concerning how people react to higher or lower taxes. All of us who have worked in this area of formal public economics know how difficult it is to write down plausible descriptions of reactions by individuals to tax or transfer changes, or in other words the structure of incentives or disincentives.

Stern (1977) and Atkinson and Brandolini (2010) have provided fairly extensive reviews of tax/transfer 'evidence on η', at more than three decades apart. They both conclude that there is a huge range of possibilities depending on the case studies used and assumptions made about perceived technologies, constraints and incentives. There are many examples of proposed social values, where η would be close to zero – many people appear to think that a dollar of purchasing power or income has the same value wherever it may be. Al Harberger famously argued, in discussing cost-benefit analysis in seminars in Oxford that I attended in the late 1960s, that 'a dollar is a dollar is a dollar', on the grounds that it can be moved around.[13] Atkinson and Brandolini (2010) point out there are examples where an attempt to use an inverse optimum problem to 'explain' income transfer policies could make it look as if η were negative: cases where policies essentially transfer resources from poorer to richer.

Some discussions of the problem of inferring η have been based on individuals or collective savings. Dasgupta (2008), for example, appeals to

[13] That, of course, abstracts from or ignores all the problems of asymmetric information (the taxpayer knows much that the government does not) which motivate the theory of income taxation à la Mirrlees.

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certain simple aggregative savings models without technical progress and concludes that η should be at least 2. But again we find acute sensitivity of the estimate to model assumptions. In savings models for example, if we assume exogenous technical progress, then we will have a far lower 'optimum' savings rate for a given η than without (see, e.g. Mirrlees and Stern 1972; DeLong 2006; Dasgupta 2007; Stern 2008). Thus to 'explain' a savings rate of 30–40% we could infer η equal to 1 or 1.5 with exogenous technical progress or η equal 3–4 without.[14] For further discussion of the role of such technical progress in inferring values, see the next sub-section on pure-time discounting.

A further attempted route at 'η inferral' has been associated with standard models of choice under uncertainty where in expected utility frameworks, η is the index of relative risk aversion (constant in this case).[15] In that context we can again find ηs that range from negative to very large: there are many who accept unfair gambles (thus a convex utility function over some range and, in this framework, negative η) and others who appear very risk-averse for some decisions (high η). We should note, however, that the expected utility model appears to perform badly as a vehicle for understanding many individual decisions (see, e.g. Kahneman and Tversky 2000; Ariely 2008; Slovic 2010).[16] Thus the risk/uncertainty route does not offer much help either in attempts to pin down η via an appeal to inverse optimum approaches.

Nevertheless it seems to remain attractive to some. Barro (2013) has recently claimed that analysis of the 'equity premium' in portfolio analysis tells him that η is around 3. Weitzman (2007b) appeared confident that 2 was a reasonable specification for η. Interestingly, Weitzman (2009) has shown that the equity premium equity can be understood in terms of strong weight in the tails on equities, i.e. results are strongly influenced by assumptions on the underlying distribution of random variables. Such discussions illustrate that an estimate is very sensitive to assumptions about what is in the mind of the decision-maker even if, in the case of uncertainty, we claim that the expected utility model, or other such model, is a good one.

A further major ethical leap is involved if, in the case of uncertainty, we try to pass from individual decisions under uncertainty to social

[14] Actually, the technical progress does not have to be exogenous. Similar results would follow from endogenous long-run technical progress.

[15] This means, if the model involves the maximization of expected utility, that an individual would be willing to pay the same proportion of wealth, β, to insure against a given proportional loss, α, regardless of the level of income. In other words, β depends on α, but not on income.

[16] The many difficulties are compounded if we distinguish along Knightian lines, between uncertainty where probabilities cannot readily be specified and risk where they can be; see Stern (2007: 38–39).

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decision-making. The relevance of the former for the latter has to be reasoned and it is not at all clear. That problem is less severe if the inferral is from the modelling of government decisions.

In the models often used in the context of climate change, η can perform three functions: (i) for modelling choice under uncertainty; (ii) for modelling intratemporal distributional issues; and (iii) for modelling intertemporal distributional issues. This is surely 'too much' for one parameter, itself located in one particular utilitarian structure. Treating the issues separately but consistently is an important subject for research with applications beyond climate change. The multiple roles of η in analyses of growth, inequality and risk aversion is illustrated by the effects of higher η in the context of growth and risk in some of the calculations associated with *The Stern Review* and subsequent discussion. If impacts of climate change involve great risk, a higher η will place greater weights on future risks, but a higher η will place lower weight on the future if underlying growth of incomes is assumed. An illustration of the interaction of these growth and uncertainty effects is provided in *The Stern Review* (Stern 2007: Technical Appendix to Postscript). With underlying growth and some given assumptions on the riskiness of the future, a higher η gives higher implied (proportional) costs of climate change because it involves greater aversion to risk, but if the future is taken as less risky, a higher η gives lower implied costs of climate change because its greater aversion to inequality puts less weight on benefits to future generations and thus heavier discounting.[17]

With the huge range and great sensitivity of estimates to assumptions, we should beware taking strong positions on what η is revealed to be or should be. However, some, such as Dasgupta (claiming η should be well above 2) (see Dasgupta 2008) and Layard (η around 1) (see Layard 2005; Layard *et al*. 2008), have been willing to do so. We have already noted that Barro appears convinced it is around 3. In *The Stern Review* from the UK Treasury (Stern 2007) we focused on η equal to 1 as an 'official position' (see 'Green Book', the Treasury's handbook on project appraisal).[18] That a number is 'official' does not by itself add greatly to its credibility as an attractive ethical standpoint. We did offer some sensitivity analysis to η in *The Stern Review* (see Stern 2007: Technical Appendix to Postscript).

There is a separate question here on what the status of a value for η might be in an ethical argument even if we found that many distributional social decisions (whether intra- or intertemporal) could be 'explained' by some given value of η. Would that level of η be compelling as a way of capturing values for climate decisions? That is not entirely clear. I note

[17] See also the discussion around Table 2 in Stern (2008).
[18] See: http://www.hm-treasury.gov.uk/data_greenbook_index.htm.

here only that estimates of ηs in inverse optimum problems are 'all over the place' and thus offer little guidance.[19]

Some might argue that it would be better to avoid all the η-inferral discussion, whether or not it gives clear results, and ask directly about values in relation to the climate problem at hand. In my view that is too sweeping. Distributional values do matter greatly and are not easy to characterize. Thus it sometimes helps to think these values through in a structured way in simple, tightly defined circumstances in order to reflect on them and understand them better. One can then ask whether those thought processes can help us in setting values for a more complex problem.

I have already expressed the view that, for climate change, with its huge range of possible outcomes, many of them potentially extremely difficult or catastrophic, the expected utility one-good framework can have only a minor role in the argument. It can give some useful insights but we should not overly focus on it. An economic approach to the problem, which grapples in a way that recognizes the magnitude of the scientific and ethical issues at stake, which has to look at many dimensions of outcomes, outcomes where people can be much poorer than now, where there is loss of life, where there are very different impacts across the income spectrum, where there is loss of biodiversity and so on, was described in Paper 1.

Distributional values involve difficult ethical questions and with climate change they are particularly severe and can involve catastrophic outcomes and loss of life on a major scale. Such questions require open discussion. That explicit ethical discussion should be set in the context of analytical frameworks appropriate to the problem and not confined to narrow formulations simply on the grounds that we are familiar with them.

1.5 Pure-time discounting

The specification of a pure-time discount rate (δ in the simplest form in equations 4–7) raises questions which go way beyond that particular narrow formulation, and are of a different nature to those concerning η which focus on how relative incomes might influence welfare weights. In discussing pure-time discounting we focus on how we treat the status of different lives in an ethical analysis, rather than on the allocation of livelihoods. The questions concern a set of issues of great significance: the ethical relations between the decisions of this generation and their

[19] See also Stanton (2011) for a discussion of using Negishi weights, which essentially stop the Integrated Assessment Models from trying to redistribute income to poorer people at any one moment in time.

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consequences for the circumstances and well-being of the following generations. We must recognize, of course, that many of those who would be radically affected 50 to 100 years from now by our current decisions are not abstract, possible, future lives: many of these people are already with us. Generations overlap. How can we discuss views concerning these profoundly important ethical issues?

If we take the simple formulation of the objective as an expectation, (3), or the still simpler version (4), we can see what might appear as discrimination by date of birth as actually counting generations equally but allowing for some probability of exogenous annihilation of the world, or at least exogenous to decisions on climate change. If survival were an issue, we might weight the contribution of the social utility at time t by the probability of the world not being annihilated by then. If annihilation, think of it say as a meteor, arrives[20] in period t to $t + \Delta_t$ with probability $\delta\Delta_t$, then the probability of survival to t is $e^{-\delta t}$. That is a clear and understandable reason for a formulation that looks like 'pure-time discounting', which might command wide agreement.

But discounting the welfare of future generations *beyond* that reason, in the context of using a formulation of an objective as in (3), looks like discrimination simply because of date of birth. We would not be doing it because of doubts about existence: that has already been covered in the arguments just made. And it is quite separate from marginal valuations which depend on the level of consumption or wealth: that comes into the social utility or welfare at date t, and is covered in the utility function, u( ), in simple cases. We are concerned here with the discounting of welfare itself, in other words, discounting lives.

Continuing to stay in the context just described, there seem to be three types of argument, beyond that of the probability of existence, which are on offer as attempts to justify pure-time discounting: (i) moral behaviour should prioritize those closer to us; (ii) people actually do not seem to care about future generations as much as their own and that tells us what their moral position actually is; (iii) technically we get into problems of incompleteness of orderings or non-convergent integrals in expressions of objectives in standard forms in economics such as (3) or (4) if we do not allow pure-time discounting, or if it is very low. None of these, in my view, holds water as a justification for pure-time discounting. We examine them in turn.

The first argument has often been associated with David Hume of the 'Scottish Enlightenment' in the 18th century; of course, just because a great philosopher has taken a position does not itself make that position compelling. In developing this first argument one could suggest that much of moral behaviour is, or should be based in, and defined by family

[20] This is essentially the first event in a Poisson process in this model.

life and those closest to us, and that any understanding of good behaviour must start there. A functional or evolutionary underpinning might be involved in the sense that it could be argued that societies where people devote themselves first to family can function better or survive better than those where they do not. But arguments concerning better functioning of a society or higher probabilities of survival of a group seem to have minimal functional or evolutionary relevance to the question of how far to imperil the whole planet – that is more like a one-shot game.

However, a more careful reading[21] of Hume indicates that he was well aware of the problems of individuals' impatience and that he saw 'governors and rulers' as being needed to overcome them, as these excerpts from 'Of the origin of government' illustrate (Hume 1888 [1739]). In discussing 'my' resolution to do the right thing ('prefer the greater good') 12 months hence, he notes that as I approach that time:

> A new inclination to the present good springs up, and makes it difficult for me to adhere inflexibly to my first purpose and resolution. This natural infirmity I may very much regret, and I may endeavour, by all possible means, to free myself from it. I may have recourse to study and reflection within myself; to the advice of friends; to frequent meditation, and repeated resolution: And having experienc'd how ineffectual all these are, I may embrace with pleasure any other expedient, by which I may impose a restraint upon myself, and guard against this weakness. (Hume 1888 [1739]: 536–537)

And a few lines later, he continues:

> Here then is the origin of civil government and society. Men are not able radically to cure, either in themselves or others, that narrowness of soul, which makes them prefer the present to the remote. They cannot change their natures. All they can do is to change their situation, and render the observance of justice the immediate interest of some particular persons, and its violation their more remote. These persons, then, are not only induced to observe those rules in their own conduct, but also to constrain others to a like regularity, and enforce the dictates of equity thro' the whole society. (Hume 1888 [1739]: 537)

It seems that, far from asserting the moral significance and ethical attraction of pure-time discounting, Hume was arguing the opposite. And, like Rawls and Sen, he emphasized the importance of seeking a greater objectivity and morality through a more remote decision-making process which promotes the 'greater good', which treats the future with less apparent impatience or disdain, and sees the possibility (perhaps optimistic) of 'civil magistrates, Kings and their ministers, our governors and rulers' as performing that function (Hume 1888 [1739]). It is clear

[21] I am very grateful to Cameron Hepburn for drawing this to my attention.

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that in his view decision-making for the collective good is very different from narrow individual decision-making. In his use of language such as 'infirmity', 'narrowness of soul' and 'weakness', Hume seems to be counselling strongly against the use of heavy discounting (based on short-term preferences) and in favour of embodying much longer-term perspectives, and much lower discounting, in values and processes, thereby encouraging 'better' individual behaviour.[22]

The second argument, i.e. 'that's the way people are' is also deeply flawed in my view. In trying to understand ethical issues and identify ethical criteria and responses we often examine, with one another, key questions and principles. We do this to try to inform a discussion and to help public reasoning (Sen's language).[23] It would seem strange to say that group decisions must be taken, implicitly or explicitly, by some sort of vote or diktat which is uninformed by any attempt to reason together on the issues at hand. If that discussion is indeed opened, as it should be in my view, then we should try to identify what principles should and can be of help and arguments that might be considered. John Stuart Mill (1909 [1848]) in particular has reminded us of the importance of discussion in shaping our views: public reasoning does not simply concern facts and mechanisms but also helps in shaping our understanding of values. That is a tradition for which Sen has argued powerfully in a number of contexts, including in *The Idea of Justice* (2009).

Perhaps even worse is an argument that says this generation has an unfettered right to impose its own views on future generations and damage their environment in any way it thinks appropriate having taken account of how much it happens to value their well-being. That would be the consequence of saying that the right thing is whatever current voters decide. Would we think it right that we knowingly harm children in pursuit of current pleasure if so decided by current voters? I hope that for many the answer would be 'no'. Then why would we think it right, on the basis of a decision by current voters, to knowingly harm now their future welfare?

A third argument has tempted some economists. It arises in one class of mathematical formulations and models and is generally associated with a tendency of such models to produce very high savings rates or recommendations for (possibly indefinite) consumption postponement.

[22] It would be interesting to speculate, as Christopher Bliss has remarked in a private communication, how far Hume would have seen other parts of the world as having important 'weight'. Some in the 'enlightened era' might have optimistically supposed that nations, as they 'learn', would become more similar and 'one of us'; they might have supposed that until they do they have less importance. Not an argument that would attract all of us now, from the perspective of common humanity, even if it might have been seen to be relevant by some then.

[23] Sen (2006, 2009).

Specifically we find that in some of these models an infinite integral over time diverges unless we assume a substantial pure-time discount rate. In a simple neo-classical growth model with growth rate, n, of population, N, and exogenous labour-augmenting technical progress at rate, α, it is easy to see (by examining the integrand $Nu(\frac{C}{N})e^{-\delta t}$, where C is total consumption) that convergence of the infinite integral requires:[24]

$$\eta\alpha + \delta > \alpha + n \tag{8}$$

This same inequality guarantees that $\lambda_t K_t$ tends to zero, the 'transversality condition' for optimum growth, i.e. that the shadow value of the stock of capital should tend to zero.[25] The intuition is that if the shadow value of the capital stock diverges we would effectively be accumulating capital inefficiently or postponing indefinitely: the social value of capital at time T is the future utility stream it can yield and, with convergence, that present social value should decrease. It is an analogous argument to that which applies in a finite horizon model, where we would try to use up everything by the end of the period. See, e.g. Stern (1972b) for a discussion of necessary and sufficient conditions for optimality in such models.

The Ramsey rule (see discussion of equations (6) and (7)) for optimality tells us that the long-run marginal product of capital and the long-run social discount rate, $\eta\alpha + \delta$, tend to equality. Note also that the marginal product of capital which maximizes steady-state consumption per head is equal to the rate of growth,[26] $(\alpha + n)$. If condition (8) were to fail, then the Ramsey rule would take us in the long run to marginal products below and capital stocks above the levels which maximize long-run consumption per head. In other words, we would be inefficiently building up excess capital: the only paths satisfying the Ramsey rule, a necessary condition for optimality, would be inefficient in the sense that more consumption in some periods with no loss in others would be possible. And they would fail to satisfy the transversality condition. The failure of (8) implies that no optimum exists. If $\eta > 1$ a higher α makes existence and convergence more likely because the discounting effect on the left-hand side of (8) is then larger than the effect through the marginal product of capital on the right-hand side. Basically the Ramsey rule plus

[24] In the long run, N grows at rate n, utility of consumption per head at (1-η)α and the sum of these two rates must be less than δ for convergence of the infinite integral. And see Stern (2007: Ch. 2A).

[25] Asymptotically, λ falls at rate $\eta\alpha + \delta$ from (7) since α is the long-run rate of growth of consumption per head and K grows at rate $\alpha + n$. For convergence of λK the former must exceed the latter.

[26] With a production function F(K,Ne$^{\alpha t}$) writing $\hat{c} = C/Ne^{\alpha t}$ and $\hat{k} = K/Ne^{\alpha t}$ we have in steady-state when $\hat{c}$ and $\hat{k}$ are constant $\hat{c} = f(\hat{k}) - (\alpha + n)\hat{k}$. Maximization of $\hat{c}$ with respect to $\hat{k}$ gives $f'(\hat{k}) = (\alpha + n)$, where $f(x) \equiv F(x, 1)$.

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the transversality condition (here taking the form of (8)) are necessary and sufficient for optimality in this type of model.

In the case of divergence of the integral, the intertemporal optimization, here embodied in the Ramsey rule, is constantly pointing to postponement. As parameter values take us closer to the divergence boundary (equality in (8)) we will see higher savings rates emerging as 'optimum'. Some take this as an ethical argument for strong pure-time discounting. In other words they use an 'inverse optimum' approach: we do not see such high savings rates therefore people or societies must have high pure-time discount rates – they have 'revealed their values'. Or, some have argued, such very high saving would 'penalize' current generations heavily and therefore there may be something ethically wrong with the assumption of low or zero pure-time discounting. Thus, 'oversaving', 'divergence of integrals', 'incompleteness of ordering' (see below), and non-existence of an optimum are very closely related.

But these problems might be telling us something about the perceived structure of the model, for example, that the perceived long-run rate of technical progress should be high; the term $\eta\alpha$ on the left-hand side of (8) is discounting that arises from the combination of growth, α, and the inequality aversion parameter, η. Or pointing to higher η. Or it may be suggesting that the whole model structure, including the framework of an infinite integral, is misleading. Whilst horizons may be long are they really infinite in the formal sense we use in the mathematics? And the centrality of condition (8), which compares long-run social discount rates with long-run growth rates, should remind us this approach is unlikely to tell us much about pure-time discounting: in the context of climate change we are really very unsure about what long-run growth rates of population might be and we have little idea of what long-run exogenous technical process might be when the physical environment may change radically. They could both be negative. Indeed, the whole idea of exogenous growth in this context is implausible (see Stern 2013).[27]

There are genuine arguments concerning why we do not postpone consumption an indefinitely long time into the future, including the possibilities of extinction and of technical progress (α could be the result of endogenous technical progress). Divergence or otherwise of integrals does not illuminate the issues greatly. Note also that we do not show a willingness to pay an infinite sum to reduce the probability of a large number of deaths. Neither does such a willingness seem to be demanded by a consequentialist code of ethics. Indeed, it would make many of our decisions very difficult to assess and manage. Generally, we know that there are many mathematical and other paradoxes associated with various formulations of the idea of infinity and they do not necessarily throw great

[27] See also Stern 2007: Appendix to Ch. 2, for some further discussion.

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light on intertemporal values.[28] The apparent tension between 'needing' a high δ for convergence of integrals and avoiding strong postponement on the one hand and the ethical difficulties of discrimination by date of birth associated with a high δ on the other could be telling us that there is something troubling about looking only to this ethical framework to examine allocation across generations.[29]

We should also remember that these models are narrowly one-good and have no uncertainty. Any apparent tensions would have to be examined in frameworks which take account of these issues and again further dimensions for 'resolving these tensions' could arise.

A fourth and related argument is based on an axiomatic approach to intertemporal welfare evaluation. There is a useful recent review in Asheim (2010); see also the book by Blackorby *et al*. (2005). This literature draws heavily on the early piece by Diamond (1965). Diamond[30] examines utility streams in an infinite horizon framework. He shows that the assumption of *both* 'equal treatment' (in the sense of a time re-ordering of a finite number of utilities being neutral) *and* 'sensitivity' (higher utility at any time point increases welfare) is inconsistent with a preference ordering which is complete and continuous. He was considering an individual assessing different infinite streams of instantaneous utilities but the result naturally carries over to the case of social welfare functions and the social evaluation of the utilities of a stream of future generations. These are essentially the results examined in a series of papers on social evaluation by Basu and Mitra (2003, 2007), which is driven by the same logic as the Diamond result (with some strengthening of the theory). In the case of social evaluation, the assumption of 'equal treatment' (also called 'finite anonymity') rules out pure-time discounting, and 'sensitivity' corresponds to the assumption that a Pareto improvement increases social welfare.

What goes wrong, in the sense of absence of completeness of an ordering, concerns the ranking of the infinite temporal tail, which behaves like a divergent integral. Essentially trying to compare divergent integrals is trying to rank infinities of the same order and that can lead to

[28] Infinity can open possibilities for a Pareto improvement by bringing consumption forward. In an overlapping generations model, the first generation can be made better off by a gift from the second, which can be compensated by a gift from the third, and so on.

[29] And remember that even within that framework η, α and n also play a role in inequality (8) so we could examine the postponement problem in principle via these parameters too and not put the focus only on δ. But I think the framework itself is too narrow.

[30] This builds on Koopmans (1960) and Diamond (personal communication) attributes the observation to Menahem Yaari.

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incompleteness (unless we are dealing with different orders of infinity such as aleph 0, 1, 2, etc., which is not the key point here).[31]

Some might be tempted to say that we have to abandon the assumption of 'equal treatment' and go for pure-time discounting (discrimination by date of birth), thus getting convergent integrals, if the discounting is strong enough, and a complete ranking. But this argument appears arbitrary. If a collection of assumptions is inconsistent, and you seek a consistent set, which one(s) do you drop? Amartya Sen has made this point over many years in his discussion of social choice theory (1970a, b, for example) and it is a clear theme in his recent book, *The Idea of Justice* (Sen 2009). And as Diamond argues (private communication, July 2013), 'The goal is to answer a policy question. If a good criterion answers the question (compares the relevant alternatives), that is the end of the story. If the criterion does not answer the question, one needs further thought.' For example, incompleteness relative to some parts of the domain of choice does not invalidate a criterion.

Asheim (2010) makes an interesting point in this context when he shows, with a 'condition of immediate productivity', that the (strong) Pareto and finite anonymity axioms imply that generation by generation, utility should be non-decreasing, in other words be sustainable in the formal sense defined in Paper 1. In the context of climate change and a potentially destructive environment we cannot assume that in all circumstances all investment can be productive. Capital and other stocks can be destroyed and thus returns on investment may be negative.

This line of argument based on investigating the consistency or otherwise of sets of axioms for integrated social choice is interesting and valuable. But it does not tell us that we should discriminate by date of birth simply on the grounds that some sets of assumptions lead to divergent integrals and incomplete orderings.

Interestingly, the rejection of pure-time discounting has been frequent amongst many economists who have thought carefully about this issue. Frank Ramsey (a philosopher and mathematician, as well as an economist) described pure-time discounting as '… defective imagination …'. Roy Harrod and John Maynard Keynes agreed.[32] So too have some of the great economists of recent times such as Bob Solow or James Mirrlees, and the philosopher and economist Amartya Sen. They have seen no strong reason why we should discriminate across generations by date of birth and thus have seen no reason for pure-time discounting. Allowing for

[31] One can attempt to rank divergent integrals using an 'overtaking criteria', see, e.g. Asheim (2010) for literature references. But this can deal with the problems only when the integrals are on the 'borderline' of divergence: in the simple one-good growth framework when the inequality in (8) holds with equality (see, e.g. Mirrlees and Stern 1972; Stern 1972b).

[32] Ramsey (1928); Harrod (1948).

the probability of existence gives rise to a similar formality but it is a different ethical issue. Of course, counting heads of proponents, even if very distinguished, is not necessarily a good way to evaluate an argument, but it does suggest that low or zero pure-time discounting is a considered position and not some capriciousness, regal edict or assertion without explanation.

It is, however, the arguments that matter. I have tried to show that attempts to justify pure-time discounting as a moral position generally flounder when scrutinized carefully. It is those who try to argue that high pure-time discounting is somehow 'pragmatic' that do the 'asserting', without robust or sound and reasoned justification. They generally (apart from invoking a weak position often wrongly attributed to Hume, who actually strongly questions it) appeal to one of two arguments: (a) people just do it (i.e. exhibit impatience); (b) some models 'go wrong' in terms of strange conclusions if we make, together with other ethical assumptions and some structural assumptions in the model, the further assumption that pure-time discounting is zero or low. The former surely has weak ethical status since it is rarely a considered response to an ethical question. The latter, as we have argued, should be seen as saying that there may be something wrong or missing from the models, or problems with other ethical assumptions, rather than necessarily implying strong statements about pure-time discounting; and we have gone further and shown that the assumptions concerning growth and decline and how they are endogenous to our choices may be critical assumptions for scrutiny. So too would be the heavy emphasis on taking literally the mathematical formulation of infinity. And if the 'problem' that 'goes wrong' is incompleteness, that may be something we can or should live with.

Low or zero pure-time discounting on the other hand is derived from consistent application of ethical principles which are transparent and widely used and explained in broader contexts than climate change. Equality of treatment and non-discrimination, under the law and in connection with human rights is basic to many constitutional or legal structures. Harsanyi (1953, 1955) embodies the idea in his 'impersonality' principle as does Rawls in his 'Veil of Ignorance' (Rawls 1971). Low or zero pure-time discounting simply applies the idea to date of birth (see also Quiggin 2012, for a formal proof in standard models with social welfare functions and overlapping generations, that equal treatment of those currently alive at any point in time requires zero pure-time discounting).

Putting the analysis of the one-good growth model together with the axiomatic treatment of Diamond, Basu-Mitra, Sen and Asheim, we see that they are telling very similar stories. Condition (8) and its derivation embodies the essence of most of the relevant lessons from infinite horizon growth analyses. They give us the intuition behind: (i)

how non-convergence of infinite integrals can arise; (ii) warn us that convergence depends on long-run parameters such as exogenous growth rates of population and productivity, which in the case of climate change are unlikely to be exogenous and could be negative; (iii) warn that if we look for optimum growth, these are the same parameter constellations that would prevent existence of an optimum; (iv) explain how the non-convergence or non-existence of an optimum arises through consumption postponement; (v) explains that the case of zero α can over-simplify intuition in a misleading way because with zero α, (8) becomes $\delta > n$ and the focus, particularly if n is assumed zero, becomes on δ the pure-time discount rate; with non-zero α, both n and α are relevant (and remember that a long-run α could arise from endogenous technical progress, it does not have to be exogenous here, neither does it have to be positive).

Thus condition (8) and its derivation go to the heart of a number of issues and illustrate, *inter alia*, the point that if a model produces difficult or inconsistent results we have to look at its whole structure and not just one parameter (here δ). And we should question, as we have emphasized in the context of climate change, one-good, exogenous technical progress, exogenous population growth, and the absence of uncertainty. We must ask, moreover, whether the particular expression of infinite horizons in the mathematical sense we use may be equivalent to the tail wagging the dog. It is the practical policy challenges of the next several decades which are at issue. The consequences for the next few centuries really do matter but that does not mean that our modelling parameters and ethics should be driven by the peculiarities of the convergence of infinite horizon integrals.

1.6 Concluding comments for intertemporal valuation

We have seen that the context of climate change, in particular the potential breadth of the effects across the whole of economic and social life, the potential scale, and the length of the time periods involved, requires us to take care to define the intertemporal and intergenerational issues in corresponding breadth, scale and time period. There is no serious alternative to framing the problem as the management of immense risks, to make our discussion of the ethics explicit and to put at the centre of that discussion the key issues associated with the scale of risk including potential large-scale environmental destruction for future generations, conflict, great poverty, major differential impacts across countries and groups at different points of time and substantial loss of life.

Lest I be misunderstood, let me be clear that I think that narrow aggregative models, be they in growth theory or Integrated Assessment Models of the standard kind often used in this area, have a contribution to make. But the contribution is modest and only one part, and not

necessarily the major part, of an argument. Further, as I have argued in Stern (2013), the Integrated Assessment Models have generally grossly under-estimated risks from climate change and thus should not be seen as a central case; they are more like extreme cases; 'what might happen if we are very lucky'.

Nevertheless, the type of models examined above can be useful simple vehicles for bringing out some of the key elements of a discussion, including intertemporal and intratemporal values and some structural growth features or assumptions. That is why it matters that we show that within this narrow framework there are important details that are all too often confused, or plain wrong, in the economics literature on ethical values and discounting. That is why we have devoted space to trying to clarify them. These have included, in particular, inferring discount rates from market rates of interest and return, and the issues around pure-time discounting.

There has been some very interesting discussion in economics of discounting which does not commit the mistakes described here and which explores important questions. For recent innovative papers see, e.g. Guesnerie (2004) who focuses on particular aspects of 'more-than-one-good' and Sterner and Persson (2008) who incorporate changing relative prices.[33] See also useful discussions by Cline (1992), Jamieson (1992), Sagoff (2004), Dasgupta (2011) and Ackerman and Stanton (2012). It is not the purpose of this paper to review all such arguments. I have tried to focus attention on those intertemporal issues where difficult and important ethical perspectives should enter most strongly into economic debate. And there are, of course, valuable approaches to intergenerational issues which go outside the standard social welfare approach as we saw in Paper 1. For example, there is an interesting discussion of intergenerational justice by Barry (1999) on the basis of responsibility for our actions and basic needs or vital interests of future generations.

There is so much economists can contribute to public discussion of intertemporal issues by applying their experience of the analyses of key intertemporal questions and the broad range of analytical tools at their disposal. But we must heed Sen's warning:

> If informed scrutiny by the public is central to any such social evaluation (as I believe is the case), the implicit values have to be made more explicit, rather than being shielded from scrutiny on the spurious ground that they

[33] See also Neumayer (2007) for a discussion on the loss of non-substitutable natural capital as a justification for climate action. And there is an interesting literature on hyperbolic discounting (where later discount rates are assumed lower than near-term rates), although that has generally been focused on behavioural psychology, addiction, etc. rather than ethics. Arrow *et al*. (2013) discuss diminishing discount rates motivated by uncertainty over which discount rates to use.

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are part of an 'already available' metric that society can immediately use without further ado. (Sen 1999: 80)

PART 2. ECONOMICS AND ETHICS OF EQUITY AMONGST PEOPLE AND NATIONS

2.1 Distributional ethics and the nature and scale of the necessary transformation

Many academic economists in rich countries jump quickly to the assumption that ethics and equity in the context of climate change concern primarily intergenerational issues and discounting. On the other hand, when those in developing countries focus on equity in the context of public discussion and in international negotiations, the most prominent questions concern who cuts emissions by how much and when and who contributes what in terms of finance and technology. The background to much of this discussion is that the rich countries got rich on high-carbon growth and are responsible for around half of the CO_2 emissions since the mid-19th century. They constitute around 1 billion of a world population now around 7 billion. Developing countries, with currently around 6 billion people, as they grow more rapidly and fight to overcome poverty, are likely to be responsible for the bulk of future emissions.

Many in the developing world argue that it is inequitable that they should make substantial cuts in emissions, and possibly slow their growth, when the difficult starting point is largely the responsibility of rich countries and those countries have the wealth and scientific expertise and technologies to pioneer new approaches. They argue: 'shouldn't the rich countries first make drastic cuts themselves and bear the bulk of the extra costs the developing countries will have to incur to cut emissions?' Much of this language is embodied in the framework of the UNFCCC with its emphasis on 'common but differentiated responsibility'. And it is reflected in the division of the Kyoto Protocol into rich countries ('Annex I'), which were required to meet quantified emissions reduction targets, and developing countries, which were merely required to develop national or regional plans containing unspecified measures to mitigate and adapt to climate change. Rich countries were responsible for meeting the 'full incremental costs' incurred by developing countries in implementing those measures.[34] Many have stressed the importance of a 'legally binding' agreement, as Kyoto was, at least in principle, particularly in the context of rich country obligations. In my

[34] 'Common but differentiated responsibility' (United Nations 1992: art 3; United Nations 1998: 9). 'Full incremental costs' (United Nations 1998: arts 4(1), (3)).

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view the language is problematic as sanctions for breaking the agreement were not very credible.

Given the responsibility for past emissions, given that poor people are hit earliest and hardest by climate change, and given that all must be strongly involved if emissions cuts on the necessary scale are to be achieved, we should ask how we can examine various ethical positions in ways which could help structure the policy debate and the framework of international understanding. The challenge is not simply to make interesting observations about ethics. A clear discussion of the ethics and an understanding of the consequences of different priorities is of great practical importance both to the international discussions and to the perception of the right way to act by particular countries. Understanding by participants of what is or is not equitable will have, and has had, a profound effect on the negotiations and has shaped the potential for agreement and disagreement.

Before we describe briefly some of the cross-country data on emissions, which is key background to an ethical discussion, we should also emphasize the importance in this context of assumptions about the necessary scale and nature of the response in terms of emissions reductions, the kind of changes that are likely to be involved across the economy, technical progress and how it emerges, and the scale of the necessary investments and costs. A failure to understand the scale and nature of the necessary response, and the process of dynamic learning which must be at its heart, has distorted the ethical discussion. In particular, a narrow formulation of the basic production processes, which models a switch to lower carbon activities as simply switching to technologies with higher input-output coefficients and costs, leads to a framing of the discussion in terms of a permanent sacrifice of living standards to protect the environment. It thus pushes the ethical questions towards 'who bears the incremental cost?' and can lead to a presentation of the issues as being largely about 'burden-sharing'.

That is a language much loved by international bureaucrats but we know in economics that confining equity discussions only to the division of a pie can badly miss fundamental issues. Sadly it is often Ministries of Foreign Affairs in particular that seem locked into such language as encapsulating 'the protection of our interests'; in other words they tend to see negotiations as defensive and a zero-sum game. The challenge here is to find ways of handling climate change that provide, and are understood to provide, very widespread benefits across peoples and over time. And given the nature of the problem and the potential attractiveness of alternative paths, we can do just that. The ethical issues look very different and much less vexing if we carry that understanding of the nature of the problem into the analysis: on the one hand, this is about externality, market failure and inefficiency on a massive scale, and, on

the other, the response is about discovery and co-benefits in terms of a more secure, safe, clean and biodiverse way of consuming and producing. There will be initiatives to be launched, investments to be made and costs to be borne, and who does what and when matters greatly. But to focus relentlessly and narrowly on the notion of 'burden-sharing' risks undermining both understanding and agreement.

However, there is a different way of understanding the transition which is, in my view, both more accurate and more positive. This focuses first on the dynamic nature of the economic transformation, second on the co-benefits of new and cleaner technologies over and above reduced emissions, and third on the benefits of collaboration. The first includes the learning and discovery which characterizes industrial revolutions and the second, benefits such as cleaner air and water, more energy security and more vibrant and productive ecosystems. Understanding the transition in this way could radically reduce the risk of 'free-riding', a notion much beloved both by the game theorists and those who seek an excuse to do very little. Relative to the gloomy, free-riding, view of the world, it is remarkable how many countries are willing to act without detailed international agreement; because they see the dangers, they believe it is responsible behaviour to contribute to a response and they see the attractions of an alternative path. The willingness to act is strengthened if there is an understanding of the measures that others are taking – better knowledge of what others are doing and discussing is a key factor in individual and mutual action.

We have already examined in Paper 1 the emissions reductions which are necessary to achieve a 50–50 chance of holding to a 2 °C increase relative to the 19th century. Global emissions have to be cut from around 50 billion tonnes CO_2e per annum (p.a.) now to below 35 in 2030 and well below 20 in 2050 – a factor of 2.5 between now and 2050. That means, assuming the global population moves from around 7 billion now, to 8 billion in 2030, to 9 billion in 2050, global emissions per capita should diminish from around 7 tonnes CO_2e p.a. now, to around 4 in 2030 to around 2 in 2050. Thus if there are not many people below 2 in 2050 there cannot be many above – the average is the average.

Emissions per unit of output will have to fall by a factor of about 3 × 2.5, or 7–8, if global output grows by a factor of 3 in the next 40 years (a global growth rate average of 2.8% p.a.). That is surely an energy-industrial revolution. The scale of change is such that no major sector can be left out, neither can any major country or group. It should be seen as a revolution involving radical change in how energy is used, and in the patterns of both production and consumption.

Energy is associated with around two-thirds of global emissions, and agriculture and deforestation the bulk of the remainder. Within energy, it is possible that action on energy efficiency could cover around one-half

of what is necessary.[35] Many of the necessary technologies are emerging and we see rapid progress in materials, building and construction, transport and power generation. The interaction with rapid progress in biotechnology, material science and information technology has provided great new potential in both energy and resource efficiency and alternative sources of power. There is likely to be much more to come, particularly with stronger investment in R&D. The story of a response on the necessary scale does not depend on some wonderful new technology coming out of nowhere, although it is likely that new and productive ideas and opportunities will appear.

If past waves of technological change are a guide, the dynamic and innovatory nature of the new industrial revolution will imply that there will be great learning and many opportunities will appear. Costs, the direction and the scale of investments will depend on the path followed and the lessons it generates. There may be major advantages to the pioneers. Thus it is very difficult to assign an 'extra cost' to specific emissions reductions in place A at time t.

These analytical difficulties and their sources, arising as they do from the potential of technological and organizational discovery, make specific calculations of how costs of a given emissions reductions programme fall on different countries and groups a shaky foundation for policy. They do not remove the relevance of economic and ethical arguments to policy analysis and international agreement: such agreements or understandings should indeed concern how rich countries should act in their own economies and what they should provide to developing countries in the reshaping of their economies. They do, however, influence how that discussion should be framed. The analytics should be focused on how poverty reduction and the necessary energy-industrial revolution can be fostered in an equitable way.

This is yet another example where the appropriate form of ethical and equity concepts and questions depends very sensitively on the basic 'positive' (as opposed to normative) economic structures which are used to understand the issues: in this case how we model the way the new low-carbon economic systems develop. It is crucial to keep the idea of a dynamic and radical transition and how it can be fostered at the centre of the discussion, because that is the change demanded by a serious analysis of the risks embodied in climate change and the opportunities involved in a response of appropriate magnitude.

Casting the equity concepts on the back of one particular economic model of production may be profoundly misleading. Past UNFCCC discussions of these issues appear to have been tightly bound to a model where alternative production technologies, in particular a switch to

[35] Stern (2012a: Lionel Robbins Lecture 2); International Energy Agency (IEA) (2010, 2013).

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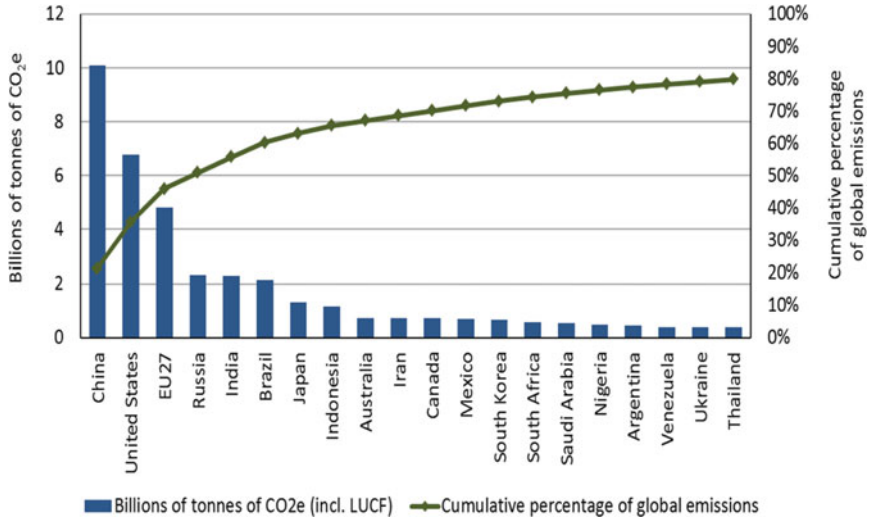

FIGURE 1. (Colour online) Top 20 largest emitters in 2010: total GHG emissions and cumulative percentage of global emissions over time.
Note: LUCF, land use change and forestry.
Source: World Resources Institute (2013).

low-carbon, are assumed to automatically lock in a particular extra cost. But to force the argument into that framework is to implicitly embrace a static model of production which is in conceptual and practical conflict with the type of change, investment and learning processes at the heart of the policy challenge.

2.2 The basic cross-country data

As a background to the examination of equity across countries and peoples it is necessary to have some data in front of us on relative recent and historical emissions. These are illustrated in Figures 1 and 2 and Tables 1 and 2 with figures for the main countries (largest emitter nations) for total emissions in CO_2e and emissions per capita for 2010. Figure 3 illustrates carbon dioxide emissions over time, from 1990 to 2010 and Figure 4 on a per capita basis over the same time period.[36]

China has firmly overtaken the USA as the world's largest emitter (Figure 1 and Table 1) (we should recall that its population is around four times as large) and its emissions are rising rapidly. In 2013 they were

[36] These are the most up to date and easily available GHG and CO_2 data with some consistency across countries. The main points we draw from these data about broad histories and cross-country comparisons would not likely be altered by more recent data.

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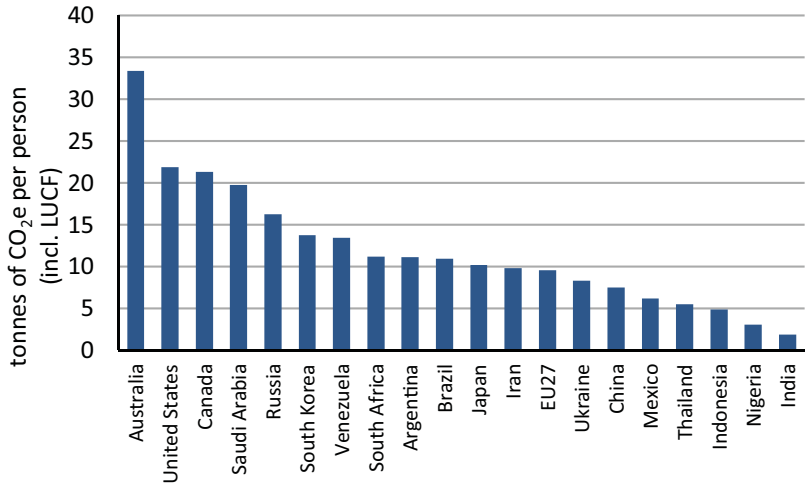

FIGURE 2. (Colour online) Top 20 largest emitters in 2010: ranked by GHG emissions per capita.
Note: LUCF, land use change and forestry.
Source: World Resources Institute (2013).

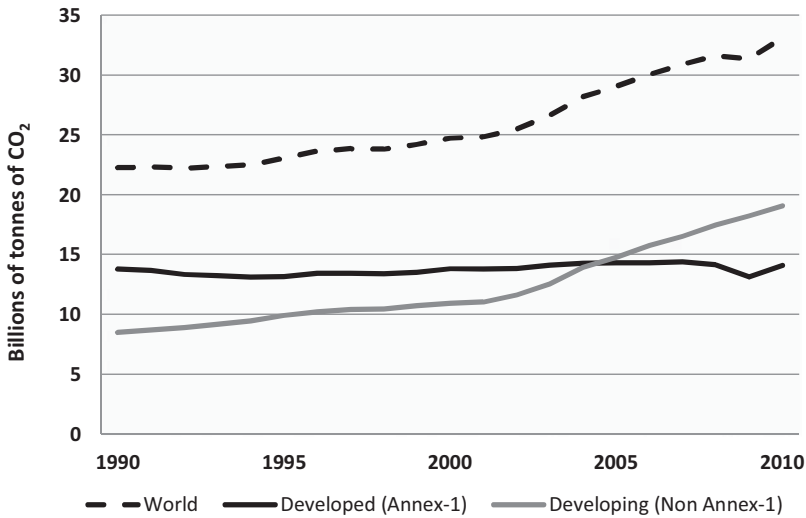

FIGURE 3. Total carbon dioxide emissions 1990 to 2010: developed and developing countries.
Source: World Resources Institute (2013).

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Country	Billions of tonnes of CO_2e (incl. LULUCF)	Share of global total (%)
China	10.08	21.37%
United States	6.77	14.36%
EU 27	4.82	10.22%
Russia	2.32	4.91%
India	2.30	4.88%
Brazil	2.14	4.53%
Japan	1.30	2.75%
Indonesia	1.17	2.48%

Note: LULUCF, land use, land use change and forestry.
Source: World Resources Initiative (2013).

TABLE 1. Data for the top eight largest emitters in 2010: total and percentage GHG emissions.

Country	Tonnes of CO_2e (incl. LULUCF)
Australia	33.38
United States	21.90
Canada	21.29
Saudi Arabia	19.75
Russia	16.27
South Korea	13.75
Venezuela	13.43
South Africa	11.20

Note: LULUCF, land use, land use change and forestry.
Source: World Resources Institute (2013).

TABLE 2. Data for the top eight largest emitters in 2010: ranked by GHG emissions per capita.

probably around 12 billion tonnes of CO_2e relative to the figure of around 10 for 2010 in Table 1. The top eight countries in emissions are China, USA, EU (27), Russia, India, Brazil, Japan and Indonesia, and are together responsible for close to 70% of total global emissions. They are all large countries in terms of one or more of population, output per head and deforestation.

The story in terms of emissions per capita is very different (Figure 2 and Table 2, and Figure 3). The United States, Canada and Australia are above 20 tonnes per capita per annum CO_2e, China around 7 or 8,

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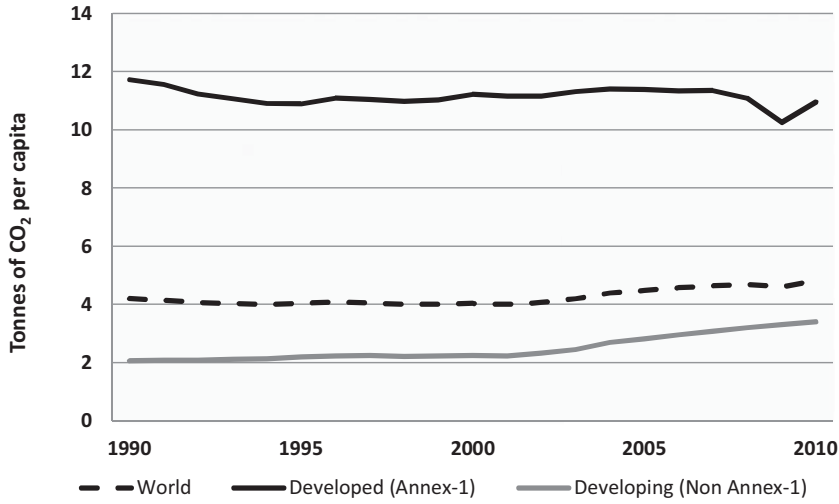

FIGURE 4. Carbon dioxide emissions per capita 1990–2010: developed and developing countries.
Source: World Resources Institute (2013).

India below 2 and many African countries between 1 and 2. Given the history of high emissions from the rich countries (and thus the use of 'carbon space' in the past) and the finite carbon space that remains, it is understandable that the debate around 'equity', expressed in terms of who takes what of the space that remains, either in terms of actual emissions or in terms of rights, is so intense. It can be seen in Figure 3 that developing country emissions overtook developed country emissions in 2005 and in Figure 4 we see an acceleration in emissions per capita in developing countries from around 2000 as growth picks up and they pass through an energy-intensive phase of development. Emissions per capita in developing countries will have approximately doubled in the quarter century 1990–2015, whilst those in developed countries will have fallen a little. Nevertheless in the middle of this decade they are still around three times as high in developed countries.

Various calculations are available on the 'remaining carbon space' on the basis of analysis of the kind described in Paper 1, Part 1, on the science (see, e.g. Allen *et al*. 2009; Intergovernmental Panel on Climate Change (IPCC) 2013). They point to figures in the region of 2500 billion tonnes CO_2e for a 50–50 chance of holding temperature increases to 2 °C – this is equivalent to about 50 times the current world annual emissions. We have also argued that emissions per capita on average for the world must be around 2 tonnes CO_2e in 2050 for paths consistent with a 50–50 chance of

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2 °C, and that since there are unlikely to be very many people well below 2 tonnes, there cannot be many well above. But if actual emissions per capita must be clustering around 2 tonnes in 2050, we must not misunderstand this as an equity statement. It follows from the science of emissions and warming, from population forecasts and from the basic arithmetic of averages – there are no ethical criteria in this calculation.

It is clear that the world will have to take some determined and tough decisions if it is to give itself a reasonable chance of holding to 2 °C. In 2030 the overall world budget for emissions would be in the region of 32 billion tonnes CO_2e. On current and fairly explicit plans (see Stern 2011, 2012b on China's 12th five-year plan), China's emissions are likely to grow substantially over the next decade from their current levels of around 12 billion tonnes of CO_2e per annum. Currently policy makers in China are speaking of a peak in coal consumption within the next decade (see Green and Stern 2014 for discussion) and some speak of peaking emissions by around 2030, though this is still a matter of debate within China (and there are some who speak of earlier peaking). This would be effectively essential for global efforts to address climate change: even if we assume, conservatively, that China's emissions will increase by only a further 3 billion tonnes in annual flows between now and 2030 (this would require a significant slowing in China's emissions growth), that would take China to around 15 billion tonnes in 2030 when the population may be around 1.4 billion (and thus per capita emissions 10 or 11 tonnes). If the USA's total were 6 or 7 billion tonnes and the EU totalled 3 or 4 then in 2030, China, USA and the EU might together total around 25 billion tonnes. With an overall global 32 billion tonne per annum budget around that time, that would 'leave' 7 billion tonnes for the other nearly 6 billion of the 8 billion in the world in 2030 (assuming the population of China/USA/EU totals a little above 2 billion people in 2030). That would require this 6 billion to average close to 1 tonne per capita 20 years from now – and the feasibility of that would be extremely unlikely. The implication is that China/USA/EU will together have to be far lower than 25 billion tonnes CO_2e in 2030 if a reasonable chance of 2 °C is to be realistic. One can see in these figures the potential intensity of the debate on who does what and where and how investment and technology are financed.

It is surely clear that (i) there is a great risk that the possibility of giving the world a 50–50 chance of 2 °C will be lost; (ii) all must be involved in strong reductions of emissions if we are to have any chance of achieving that target; (iii) even if rich country emissions were zero in both 2030 and 2050, the per capita emissions of developing countries would have to be around 4–5 tonnes by 2030 and 2.5 tonnes by 2050; and recall that China is currently heading for more than 10–11 tonnes per capita in 2030. It is crucial that all countries, both developed and developing, recognize

the arithmetic in points (i)–(iii), if an outcome which is both effective in reducing emissions as required and ethical in its allocations and actions is to be achieved.

2.3 Where and when should reductions take place: carbon space and rigid formulae?

What sort of principles can we bring to bear in examining targets for countries or for people? A popular assertion is that it is equitable to have per annum 'allocations', 'quotas' or 'permits to emit' which are equal for everyone, e.g. for 2050 around 2 tonnes CO_2e per person, or for 2030 around 4 tonnes per person (representing the 32 billion tonne per annum CO_2e world budget divided by an 8 billion world population) and similarly for intervening periods from now. Sometimes such arguments are augmented by looking at past emissions or at allocations for a period of several years or a few decades rather than a single year. We examine such arguments in this subsection: we will conclude that the arguments for 'equal per capita allocations' do not stand up to close ethical and economic examination and conclude that this route does not look promising as a way to analyse the equity issues. But, let me be clear that a number of key ethical and conceptual concerns about the arguments point to the conclusion that 'equal per capita' allocations are not equitable enough.

Past international discussions have got locked into particular formulations of 'common but differentiated responsibilities', of 'full incremental costs', and of divisions into particular groups of developed and developing countries. I will argue that it is time to break away from the narrow formulations and examine equity issues on economic and ethical bases which fit better to the outcomes and processes the problem demands, i.e. fostering the dynamics of the transition. Lest I be misunderstood, this is not an attempt to avoid or play down the equity issues. On the contrary it is to take them very seriously indeed and integrate them into approaches that are founded both in ethical principles and the scale and dynamics of the challenge.

There is at times some evidence that the arguments are moving in this direction. At the UNFCCC in Cancún (December 2010), on the basis of language suggested by India, the equity issues were summarized in terms of 'equitable access to sustainable development', the 2 °C target was adopted and the idea of a Green Climate Fund endorsed. Giving meaning to this language offers an important way forward and I shall return to the issue below. At the UNFCCC in Durban (December 2011), the 'gap' between the total of current intentions across countries and the emissions necessary for a reasonable chance of 2 °C was recognized and the idea of an eventual common legal basis, applying to all countries, for emissions targets was accepted. But the tensions over perceived equity issues remain intense.

Let us continue our discussion of equity by focusing on the common suggestion of an allocation of equal-per-capita quotas each year. Whilst I shall be fairly negative about this proposition, its analysis helps illuminate some key questions. If such allocations were made and permits or quotas could be marketed then low emitters, mostly poor countries, would be selling permits and rich countries would be buying. At US$ 30 a tonne of CO_2e (say) in 2030 the total value of a world asset totalling 32–33 billion tonnes CO_2e in 2030 (the world budget) would be US$ 1000 billion or around a trillion dollars. World GDP then might be US$ 100–150 trillion. Thus it would be a total world asset that whilst large might be of the order of 1% of world GDP. If Africa had, on a population basis, 20–25% of the allocation then the value of the allocation at US$ 200–250 billion might represent of the order of 20% of its GDP and would likely be a large multiple of foreign aid. And the carbon price might be, indeed should be,[37] far higher than US$ 30 per tonne CO_2e in 2030.

We must take care, however, in understanding how carbon markets might work. The price for marginal trades should be equal across countries and high enough to limit demand to the carbon budgets, if efficiency and effectiveness are to be achieved. But not all trades need take place at the marginal price.

The 'logic' behind the assertion that allocations should be equal appears to be the claim that 'there should be equal rights for each person to the atmospheric commons' where the size of the commons in each year is represented by the carbon budget. This is a story articulated by many (see, e.g. Agarwal and Narain 1991; Jamieson 2001; Baer 2002; Höhne *et al*. 2006; Gardiner *et al*. 2010; Singer 2010), with varying degrees of rigour in the arguments offered. The proposition clearly has some instinctive attraction to many.

The argument, at least in its simple form, has serious problems scientifically, ethically and economically. Scientifically, equality on a flow basis makes little sense: it is the time path of concentrations that is of primary importance in determining warming and climate change. But if we switch to stocks we find that equality which focuses on stocks or the sum of flows over a period of time raises very difficult questions of when the 'clock should start' for the summation. Is it now, so that e.g. everyone has an equal share of the total headroom that remains? What is the relevant population given that it has changed over recent history, and will change, differently in different places? Should there be accounting for past emissions? Is there a responsibility starting from when the problem was scientifically identified and embraced by the body politic? When was that – Fourier in the 1820s, the launch of the IPCC in 1988, the creation of the UNFCCC in 1992? Thus criteria based on equal per capita allocations

[37] For example, market prices of US$ 50 or more may be necessary to sustain carbon capture and storage which itself is likely to be a necessary part of a path holding to 2 °C.

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have deep conceptual and practical problems. Nevertheless, if we go down the route specified by this argument, it would be hard to argue in favour of a starting date later than 1992. The emissions by rich countries in the 20 years since then have consumed a great deal of 'carbon space'[38] and these actions of emitting should have a bearing on moral responsibilities from most ethical perspectives.

Ethically, the assertion of a right to the atmospheric commons is not one which it is easy to explain or justify. There are some who might argue that there is a right to development, a right to energy or a right to shelter associated with basic human needs. These rights do have a reasoned basis, see, e.g. Sen (1999, 2009), and some are embodied in constitutions (e.g. South Africa). But these neither separately nor together imply a right to emit. There are no fixed coefficients between development, shelter or energy on the one hand, and emissions on the other. Indeed policy on climate change is in large measure about altering those coefficients.[39] Further emissions cause real damage to, indeed can kill many, from future generations. Is there a right to endanger life? As the late Prime Minister Meles Zenawi of Ethiopia put it in Durban in December 2011 on Africa Day at the UNFCCC gathering 'It is not equity or justice to foul the planet because others have fouled it in the past'.[40]

If we change the language from 'rights' to tradeable quotas then the issues look somewhat different: economically, the issues concern the distribution of a new asset, perhaps of total value of the order of US$1 trillion p.a. in 2030. There is nothing in the economics of public policy that points to each person in the world being entitled to an equal share, e.g. US$125 for each person, if there are 8 billion people in 2030. Most distributional frameworks in theory and in practice would point to poorer people getting more. There are some, implausibly in my view, who argue that allocation of quotas should be in relation to production (with some standard coefficient relating emissions to production). They invoke the idea that everyone should be at liberty to produce what they can and policy should focus on encouraging greater carbon efficiency in the sense of reducing emissions per unit of output. The efficiency aspects of the argument of this last sentence are not mistaken; what is illogical is to say that it implies that those who are richer, in the sense that they produce more, have a proportionally greater right to damage others through their

[38] Probably of the order of half a trillion tonnes CO_2e.

[39] Some appear to advocate equal per capita emissions as a 'pragmatic' expression of equal right to development on the grounds that emissions are necessary for development. But, as I have argued, whilst energy may be necessary there is no rigid relationship between energy and income/output or between energy and emissions. The challenge is indeed to break the relationship between energy and emissions and use energy much more efficiently. Further, the insistence on such a formula is not 'pragmatic' if the formulation leads to deadlock (see below).

[40] I was part of the panel discussion during which he made the remark.

emissions, in being entitled to quotas related to production; the argument about efficiency is silent on equity.

If one attempts a formulaic approach to allocations, in a standard context in welfare or public economics with a Bergson–Samuelson social welfare function, it might look something like the following. We could fix the 'starting date' T_o for 'knowledge of problem' and total available resources for transfer payments as X (this can also be a choice variable). We could then fix the 'remaining pot' of emissions as Y (although in some modelling approaches this might also be a choice variable) constraining the sum over i and t of y_{it}, emissions of country i at time t. Then we could set up criteria for evaluating how y_{it} and x_{it} (the compensation or transfer payment to country i at time t) should be determined as a function of X, T_o, and Y. In most simple models with concave social welfare functions (diminishing social marginal utility of income) we could not avoid the formal conclusion that allocation of the resources available for transfer payments should be largely to the poorest (e.g. up to point of equal social marginal utility of income). The allocation of a tradeable emissions quota is essentially a transfer in this type of model.[41]

The argument of the last two paragraphs emphasizes the importance of avoiding seeing justice and rights only in terms of the one dimension of emissions: Caney has termed such a perspective 'isolationism' (see Caney 2010: 214 for a discussion). Certainly most applications of the economics of public policy (see above) would regard income and wealth as relevant to the allocation of emissions quotas. But while 'isolationism' makes little sense, because we can recognize immediately some factors beyond emissions which are relevant to distributional allocation of quotas, we do encounter difficult problems when we go beyond it. Should rich countries be credited with their development of technologies? Should the British be credited with the Indian railways built under colonialism; if so, then what about the debts incurred and crimes committed by the British in the colonial period?

2.4 The danger of impasse and a way forward

There have been various attempts to create one-dimensional[42] 'formulae for equity' along the lines just discussed, relating to past and current emissions, for example the Tata Institute of Social Science report (2010), and papers from the Tata Institute of Social Science, 'Global Carbon Budgets and Equity in Climate Change' conference on 28–29 June 2010. Generally they share key elements of the above formal structure and thus

[41] One could complicate by building in various incentive and response structures to transfer payments, but the basic point of the direction and magnitude of transfers being strongly influenced by the social marginal utility of income would stand.

[42] Or 'isolationist' in the Caney sense.

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tend to point to 'allocations of rights or permits' which are similar to, or still stronger in allocations to poor countries, than equal per capita rights to the remaining carbon space.

One might try to invoke an argument that locations where emissions reductions can be made very cheaply should have a downward adjustment in allocation to avoid creating an 'excessive rent' associated with the happenstance of their location or past. This reflects the reservations which arose when Russia received high allocations under Kyoto because energy usage in the former Soviet Union was so inefficient and allocations were in part historically based. The problem was referred to as 'hot air': Russia faced no or negative cost in complying with emissions targets created in this way and had a lot of permits to sell. Interestingly there has been a disinclination to buy such permits on the grounds that they do not represent 'real reductions' – i.e. one would be buying 'hot air'. This suggests that under Kyoto the emphasis was on finding efficient ways of reducing overall emissions by the necessary amounts, and getting international agreement via 'grandfathering' existing allocations, rather than equity. Grandfathering embodies the notion of entrenched rights associated perhaps with costs of change or avoiding 'retrospective' taxation. There appears to have been a disinclination to see the allocation of permits as a large-scale method of income distribution, particularly by those, often the richer countries, who saw themselves as potential losers.

Elsewhere (see Stern 2009) I have argued that global agreements on climate change should be 'effective, efficient, and equitable' both as a matter of principle, but also pragmatically if they are to be built and sustained. The discussions around Kyoto and on 'hot air' point to an apparent desire, at least by some countries, to have allocations and trading mechanisms focused on effectiveness (meeting the desired overall reduction targets) and efficiency (keeping the costs down). It seems that in those discussions, implicitly or explicitly, there was a mutual understanding, rightly or wrongly, that the subject of equity should be handled in some other way, or perhaps the rich countries thought it should have a very limited role.

How should we evaluate this perspective or implicit understanding? Standard second-best welfare economics says that if income distribution mechanics are constrained (e.g. by disincentive effects of income taxation or of income-contingent transfers) then policies focused primarily on other issues, such as efficiency, should have their distributional impacts included in any assessment.[43] And this is revealed in practice to be important in public discussions of, say, energy or water pricing. In this

[43] See, e.g. Drèze and Stern (1990), or more generally, e.g. the *Journal of Public Economics*. The arguments go back at least to James Meade and Paul Samuelson in the 1950s and

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'public economics' approach, if a new instrument emerges, such as the allocation of quotas, then its potential for improving income distribution should be regarded as an advantage.

That argument is technically correct and of substance. But in the case of cross-country transfers we already have mechanisms, used insufficiently in my view, to make transfers. However, those in rich countries choose to make, via those mechanisms, only modest transfers as overseas development assistance. Sometimes issues such as corruption, ineffectiveness or 'aid-dependence' are raised. But it seems reasonable to conclude that larger transfers are not made mainly because the people and political systems of rich countries do not want to make them. In other words, there is an underlying feeling that 'I do not feel the obligation to give very much to poor countries' and 'My sense of community responsibility for inequality does not extend strongly to the rest of the world'. If this is the case, as I think it is, we cannot expect agreement by those in rich countries to make large transfers, perhaps considerably larger than current or planned overseas aid, through another route. We can try the arguments about paying for past pollution but the evidence of international discussion suggests they are unlikely to have strong traction. I write as someone who has tried, with very limited success, both the distributional and compensation arguments publicly and privately in international discussion. And I have observed the largely unsuccessful efforts of others.

Equity, at least if it is formulated in the rather mechanical and one-dimensional ways we have discussed, via quotas and rights, is on a collision course with practical politics; we seem, in this discussion, to have arrived at an impasse. Equity arguments and historical responsibility together point to allocations of emissions rights which would give large transfers to poor countries. Yet rich countries are most unlikely to accept the arguments for so doing or at least they will refuse to make the transfers, whether or not they acknowledge the validity of the arguments. The result, if we insist on acceptance and implementation of these rights and transfers before action by poor countries is agreed or implemented, will be the most inequitable of all – unmanaged climate change. However frustrating and unjust it may seem, there seems little sense in insisting on one narrow, and conceptually problematic, formulation of equity, i.e. via quotas, if such insistence is likely to lead to this outcome. Demonstrating that the equity case is very powerful (beyond an emissions per capita approach) does help show how deeply unattractive rich country intransigence is – but a rigid and formulaic view blocks progress. Whilst the poor countries have much the better of the argument on equity,

are expressed with great lucidity in Meade's *Trade and Welfare* (Meade 1951, 1955) and its mathematical supplement.

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the rigidity or intransigence of two groups (poor countries insisting on only one way of formulating equity, and rich countries saying 'that is unacceptable') is holding hostage the future of their children and risks severe damage or destruction. And it is poor people who are at the most risk.

But there is a way forward. It is not to drop the equity criteria but to embed them in the twin ideas of rich countries embarking on a dynamic and attractive transition to the low-carbon economy in their own economies and supporting that transition in the developing world as a policy chosen by those countries themselves as a driver of growth and poverty reduction that is capable of becoming sustained. In other words to give life to the idea of 'equitable access to sustainable development' proposed by India and adopted in the UNFCCC agreement in Cancún in December 2010.

To do this we must start by being clear about five things: first, the scale of the necessary emissions reductions; second, that a radical economic transformation is required; third, that it will have many attractive features beyond reducing climate risk; fourth, that it is a sustainable growth story with great potential for overcoming poverty in the next few decades; fifth, substantial investment resources and new technologies are required. An attempt at high-carbon growth will self-destruct on the deeply hostile physical environment it is likely to create. There is little point in 'equitable access to a train wreck'. And neither should we try to make the transition to sustainable development by expecting poor countries to make the necessary substantial investments without strong support in resources and technology.

This is not the place for an extended discussion of 'equitable access to sustainable development'. However, it should start with what is necessary for a transition to a low-carbon economy because that is central to sustainable development. An analysis of policies would focus on a dynamic public economics of change. This could start by analysis of some basic market failures: (i) emissions of GHGs; (ii) R & D and the publicness of knowledge and discovery; (iii) networks (electricity grids, broadband, public transport, recycling, and so on); (iv) weakness in long-run capital markets in handling risks; (v) information on available goods and services concerning options, e.g. energy efficiency opportunities; (vi) co-benefits (energy security, biodiversity, safety …). For a further discussion see Stern (2012a).

The 'equitable' in 'equitable access to sustainable development' would concentrate on the nature and type of support. It would be directly influenced by attitudes to discounting, risk and inequality; the lower the pure-time discounting, the greater the risk aversion and the greater the aversion to inequality the more powerful are the ethical arguments for strong support by rich countries in resources and technology for the

transition in poor countries. Research to provide evidence, structure and life to the idea of 'equitable access to sustainable development' should be the highest priority. It will require economists, economic historians, political scientists, philosophers, scientists, engineers and many more professional skills. And, critically, the involvement of business people, investors and politicians.

There are some who might interpret this concept as requiring 'zero-growth', particularly in rich countries, as a number of authors (e.g. Jackson 2009) have proposed. There are three reasons I find the arguments unconvincing: quantification, focus, political.

Quantitative: if all countries stopped growth now our global emissions at 50 billion tonnes CO2 p.a. are, as we have seen, far too high to be consistent with avoiding dangerous climate change. Focus: it follows that the focus of attention should be breaking the link between production and consumption on the one hand and emissions on the other, and a zero-growth proposition could divert attention. Political: if we try to turn this into a battle about growth rather than the nature of growth, or express it as an artificial horse-race between growth and climate responsibility, the most likely outcome is that growth will win and climate responsibility will lose. That would be the most inequitable of outcomes.

Countries and people in the developing world will examine their own circumstances and opportunities and thus transition paths. And there is much the rich world can do to support analysis of what is possible, providing resources and finance, and developing and sharing technologies. In the process we will begin to define the meaning(s) of 'equitable access to sustainable development'.[44]

As these discussions develop, it is vital that three thoughts are at the forefront. First, delay is dangerous. Second, it is crucial to make an effort to understand what other countries are doing and to explain what you are doing. Third, respect for and understanding of ideas of equity must play a part in any credible set of agreements or shared ways forward.

PART 3. SUMMARY AND CONCLUDING COMMENTS: (1) AVOIDING SHOE-HORNS AND BLINKERS IN ECONOMICS AND ETHICS; (2) COLLABORATIVE NOT FORMULAIC ROUTES TO EQUITABLE ACCESS TO SUSTAINABLE DEVELOPMENT

3.1 Applying the ethics

3.1.1 Modelling. Conclusion 1. Attempts to force a problem concerning immense risks into a model of minor perturbations within standard aggregative growth models distort the basic scientific, economic and ethical issues. They often lead to the misleading conclusion that there should be high discounting, and thus

[44] See Romani *et al*. (2012).

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small weight on medium-term and longer-term climate impacts, on the grounds that future generations will be rich, as a result of the assumed growth.

Let me be clear, this is not to dismiss modelling; far from it. It is simply to say that shoe-horning climate issues into a model with perturbations around a growth path with given underlying growth drivers or rates, risks omitting the key issues of the possibility of immense damages which reverse growth and development. Discounting future effects on the assumption that the inexorable driving force of underlying growth in such models will mean future generations are automatically 'well-off' is to misunderstand both the science and the processes of growth;[45] it comes close to assuming directly that discount rates must be high and that effects in the medium-term future are of little importance.

3.1.2 Discounting. Conclusion 2. Some infinite horizon models with particular assumptions and axioms concerning growth and social preferences can lead to non-convergence of utility integrals, paradoxes of 'over-saving' and possible incompleteness of social orderings. We showed, in a simple one-good growth model of the Ramsey kind, that these phenomena are closely connected and that the conclusion that we should respond to these problems by imposing pure-time discounting was invalid. Non-convergence or incompleteness arise from a number of assumptions and can be avoided by adjusting some of them (for example concerning the role of long-run growth or distributional values). And incompleteness of an ordering over an infinite horizon may not be a reason to reject assumptions if they appear valid for other reasons and the ordering can handle the key questions at issue.

It is well-known that there are 'paradoxes of infinity', and they require examination, but it would be unwise to insist that their technical resolution requires us to recast our core moral values. We may, for example, want to re-examine the assumptions about growth and infinite horizons. Technically, problems of incompleteness of social orderings are closely related to the paradoxes of infinity. These arise in an approach based on axiomatic social choice theory, in the context of a set of assumptions, including Pareto sensitivity, zero pure-time discounting (or anonymity), and infinite utility streams. But that does not imply that one particular assumption in the set should be jettisoned. And incompleteness may not be too worrying if the criteria can deal with the choices at hand.

The immense dangers of unmanaged climate change can arise with quite high probability 50 or 100 years from now and many of the people likely to be affected are already alive and amongst us. We need economic analysis which examines these great issues directly and which avoids dismissing the central question of the management of these immense risks by the arbitrary devices of asserting or assuming inexorable growth

[45] See Stern (2013) for a development of this discussion.

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or insisting on technical devices such as strong pure-time discounting which have dubious ethical foundations. We have to examine ethical issues directly and bring the economic modelling in line with the risks at issue.

Conclusion 3. Discounting long-term climate impacts by inferring discount rates from current and historical market rates involves basic errors in this context, arising from mis-specification of the underlying model, of the ethical questions and of the definitions of discounting, and from ignoring key market failures. Further, attempts to infer social valuations for use in intertemporal evaluation of climate policy from explicit or implicit public decisions, which may be deemed to be 'analogous' to decisions relevant for climate change are largely inconclusive and likely to remain so.

Assuming that underlying future growth will be like the past is a basic mis-specification of choices in relation to climate change and its possible consequences; so too is the assumption of just one aggregate good when the environment and its effect on lives and survival of many are at stake. Of course, all models are simplifications but in this context these assumptions are so badly wrong the formulation and its conclusions are simply unacceptable. Attempting to derive relevant evaluation criteria or parameters from market discount rates or rates of return generally depends on completely untenable assumptions about those markets: such derivation would generally require us to assume perfect information, the existence of very long-term markets for trades based on collective decisions, and so on.

Attempting to derive values from 'inverse optimum' analyses of public decisions is undermined by the need to model the constraints and incentive structures which are assumed to be perceived by the 'optimizers'. As we saw in the optimum growth discussion (in Conclusion 1) above, different assumptions on the perceptions of the 'optimizers' give such different answers as to render such an approach thoroughly inconclusive. Similar sensitivity is observed in attempts to derive values from tax or expenditure decisions.

That public sector discount rates for projects over 20 or 30 year horizons may be at, say, 3–6% real or more is not evidence that pure-time discount rates should be high. Often risk in the business or political environment plays a prominent role in arguments for such rates and such risk to a particular project may not be small. The pure-time discount rate in the context of social welfare evaluation is a concept logically separate from that kind of treatment of risk.[46] Further, the assumption that 'public

[46] Modelling of the risks concerned with exogenous threats to the existence of the population of the planet can lead to a maxim and which has a mathematical form similar to that of pure-time discounting.

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decisions' can be seen as if they are the actions of a single optimizer is itself problematic.

Conclusion 4. Given conclusions 1, 2, 3, arguments for heavy pure-time discounting are (i) usually purely asserted or assumed, or (ii) invoked by (dubious) appeal to the empirical existence of short-termism.

They are asserted or assumed in the sense that notwithstanding conclusions 1, 2, 3 above, and their demonstration of the weakness of a conceptual or ethical case for pure-time discounting, a modeller finds it convenient to use a high pure-time discount rate for the particular model constructed in order to avoid the failure of the model, for example via the divergence of infinite integrals: this is confused pragmatism in the context of a model, which is likely to be inappropriate to the issue at hand. That many people act in short-sighted ways or as if they had heavy discount rates is not an argument that collective ethical issues should be settled in this way. And, sadly, some people, including some economists, appear to confuse pure-time discount rates and discount rates.

The proposition that pure-time discounting should be zero is generally derived from the principle of equal treatment of people in similar circumstances. In other words, it is regarded as ethically right to treat the lives of different individuals equally and not to discriminate between lives by happenstance of the date of birth at which they began. This idea of equal treatment or neutrality is itself a clear and transparent principle which is common in many constitutional and legal arrangements, and can be derived from a number of ethical positions.

3.1.3 Equity across people and nations. Conclusion 5. Most formulaic approaches to equity in relation to group or country allocations of, quotas for, or rights to 'carbon space' have serious problems scientifically, ethically and economically.

Scientifically, what matters for warming and climate change are the levels of concentrations over time, rather than flows. Ethically, carbon emissions appear to be a strange basis for a discussion of rights: we may invoke rights to development and recognize the importance of energy, but that is not to speak of a right to emit. There are no fixed coefficients between development and emissions, and emissions threaten directly lives and livelihoods; the challenge is to break the link between emissions and economic activity and we know it to be possible. Economically, the allocation of a tradeable quota is an allocation of a financial asset, and in an unequal world there is no strong case for equal allocation of such an asset. In transfer systems, in practice most people argue that poor people should get more. This illustrates the dangers of looking at rights and justice in this context in a way which focuses on just one dimension, emissions.

Various attempts to create 'formulae for equity' tend to point to 'allocations of emissions rights or permits' which would give large

transfers to poor countries. Rich countries, however, are most unlikely to accept the arguments for so doing, or at least be unwilling to act on them whether or not they regard them as appropriate. Thus, notwithstanding that the poor countries have powerful ethical arguments in their demand for carbon space and transfers of resources and technology, a purist insistence on formulae which are based on one-dimensional treatments of allocation is likely to lead to policy impasse and inaction. That is the most inequitable outcome of all, with poor countries being hit earliest and hardest by climate change.

Conclusion 6. Reframing interpersonal and cross-country questions as 'equitable access to sustainable development' is a promising way of casting the policy issues and analysis: it recognizes the importance of ethics, the dynamic nature of the necessary economic transformation, and is more likely to lead to agreement.

Abandoning an attempt to embody ethics in policy, because of the difficulties of a narrow formulaic approach, makes little ethical, political or practical sense. But there is a way forward. It is not to drop the equity criteria but to embed them in the idea of rich countries fostering the dynamic and attractive transition to the low-carbon economy in both their own countries and supporting developing countries in their drive for an approach to growth and poverty reduction which is both effective and sustainable. In other words, to give life to the idea of 'equitable access to sustainable development'. Thus what is dropped is not the ethics but a particularly narrow and static version of the underlying economics, one which risks derailing progress. Progress requires both developing and developed countries to see the opportunities and ethics in a different way so that they can understand that there are dynamic gains that make the problem very different from a 'zero-sum' game of 'burden-sharing'.

Detailed discussion of the meaning of sustainable development has not been our prime purpose here.[47] 'Equitable access' surely refers to the ability to participate in sustainable development. That will mean support from those who have the wealth, learning and technology by both demonstrating what is possible in their own actions and assisting others in finding ways to achieve sustainable development in their own circumstances.

In putting policies together it must be recognized that sustainable development, and equitable access to it, has to be understood at individual, community, country and global levels. Those perspectives should not be taken narrowly only in terms of country-to-country discussions. And we should recognize that sharing, for example of new ideas and approaches, can go in a number of geographical and

[47] Although we have presented key concepts in Stern (2014), the first paper in the series, and see, e.g. Stern (2009, 2012a) for some further development.

intellectual directions. The paper does not attempt to pursue the analysis of sustainable development any further, but it does emphasize that this approach does have sound ethical, scientific and economic foundations and seems a sensible and practical way forward as a basis for international and other discussions. Research on 'equitable access to sustainable development' should be high priority and will require the collaboration of a whole range of professional skills, as well as investors, large and small, and politicians.

3.2 A way forward

Conclusion 7. Policies for sustainable development and overcoming poverty require breaking the link between production and consumption activities on the one hand and emissions on the other. Essentially we need a new energy-industrial revolution.

Agreement on the implementation of fundamental change from the past and on the fostering of a new energy-industrial revolution requires clarity on five key issues and propositions: the scale of emissions reductions; second, that a dynamic and radical economic transformation is necessary for those reductions; third, that it will have many attractive features beyond reducing climate risk; fourth, that it is a sustainable growth story with great potential for overcoming poverty; fifth, substantial investment and new technologies are required. Such a picture of the necessary response including its radical nature and the importance of the dynamics of learning and transition, is a crucial part of the whole challenge of putting the science, ethics and economics together. Describing the dire consequences of inaction is a fundamental part of the ethical case; but there should also be a description of the other paths and why they look so much more attractive than continuing as we are, over and above the great reductions in climate risks they can deliver. In this case, the alternative paths do indeed appear very attractive: cleaner, quieter, safer, more secure and more biodiverse.

The principal purpose of both Paper 1 and 2 has been to set a framework for the ethical analysis of climate change in the context of the science and economics. The detailed economics will involve, *inter alia*, the economics of: growth and development; public policy; technological change; environment; game theory; international relations; finance; economic history; institutions and so on. We, as economists, have so much to offer. If we start with a careful examination of the science and the relevant ethics, then the economic analysis of policy can be, and I think should be, in the lead. If we try to narrow the science and ethics to fit with the most convenient and familiar economic models and approaches we risk distorting the ethics and the science, creating deeply misleading policy conclusions and undermining the credibility of our discipline.

In the process of pursuing our purpose we have not only drawn the above seven conclusions (in addition to the six from Paper 1). We have also seen that the way we frame and discuss the ethical arguments is likely to have a profound effect on policy discussions and the ability to gain international agreement. Reasoned ethical argument, its foundations, and the way it is conducted are vital to policy-making, not just conceptually, but also practically. Ethics matters.

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