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Intertemporal Equity, Discounting, and Economic Efficiency

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SUMMARY

The discount rate allows economic effects occurring at different times to be compared. It plays a vital role in public policy analysis of actions with varying time paths of costs and benefits. It is particularly important in climate change: Because of the very long times involved in climate change decisions, the choice of a discount rate powerfully affects the net present value of alternative policies, and thus the policy recommendations that emerge from climate change analysis.

Two major approaches are used to determine the appropriate discount rate for climate change analysis. The normative or ethical perspective (called the *prescriptive approach* in this chapter) begins with the question, "How (ethically) should impacts on future generations be valued?" The positive perspective, called here the *descriptive approach,* begins by asking, "What choices involving trade-offs across time do people actually make?" and, "To what extent will investments made to reduce greenhouse gas emissions displace investments elsewhere?"

The prescriptive approach tends to generate relatively low discount rates and thus favours relatively more spending on climate change mitigation. The descriptive approach tends to generate somewhat higher discount rates and thus favours relatively less spending on climate change mitigation.

Although economists support the concept of discounting for climate change analysis, they continue to debate which of the two approaches is correct, and the parameters to be used in calculating the rate. These choices in turn significantly affect the conclusions of the analysis.

4.1 Introduction

The discount rate allows economic effects occurring at different times to be compared. Discounting converts each future dollar amount associated with a project into the equivalent present dollar amount. The discount rate is generally positive because resources invested today can be transformed into, on average, more resources later; this holds for investments in both physical capital (e.g., machines) and human capital (e.g., education).

Greenhouse gas control programmes may be viewed as an investment: Money is spent today to reduce the costs of climate change tomorrow. If the real rate of return on investment in greenhouse gas controls exceeds the rate of return on investment in machines or education, then future generations would be better off if less were invested today in machines and education and more in controlling greenhouse gas emissions. The converse also holds, provided that the money is spent on investment rather than consumption.

Because of the very long times involved in climate change decisions, the choice of a discount rate powerfully affects the net present value of alternative policies, and thus the policy recommendations that emerge from climate change analysis.[1]

The benefits of greenhouse gas abatement accrue decades or even centuries in the future. For this reason, use of a high discount rate results in a low present value of actions that slow climate change. For example, at a discount rate of 7% annually (as is commonly used in short-horizon project analysis), damages of $1 billion 50 years hence have a present value of only $[\$1 \times 10^9]/[1.07^{50}]$ = $33.9 million; the same damages 200 years hence have a present value of only $1300. Thus the use of too high a discount rate will result in too little value placed on avoiding climate change and too little investment in climate change programmes. Conversely, applying too low a discount rate to climate change programmes will result in too much investment in them and crowd out better uses of the resources.

Determining the appropriate discount rate involves issues in normative as well as positive economics. These two perspectives raise very different questions. From a normative or ethical perspective, the key question might be: "How (ethically) should impacts on future generations be valued?" From a positive perspective, the appropriate question might be: "To what extent will investments made to reduce greenhouse gas emissions displace investments elsewhere?"

The debate is often confusing, in part because three separate issues are being addressed: how to discount the *welfare* or *utility* of future generations, how to discount future dollars, and how to discount future pollution. Further, the argument often combines questions of efficiency and questions of ethics. Although economists can make no special claim to professional expertise in questions of ethics, they have developed rigorous methods for analyzing the implications of ethical judgments.

Climate policy raises particular questions of equity among generations, as future generations are not able to influence directly the policies being chosen today that will affect their well-being (Mishan, 1975; Broome, 1992). Moreover, it may not be possible to compensate future generations for reductions in well-being caused by current policies, and, even if feasible, such compensation may not actually occur.[2]

4.1.1 *Areas of agreement and disagreement*

Economists are in general agreement that cost-benefit analysis, including discounting, is useful in examining policies with long or complex time paths, or policies whose effects extend across generations (see, for example, Layard, 1976; Cline, 1992; Lyon, 1994). At the same time, cost-benefit analysis, and the techniques that go with it, including discounting, focus on economic efficiency, and therefore have limitations as a guide to policy.[3]

The trade-off between consumption today and consumption in the future raises two central questions: first, how to think about this trade-off; second, what numerical value to attach to it. Many economists subscribe to a general framework that focusses on the social marginal utility of consumption today compared with consumption in the future. In this framework, the discount rate can be expressed as:

$$d = \rho + \theta g, \tag{4.1}$$

where d is the discount rate, ρ is the rate of pure time preference (also called the utility discount rate, a measure of the difference in importance attached to utility today versus utility in the future),[4] θ is the absolute value of the elasticity of marginal utility (a measure of the relative effect of a change in income on welfare), and g is the growth rate of per capita consumption. Equation 4.1 provides a way to think about discounting that subsumes many related subtopics, including treatment of risk, valuing of nonmarket goods, and treatment of intergenerational equity.

This equation sets out explicitly the two reasons for discounting future consumption: either (1) one cares less about tomorrow's consumer than today's, or about one's own welfare tomorrow than today (reflected in the first term, ρ); or else (2) one believes tomorrow's consumer will be better off than today's (reflected in the second term, θg). For a discussion of the derivation of equation 4.1, see Annex 4A.

Economists are in general agreement about several empirical issues that affect the discount rate, including the range of returns to investment, and the average interest rates earned and paid by consumers.

There is also a general consensus about certain basic principles of discount rate analysis. Most economists believe that considerations of risk can be treated by converting outcomes into *certainty equivalents,* amounts that reflect the degree of risk in an investment,[5] and discounting these certainty equivalents. There is general agreement that in evaluating competing projects, all spending, including investment, is to be converted into consumption equivalents first, then discounted (Arrow and Kurz, 1970; Lind *et al.,* 1982). Environmental impacts may be incorporated by converting them to consumption equivalents, then discounting. Many people expect the relative price of environmental goods to increase over time, which would have consequences equivalent to adopting a lower discount rate for such goods at unchanged prices.

However, given appropriate estimates of relative prices, there is no reason to explicitly modify the discount rate for environmental goods (see Annex 4A). In addition, economists generally believe that future generations could be compensated for some loss of environmental amenities by offsetting accumulations of capital.[6]

Economists disagree, however, about several other issues that affect the choice of a discount rate, including key parameters such as the likely rate of future per capita economic growth and the changing relative scarcity of environmental goods. These calculations require economic judgments about the degree of economic efficiency reflected in market outcomes, the extent of constraints on policy, and the proper approach to distributional concerns. Disagreements on these points drive the differences in conclusions about the discount rate.

The next section presents the two most prominent approaches to discounting for climate change analysis, together with the reasons for their differing conclusions. The two approaches start from very different places. What is called below the *prescriptive approach* begins with ethical considerations. What is called the *descriptive approach,* on the other hand, begins with evidence from decisions that people and governments actually make.[7]

4.2 Prescriptive Approach

The prescriptive approach, which is usually associated with a relatively low discount rate, begins with a *social welfare function* (an algebraic formulation that "adds up" the consumption of different individuals, yielding a measure of the well-being of society as a whole) constructed from ethical principles. Those who hold the prescriptive view typically argue that market interest rates often provide a poor indicator of the marginal trade-offs to society, because of market imperfections and suboptimal tax (and sometimes expenditure) policy, and because of constraints on policy, especially the difficulty in making transfers to future generations.

In the absence of such limitations, the social marginal utility of consumption would be the same at each point in time, and the social marginal rate of substitution between consumption today and consumption tomorrow would equal the market rate of interest. In the presence of such limitations, the social marginal rate of substitution will in general differ from market rates of interest.

Some advocates of the prescriptive approach use the term *social rate of time preference* (SRTP) to refer to the discount rate they derive. In this chapter, the term SRTP will be reserved for the discount rate derived from the prescriptive approach. Using this new expression, equation (4.1) is

$$SRTP = \rho + \theta g$$

The first term, ρ, reflects discounting of the utility of future generations. This term is sometimes said to represent discounting for impatience or myopia; alternatively, it may represent discounting for empathetic distance (because we may feel greater affinity for generations closer to us). See Annex 4A.3 for more discussion on the pure rate of time preference.

The second term, θg, reflects discounting for rising consumption (or consumption equivalents). If per capita consumption is growing at rate g, then an extra unit of consumption in the next period should be discounted by the term θg to take account of the lower marginal utility of consumption at higher consumption levels. Even if present and future generations are given equal weight, so that pure time preference is zero ($\rho = 0$), future consumption would still be discounted if later generations are expected to be better off; in this case, an extra unit of consumption would not be worth as much in the future as it is today. For example, if technical change continues at the pace of the last century, with productivity and living standards doubling about every thirty years, then this high value of g would push up the SRTP. This means that an additional unit of consumption by future generations, who would be much richer than we are, would count much less than an additional unit of consumption today.[8]

The SRTP approach values the total change in consumption at each date, not just the direct outputs of the project. Where mitigation projects displace other investment, future consumption must be reduced by the consumption that the displaced investment projects would have generated. (This requires an explicit analysis of the project's effects on consumption and investment.) The SRTP is then applied to net consumption. In effect, all results are converted to their consumption equivalents, then discounted at the SRTP.

The prescriptive approach arrives at the following conclusions:

(1) It is appropriate to apply a discount rate to public and private investment, including regulatory decisions. This discount rate should be derived from ethical considerations, reflecting society's views concerning trade-offs of consumption across generations.

(2) Because of practical limits on the feasibility of intergenerational transfers, and in the absence of optimal tax policy,[9] the SRTP will in general fall below the producer rate of interest.

(3) The cost of a greenhouse mitigation project must include the forgone benefits of other competing investments not undertaken. This means that costs should be adjusted for the shadow price of capital, the present value of the future consumption yielded by a unit of capital. If a mitigation project would displace private investment, and returns to both projects accrue to the same generations, then it is appropriate to use the opportunity cost of capital – the return that the private investor would have received from the forgone capital investment. Only after doing this will it be appropriate to use the social rate of time preference to discount consumption.

4.2.1 *Discount rate estimates – Prescriptive approach*

If the pure rate of time preference (ρ) is zero, then high rates of productivity increase (and thus high g), of the order of 1.5%, plus high (absolute) values of the elasticity of marginal utility (θ)[10] imply a social discount rate of about 3%. With low rates of productivity increase, of the order of 0.5%, and low (absolute) values of the elasticity of marginal utility, the social discount rate is of the order of 0.5%. In a gloomy scenario, in which future output and consumption decline, then g and thus the SRTP may be negative (Munasinghe, 1993). Also, the discount rate need not be constant over time even if ρ and θ are constant, since g need not be constant.

The economic literature on global warming has used a range of discount rates. To follow the approach suggested by Cline (1992), with a zero rate of pure time preference (ρ), and using the central case consumption growth rate of 1.6% per capita from the IPCC scenarios (IPCC, 1992), multiplied by an elasticity of marginal utility (θ) of 1.5, gives an SRTP of 2.4%. If, instead, it is assumed that per capita growth is only 1% (perhaps because of slower growth after 100 years), or if $\theta = 1$, then the SRTP becomes 1.5%. After taking account of the share of resources coming out of capital (20% economy-wide versus 80% out of consumption) and taking into account the opportunity cost of displaced capital and depreciation, the effective discount rate becomes 2 to 3%.

A higher SRTP may apply to developing countries with higher rates of productivity growth. If labour productivity increases by 5-8% per year, as experienced by the high-growth countries of Asia, and with an elasticity of marginal utility of 2, discount rates of the order of 10 to 16% could be justified. Similarly, low-income countries close to subsistence levels could have high elasticities of marginal utility (this assumes a rapid fall-off of marginal utility from the extremely high initial levels associated with privation), so that their SRTPs could be high even if they were experiencing slow growth over long periods. These distinctions imply that developing countries may be less willing than industrialized countries to assume abatement costs now in anticipation of climate change benefits later.[11]

These discount rates apply to consumption only. They can be used only after the forgone benefits of other investments not made (i.e., the opportunity costs) have been included in the costs of the programme. If the forgone investments would have produced a high return, then calculated output and future consumption will suffer, making the mitigation programme relatively less attractive.

Critics of the prescriptive approach note that the opportunity cost of capital (the market rate of return) usually exceeds the SRTP. This suggests that society should not make decisions on the basis of a 2% discount rate, because in doing so we would be forgoing better alternative investments. Prescriptionists argue that the SRTP does not equal the market rate of interest because important alternatives are not feasible – in particular, because society cannot set aside investments over the next three centuries, earmarking the proceeds for the eventual compensation of those adversely affected by global warming. Accordingly, if the SRTP is 1 to 2%, a climate change investment returning 2% is better than no investment at all. Critics of the prescriptive approach also point out that a discount rate of 2% is glaringly inconsistent with observed behaviour (e.g., government spending on education or research, or development assistance by donor countries). To this, prescriptionists reply that just because the government fails to allocate resources in one area on the basis of ethical considerations, that is no reason to insist that decisions in other areas be consistent with that initial decision.

4.3 Descriptive Approach

The other widely employed approach focusses on the (risk-adjusted) opportunity cost of capital. Most global warming optimization models (e.g., Nordhaus, 1994; Peck and Teisberg, 1992; Manne *et al.*, 1993) rely on the descriptive approach, which rests on three arguments:

(1) Mitigation expenditures displace other forms of investment. Advocates of the descriptive approach advise decision makers to choose the action that leads to the greatest total consumption (Nordhaus, 1994).[12]
(2) If the return on mitigation investments lies below that of other investments, then choosing other investments would make current and future generations better off. Transfers to future generations, if necessary, are to be considered separately.
(3) The appropriate social welfare function to use for intertemporal choices is revealed by society's actual choices (hence the name, descriptive approach). Believing that no justification exists for choosing an SWF different from what decision makers actually use, advocates of the descriptive approach generally call for inferring the social discount rate from current rates of return and growth rates (Manne, 1994).

Critics have questioned all three arguments.[13]

4.3.1 Formulation of the descriptive approach

The descriptive approach looks at investments in the real world, and sets the discount rate accordingly. The descriptive approach implicitly aims to maximize the economic resources available to future generations, allowing them to decide how to use these resources. Nordhaus (1994), Lind (1994), Birdsall and Steer (1993), Lyon (1994), and Manne (1994), among others, have all stressed the importance of the opportunity cost of capital, noting that even apparently small differences in rate of return result in large differences in long-run results. Over 100 years, an investment at 5% returns 18 times more than one at 2%. Thus, where some redistribution of future returns is possible, society would be foolish to forgo a 5% return for a 2% return.

Birdsall and Steer of the World Bank (1993) explain the need to direct investment to the most productive uses, warning against use of too low a discount rate:

> We feel that meeting the needs of future generations will only be possible if investable resources are channelled to projects and programmes with the highest environmental, social, and economic rates of return. This is much less likely to happen if the discount rate is set significantly lower than the cost of capital.[14]

Wildavsky (1988) explains the point in the context of health and safety regulations:

> Insofar as we today should consider the welfare of future generations, our duty lies not in leaving them exactly the social and environmental life we think they ought to have, but rather in making it possible for them to inherit a climate of open choices – that is, in leaving behind a larger level of general fluid resources to be redirected as they, not we, see fit.

To advocates of the prescriptionist approach who claim that on ethical grounds, it is difficult to support a rate of pure time preference much above zero (Cline, 1992), advocates of the descriptive approach point to actual behaviour of individuals and nations. For example, development assistance budgets for the OECD countries average about 0.25% of GDP – certainly inconsistent with the ethical arguments used to justify the assumption that $\rho = 0$.[15]

Further, as Manne (1994) demonstrates, a low SRTP implies a high rate of investment: A discount rate of 2% implies far more investment than actually occurs in any country now, and thus would require a big jump in savings rates to finance.[16] But tax policy in most OECD countries significantly depresses investment, which raises the return to investment at the margin, and is therefore inconsistent with a low SRTP. What conclusion to draw from this evidence depends on whether tax policy is viewed as a constraint or as the result of optimizing an SWF. Most advocates of the descriptive approach hold the latter view. Descriptionists also emphasize that in the presence of multiple departures from perfect competition, the piecemeal fix proposed in the prescriptive approach may make matters worse rather than better.

Advocates of the descriptive approach have debated whether to use the producer interest rate i (the private rate of transformation between investment today and investment in the future), the consumer interest rate r (equal to the producer rate after taxes), or something in between. The choice depends in large part on the degree of distortion introduced in the tax system.

The rate of return on corporate capital, equities, and even bonds can be thought of as including a risk premium for various uncertainties, including the risk of inflation. The very low return on short-term government bonds has the lowest risk component and, some would argue, is closer to the risk-adjusted rate we are seeking.

4.3.2 Returns to investment and discount rate estimates – Descriptive approach

A review of World Bank projects estimated a real rate of return of 16% at project completion; one study found returns of 26% for primary education in developing countries. Even in the OECD countries, equities have yielded over 5% (after corporate and other taxes) for many decades, which is comparable to a pretax rate of at least 7% (see Table 4.1).[17] Note that although average rates of return are observed, decisions are based on marginal rates of return.

Table 4.1. *Estimated returns on financial assets and direct investment*

Asset	Period	Real return (%)
High-income industrial countries		
Equities	1960–84 (a)	5.4
Bonds	1960–84 (a)	1.6
Nonresidential capital	1975–90 (b)	15.1
Govt. short-term bonds	1960–90 (c)	0.3
U.S.		
Equities	1925–92 (a)	6.5
All private capital, pretax	1963–85 (d)	5.7
Corporate capital, posttax	1963–85 (e)	5.7
Real estate	1960–84 (a)	5.5
Farmland	1947–84 (a)	5.5
Treasury bills	1926–86 (c)	0.3
Developing countries		
Primary education	various (f)	26
Higher education	various (f)	13

Sources: Quoted in Nordhaus, 1994: (a) Ibbotson and Brinson, 1987, updated by Nordhaus, 1994; (b) UNDP, 1992, Table 4, results for G-7 countries; (c) Cline, 1992; (d) Stockfisch, 1982; (e) Brainard *et al.*, 1991; (f) Psacharopoulos, 1985.

4.4 Conflicts Between the Two Approaches

Much of the disagreement between the prescriptionist and descriptionist views turns on the question of compensation among generations. The descriptive approach assumes compensation from one generation to another for any loss of environmental amenities, implicitly leaving unanswered whether compensation is likely to occur.[18] The prescriptionist view implies not only that transfers to future generations are constrained, but that climate change policies are the only way to make these transfers (Manne, 1994). The descriptionist view argues for choosing the path that maximizes consumption, making transfers among generations separately out of the larger present value of consumption. The alternative – overriding market prices on ethical grounds – opens the door to irreconcilable inconsistencies. If ethical arguments, rather than the revealed preferences of citizens, form the rationale for a low discount rate, cannot ethical arguments be applied to other questions? If it is argued, on ethical grounds, that it is unethical to pay rents (royalties) to oil companies, does that mean that cost-benefit calculations should use $2 for the price of oil (Nordhaus, 1994)?

4.5 Conclusion: What Can Discounting Contribute to Climate Change Analysis?

The prescriptive approach can be interpreted as doing as much as is economically justified to reduce the risk of climate change; the descriptive approach can be interpreted as maxi-

BOX 4.1: EXAMPLE OF PROJECT EVALUATION USING PRESCRIPTIVE AND DESCRIPTIVE APPROACHES

Suppose a greenhouse mitigation project is under consideration. If undertaken now, it will cost $1 million. If not undertaken, a new sea wall might be required in year 50, costing $10 million. If it is necessary, building a sea wall would avoid damages of $1 million per year.

Capital cost	$1 million
Time until damages begin	50 years
Cost of sea wall, year 50	$10 m
Avoided damages, years 50, 51, 52, 53, . . .	$1 m/yr
Opportunity cost of capital	5%

The decision maker has four options:

(a) Do nothing (year 0), do nothing (year 50)
(b) Do nothing (0), build sea wall if necessary (50)
(c) Mitigation project (0), do nothing (50)
(d) Other investment (0), build sea wall if necessary (50)

The stream of benefits is as follows:

Option (year)	**0**	. . .	**50**	**51**	**52**	. . .
(a)	0	. . .	0	0	0	
(b)	0		-10	1.0	1.0	. . .
(c)	-1		1.0	1.0	1.0	. . .
(d)	-1		11.5 -10 =1.5	1.0	1.0	. . .

At discount rates below 10%, option (b) dominates option (a) – if the sea level rises, it is better to build the sea wall than do nothing. Option (d) dominates option (c), as investing the $1 million in year 0 at 5% yields $11.5 million in year 50, enough to build the sea wall with $1.5 million left over. Thus, the descriptive approach would point to option (d) or (b). But option (d) may be institutionally infeasible, as there may be no way to put aside $1 million today and leave it untouched for 50 years as a Fund for Future Greenhouse Victims. If (d) is infeasible, as advocates of the prescriptive approach might suggest, then the decision maker must choose between (b) and (c). In summary, then, descriptionists would choose between (b) and (d), whereas prescriptionists would choose between (b) and (c). In either case, the choice will depend on the value attached to the consumption between years 1 and 49, which depends on the consumption rate of discount.

mizing the economic resources available for future generations and allowing them to decide how to use the resources. Both include the opportunity cost of capital – directly in the case of the descriptive approach, indirectly in the case of the prescriptive approach, which takes account of the full impact on consumption and, thus, of the cost of any displaced investment (see example of project evaluation in Box 4.1). The prescriptive approach looks at the risk-adjusted marginal return to capital, which may be considerably lower than observed average rates of return to capital. Refinements to the descriptive approach would take into account limitations on intergenerational transfers, including the absence of lump sum redistributive taxes.

The discount rate is particularly important in climate change analysis. Because of the very long times involved in climate change decisions, the choice of a discount rate powerfully affects the net present value of alternative policies, and thus the policy recommendations that emerge from climate change analysis.

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Annex 4A: Methodological Notes on Discounting

4A.1 Intertemporal maximization of well-being

In an influential series of articles, Koopmans (1960) conducted a series of thought experiments on intertemporal choice to see the implications of alternative sets of ethical assumptions in plausible worlds. He suggested that we can have no direct intuition about the validity of discounting future well-being, unless we know something concrete about feasible development paths.

Koopmans considered the set of feasible consumption paths (from the present to the indefinite future) and the corresponding set of welfare or "well-being" paths. These paths could then be ordered to select the optimum path of well-being, according to the criterion:

$$z = \int_{t=0}^{\infty} W(c_t)\, e^{-\rho} dt \tag{4A.1}$$

with $\rho > 0$, where W is welfare, and c_t is consumption at time t. Correspondingly, the discount rate for the time path of consumption is:

$$i_t = i(c_t) = \rho + \theta(c_t)\, [dc_t/dt]/c_t \tag{4A.2}$$

where $\theta(c_t)$ is the elasticity of marginal well-being, or marginal utility, at time t (Arrow and Kurz, 1970). (Note that whereas the main text treats this term as a constant, it is explicitly considered to vary with the level of consumption in the treatment here.) Along a full optimum path, the consumption rate of discount equals the productivity of capital (i.e., the social rate of return on investment; in this case, i_t equals the producer rate of interest). This is the Ramsey Rule (Ramsey, 1928).

A convenient form of W is one giving a constant elasticity of marginal utility, such as:

$$W(c) = c^{-\theta} \tag{4A.3}$$

As discussed in the text, the greater the rate of pure time preference (ρ), the lower the weight accorded to future generations' well-being relative to that of the present generation. Mirrlees' (1967) computations introduced this possibility ($\rho > 0$) as a way of countering the advantages to be enjoyed by future generations should the productivity of capital and technological progress prove to be powerful engines of growth.

A higher value of θ means greater emphasis on intergenerational equity. As $\theta \rightarrow \infty$, the well-being function in (4A.l) resembles more and more the Rawlsian max-min principle; in the limit, optimal growth is zero.

In (4A.3), *W(c)* has no minimum value. If $\rho = 0$, this ensures that very low future consumption rates would significantly affect aggregate intertemporal welfare. On the other hand, if ρ were positive, low rates of consumption by generations sufficiently far in the future would not be penalized by the optimal path criterion in (4A.l). This means that unless the economy is sufficiently productive, optimal consumption will tend to zero in the very long run. Dasgupta and Heal (1974) and Solow (l974a) showed in a model economy with exhaustible resources that optimal consumption declines to zero in the very long run if $\rho > 0$ and in the absence of technical change, but that it increases to infinity if $\rho = 0$.

It is in such examples that notions of sustainable development can offer some analytical guidance. If by sustainable development we mean that the chosen consumption path should never fall short of some stipulated positive level, then it follows that the value of ρ would need to be adjusted downward in a suitable manner to ensure that the optimal consumption path meets the requirement. This was the substance of Solow's remark (see Solow, 1974b) that in the economies of exhaustible resources the choice of ρ can be a matter of considerable moment.

So far an assumption underlying this discussion has been that well-being or utility has not been bounded. If we impose bounds on well-being, other results obtain, because of the mathematical properties of the space of bounded sequences. For such sequences present value calculations are not rich enough to capture all the subtleties of evaluation of a utility stream. Instead, one must add another term to the present value. This second term will in general have the form of a long-term average. It could be approximated by minimum requirements for the long-run stocks of environmental resources. This formulation attempts to account for both basic levels of human needs and limitations on total resources.

4A.2 Consumption versus investment discount rate

Sandmo and Dreze (1971) address the choice of the correct rate of discount to use in the public sector when there are distortions in the economy, for example, in the form of taxes, which prevent the equalization of marginal rates of substitution and transformation in the private sector. Under certain assumptions, the corporate tax drives a wedge between the marginal rate of time preference of consumers and the marginal rate of transformation in private firms.

They find that for a closed economy:

$$1+r < 1+i < 1+[r/(1-t)] \tag{4A.4}$$

where r is the consumer interest rate, t is the tax rate, and i is the public sector's discount rate. This rate should thus be a weighted average of the rate facing consumers and the tax-distorted rate used by firms. Since $1 + r$ measures the marginal opportunity cost of transferring a unit of resources from private consumption, and since $1+[r/(1-t)]$ is the measure for transfers from private investment, a unit of resources transferred from the private to the public sector should be valued according to how much of it comes out of consumption and how much out of investment.[19]

The general idea of the prescriptive approach is to calculate impacts on consumption and to find the appropriate discount factor for discounting those changes. We are, in effect, taking consumption as our standard of measure. This is convenient and natural, but there are other ways of performing the calculations, using other measures. If these other measures are used, relative prices over time (discount factors) will differ from those associated with the consumption measure.

By the same token, if, for example, systematic relationships exist between the outputs and inputs of a project and the total changes in consumption they induce, and if consumption changes over time, then instead of discounting total consumption impacts at the SRTP, one could calculate the direct impacts using another discount factor. The discussion above of the Sandmo-Dreze formulation is a case in point. These alternatives do not provide prescriptions, only alternative formulas for arriving at the same point.

The discrepancy between public evaluation of a marginal dollar to future generations and individuals' own intertemporal evaluations can arise even in the case of very simple social welfare functions. Thus, assume that there is a utilitarian social welfare function, which simply adds up the utility of successive generations, and for simplicity, assume each generation lives for only two periods. The t^{th} generation's utility is represented by a utility function of the form:

$$U^t(c^t_t, c^t_{t+1}) \tag{4A.5}$$

where the first argument refers to consumption during the first period of the individual's life, the second to consumption during the second period. Then observed market rates of interest refer to how individuals are willing to trade off consumption over their own life. These may or may not bear a close correspondence to how society is willing to trade off consumption across generations. The former (the investment discount rate) corresponds to U^t_2/U^t_1, whereas the latter (the consumption discount rate) corresponds to U^{t+1}_1/U^t_1.

If the government has engaged in optimal intertemporal redistribution and does not face constraints in imposing lump sum (i.e., nondistorting) taxes on each generation, then the two discount rates will be the same and equal to the marginal rate of transformation (in production, i.e., the return to investment). But whenever either of these conditions is not satisfied, then market rates of interest facing consumers (measuring their own marginal rates of substitution) need bear no close relationship to society's marginal rate of substitution across generations. Diamond and Mirrlees (1971) show that if the only reason for the discrepancy between producer and consumer interest rates is optimally determined commodity taxes, and there are no after-tax profits, possibly because there is a 100% pure profits tax, then the government should use the producer rate of interest. Stiglitz and Dasgupta (1971) have shown that this result does not hold if either of these assumptions is dropped.

Under certain circumstances (in particular, the existence of optimal intergenerational lump sum transfers), asymptotically the producer rate of interest will equal the pure rate of time preference of society. More generally, when the government must resort to distortionary taxes, not only is this not true, but the rates of discount employed may reflect distributional considerations (see Stiglitz, 1985).

4A.3 The social rate of time preference

As stated in the main text, the social rate of time preference (SRTP) is composed of pure time preference (ρ) and a discount rate that takes into account falling marginal utility as the level of consumption rises (θg); or $SRTP = \rho + \theta g$.

Pure time preference. The earliest economics literature, in addressing these issues, argued that the appropriate value of ρ was zero (Ramsey, 1928). Ramsey based his argument on the ethical presumption that all individuals, including those living in different generations, should be valued the same. The argument since then has advanced only slightly. Some have argued that the discount rate should be adjusted for the probability of extinction. Plausible estimates of this effect would add very little to the discount rate. Others have pointed out that a positive discount rate is needed for acceptable optimization results: In the absence of a discount factor, the sum of future utilities may be infinite, so that the mathematics of maximizing a social welfare function are ill-defined. Because even a very small positive discount rate, however, would resolve the mathematical issue, this objection has little practical moment.

In a society in which income levels are not expected to rise, impatience may still cause a household (or the present generation) to discount the future (generation), that is, to prefer consumption today to consumption tomorrow; in discounting terms, this means equating a smaller amount of consumption today with a larger amount in the future. In his classic paper on optimal saving, Ramsey (1928) judged that any allowance for pure time preference ($\rho > 0$) "is ethically indefensible and arises merely from the weakness of the imagination." Correspondingly, he argued that future generations should have equal standing with the current generation; there was no moral or ethical basis for giving less weight to the welfare of future generations than to that of the current generation.

For an individual, some nonzero value of pure time preference can make sense, because he or she has a finite life and thus uncertainty about being alive to enjoy future consumption. Nonetheless, for a life span of 70 years, pure time preference at even 1% per annum implies that consumption at the end of life is worth only half that at the beginning. Evidence also suggests that individuals' discount rates may change over time, with lower discount rates being used for longer time horizons.

Considerations for society as a whole are different. The social welfare function approach asks: If society values different generations in a particular way (reflected in the social welfare function), how should changes in consumption in different generations be compared? Ramsey's analysis focussed on the ethical presumption that consumption by all generations should have equal value. But this does not exclude the possibility that, as a matter of *description,* the current generation gives less value to consumption of future generations.

Diminishing marginal utility. The second term on the right side of equation (4.1) (θg) raises two questions. First, what are reasonable expectations concerning increases in per capita income (growth rate g in the equation)? Second, how should intertemporal differences in expected consumption per capita be translated into social weights, that is, marginal valuations of dollars of future income? This second question refers to the parameter θ, the elasticity of marginal utility, which tells how rapidly the additional utility from an extra unit of consumption drops off as consumption rises.

No consensus on the first question has emerged. Although no consensus has emerged on the answer to the second question, there is a generally accepted method for approaching the issue. The evaluation of any individual's consumption can be summarized by a utility function of the form $U = U(c)$ where the parentheses indicate that U, utility, is a function of c, per capita consumption. Marginal utility is positive ($U'(c) > 0$), but declines as consumption rises ($U''(c) < 0$). A new shirt, for example, benefits a pauper more than a prince. That is why if consumption of some future generation is higher, the marginal valuation of its consumption will be lower. The question is, how much lower? Formally, the answer is given by the elasticity of marginal utility (θ) or:

$$[dU'/U']/[dc/c].$$

Individuals in their day-to-day decision making reveal information about their perceptions concerning their own utility functions in at least two different contexts: behaviour towards risk and behaviour towards intertemporal allocation of consumption. In both contexts, there seems to be a consensus that elasticities of marginal utilities lie in the range of 1 to 2, even though the empirical studies require strong assumptions about the specific form of the utility function (symmetric and time separable). Thus, one of the most commonly used utility functions, the logarithmic, implies $\theta = 1$, meaning that if income rises by 1% the marginal utility of consumption falls by 1%. Attempts by Fellner (1967) and Scott (1989) to estimate this elasticity place it somewhat higher, at 1.5, whereas recent estimates reviewed by Pearce and Ulph (1994) place it in the vicinity of 0.8.

Just as the choice of the rate of pure time preference (ρ) has important implications for intergenerational equity, as discussed above, so does the choice of the elasticity of marginal utility. The more weight the society gives to equity between generations, the higher the value of θ. Thus, a value of, say, 3, would mean that it would require a 30% rise in the next generation's per capita consumption to warrant a 10% reduction in that of the present generation; or, under a bleaker outlook, that if the future generation is expected to be poorer than the present, the present would be prepared to accept a 30% reduction in consumption to secure a 10% increase in that of the future generation (so long as the two relative consumption levels did not reverse). Even $\theta = 1$ gives some emphasis to equity, however. When $\theta = 1$, a 10% reduction in the richer generation's income will be an acceptable trade-off for a 10% increase in that of the poorer generation, even though the absolute reduction of the one exceeds the absolute increase of the other (because the absolute consumption base of the one is larger than that of the other).

Risk. Utility may also be discounted for risk. The standard treatment of risk in models involving impacts over a single individual's life is not to raise the discount rate for riskier projects, but instead to convert probabilistic consumption patterns into their certainty equivalents and then discount the results at the standard rate. The same should be true for the pure time preference component of the SRTP when discounting across generations. This component should remain unchanged with respect to risk, and the influence of risk should instead be incorporated in the stream of expected consumption effects.

There would seem to be an argument for varying the growth-based component of the SRTP with respect to risk, however. If there is uncertainty about the rate of per capita income growth, g, then consider the effect on the component θg in the SRTP. Suppose two scenarios each have 50% probability: per capita income growth of 1% and per capita growth of 2%. There will be two resulting possible streams of marginal utility over time. The stream of expected value of marginal utility will be the average of these two streams. But if marginal utility is a convex function of consumption, this average will be greater than the stream of marginal utility generated by considering the simple average growth rate over time, 1.5%. That is, with diminishing marginal utility, at any point in time marginal utility along the path for 1.5% growth will be closer to that of the 2% growth path than to that of the 1% growth path. Correspondingly, the expected marginal utility path lying halfway between the two scenarios will coincide with the marginal utility stream for a growth rate closer to 1% than to 2%. Essentially, the expected value of marginal utility is greater than the marginal utility of expected income. On this basis, there would be grounds for reducing the growth-based component of the SRTP under circumstances of risk. Because the risk in predicting per capita growth on centuries-scale horizons is high, this consideration is particularly relevant for the problem of global warming.

Other arguments. Empathetic distance provides another rationale for discounting. Rothenberg (1993) and Schelling (1993) have suggested that although nonzero pure time preference might make sense for an initial two or three decades, beyond a certain future point it makes no sense to apply further discounting of consumption for pure time preference. Thus, "as the future recedes . . . single generations come to be perceived more and more as homogeneous entities" (Rothenberg). Similarly, "time may serve as a kind of measure of distance. . . . Beyond certain distances there may be no further depreciation for time, culture, geography, race, or kinship" (Schelling). A graph of the fraction of face value accorded to each successive generation (for constant real consumption) would thus be a series of declining, successively shallower steps that eventually reach a horizontal plateau. A deep plateau signifies major discounting for empathetic distance; a horizontal line beginning and remaining at unity is the zero pure time preference rate across generations recommended by Ramsey. Policy based on empathetic distance (a shelf lower than unity) may be more defensible in a normative sense when the action is refraining from conferring a windfall gain (as in penurious aid budgets) than when it involves the imposition of windfall damage (as in global warming's effects on future generations).

Another argument for nonzero pure time preference is that setting the rate at zero could imply that the present generation should accept near-starvation consumption levels and correspondingly low utility because, with even very small returns on investment, an endless stream of future generations could enjoy increased consumption and (to a lesser degree) utility as a result. To some extent, however, this concern is already addressed in the overall discount rate equation (4.1). As noted, the first term in that equation discounts utility (pure time preference), but the second term additionally discounts consumption to take account of falling marginal utility. The present generation is protected against an optimizing programme setting its consumption near zero if the elasticity of marginal utility (θ) is large enough and marginal utility drops off fast enough to rule out impoverishment of the present generation for gains to future generations.

Koopmans (1966) and Mirrlees (1967) have expressed the concern that zero time preference would imply unacceptably low levels of current consumption, and even no consumption under some circumstances. Even positive but very low discount rates might, in the absence of technological progress, lead to unreasonably high savings rates. (This illustrates a general problem with models founded on utilitarianism: They may imply very large sacrifices from one generation or group.) These models might well be seen as providing arguments that the rate of time preference is greater than zero, though they do not go far in specifying its proper magnitude.[20]

4A.4 The social welfare function

Economists have long debated the equity of discounting distant future benefits (Ramsey, 1928; Mishan, 1975; Rawls, 1971; Sen, 1982). The usual approach to issues of equity since Bergson (1938) has involved the choice of a social welfare function, and arguments about the choice among alternative social welfare functions have turned on the ability to derive a particular function from sound theoretical principles (seemingly plausible axioms) and on the resulting reasonableness of its derived implications.

Although all social welfare functions have been criticized for assuming interpersonal comparability of utility, there seems to be no way of addressing the ethical issues involved in making decisions affecting different generations without making some assumptions implicitly or explicitly about interpersonal comparability. Two polar views are represented by the utilitarian approach, in which social welfare is the sum of utilities, and the Rawlsian approach, in which social welfare reflects the welfare of the worst-off individuals. Whereas the utilitarian approach can be derived from what many view as a persuasive axiomatic (theoretical) structure (Harsanyi, 1955), the Rawlsian approach is derived from a "max-min" strategy (maximize the minimum outcome for any given party). Although this strategy is popular in game theory, it does not rest on widely accepted axiomatic principles.

The Rawlsian max-min principle is the strongest in assuring (the least fortunate groups of) future generations levels of consumption at least as great as that of (the least fortunate groups of) the current generation. It is consistent with the Brown-Weiss (1989) approach noted below. The max-min criterion permits inequality in consumption between individuals (or in this case, between generations) only if it improves the position of the poorest. In the absence of technical change this would imply that consumption per head should be the same for all generations. By contrast, the utilitarian criterion allows future consumption, in principle, to fall below current consumption, provided the current generation is made sufficiently better off as a result. Correspondingly, it also allows for decreases in present consumption, provided the future generation is made sufficiently better off as a result.

The Rawls and utilitarian social welfare functions can be viewed as limiting cases of more general social welfare functions embracing social values of equality (Atkinson, 1970; Rothschild and Stiglitz, 1973). In practice, so long as there is sufficient scope for technological change, optimizing any egalitarian social welfare function over time yields increases in consumption per capita. Moreover, with any of the approaches, earlier generations are entitled to draw down the pool of exhaustible resources so long as they add to the stock of reproducible capital.

Within the individualistic utilitarian social welfare approach, there is still the question of the appropriate value of ρ, the pure rate of discounting future utility relative to current utility. Ramsey and others have argued that there exists no ethical basis for treating different generations differently; thus ρ should be zero. The individualistic social welfare function, accepted by most economists as the basis of ethical judgments, accepts individuals' own relative valuations of different goods. It does not place separate valuations on unequal access to particular goods, other than through their effects on the affected individuals. Although this probably represents the consensus view, some economists have insisted that for particular goods, individuals' valuations need not be the basis of societal valuations. For instance, Tobin (1970), in what he called specific egalitarianism, argued that society might argue for greater equality in distribution of health care than would be reflected in individuals' own evaluations. Most economists, however, reject this view.

Sen (1982) similarly suggests a basis for not discounting when environmental effects are in question. He argues that a fundamental right of the future generation may be violated when the environment is degraded by the present generation, and that the resulting "oppression" of the future generation is inappropriate even if that generation is richer than the present and has a lower marginal utility of consumption. In this framework, intertemporal equity for environmental questions requires "a rejection of 'welfarism,' which judges social states exclusively by their personal welfare characteristics." It should be noted that this recommendation leads to paradoxes and inconsistencies.

4A.5 Departures from "first-best" assumptions

Analysis of optimal tax and expenditure policy occurs in a hypothetical "first-best" world, with complete markets and optimal redistribution policy (i.e., in which redistribution occurs only through lump sum taxes that do not change relative prices). In such a world, the discount rate will equal the marginal product of capital (i.e., the value of the additional output resulting from an additional unit of investment), which will equal the interest rate faced by both producers and consumers (Lind *et al.*, 1982).

Because the real world economy may differ in important respects from the first-best world, the literature also addresses departures from the first-best assumptions. Taxes drive a wedge between i, what producers pay to borrow, and r, what consumers receive on their savings. If money for public investment comes entirely from other investment, then the discount rate should be the producer interest rate i. If the money comes entirely from consumption, then the discount rate should be the consumer interest rate r. If the money comes partly from investment and partly from consumption, then the appropriate discount rate will fall somewhere between r and i; the exact answer requires an explicit analysis of how climate policy affects investment and consumption.

In the general case in which costless intergenerational transfers are not possible, no single discount rate can be applied. Rather, project-specific discount rates are required. Market rates are no longer a reliable indicator of the appropriate discount rate, which may be greater than or less than the before-tax return on investment (Stiglitz, 1982). In this general case, no theoretical rule connects the discount rate to any observed market rate, although market rates still contain valuable information that should be used in arriving at a discount rate.

Economists have long recognized that a competitive market equilibrium yields a Pareto-efficient outcome under appropriate conditions (perfect competition, no externalities, etc.). The distribution of income that it yields, however, does not in general maximize any particular social welfare function. It is a well-recognized function of government, therefore, to intervene in the distribution of income, for example, by establishing programmes for the very poor. Prescriptionists note that the *intertemporal* distribution of welfare that emerges from the market will not, in general, maximize any particular social welfare function either. Although it is a legitimate function of government to intervene to change the intergenerational distribution of welfare, there is no presumption that the government has in fact intervened to make the observed resource allocations maximize intertemporal social welfare. Moreover, in the case of climate change, no one government exists to make these decisions.

Prescriptionists emphasize that the market rate of interest – the relative price of consumption of one generation in one year of its life to its consumption in another year – will not in general equal the SRTP. In standard life-cycle models, with no technological progress and an economy in steady state, there would be no discounting for society's purposes: Each generation is identical, so the marginal utility of consumption of each is the same. Nonetheless, the market rate of interest will be positive in any efficient equilibrium under certain reasonable assumptions about utility functions (such as individual impatience and zero bequest motive; Diamond, 1965). In such models the market rate of interest would thus always overestimate the SRTP. Under some special conditions, with governments intervening with nondistorting taxation to optimally redistribute income across generations, observed market rates of interest will accord with the SRTP. But these are highly specialized conditions (see Stiglitz, 1985; Pestieau, 1974). The market rate of interest remains relevant because it reflects the opportunity cost of capital, which strongly affects the changes in consumption generated by any change in policy.

4A.6 Special considerations for discounting in government projects

A large literature has debated whether, for small changes in consumption levels, observed rates of interest provide the appropriate basis of trading off government expenditures and changes in consumption of individuals of different generations at different dates. In the simplest case, in which there is no taxation, there are no market distortions, and a single individual living forever (or else "dynastic" utility functions in which individuals take full account of their descendants' welfare), society's intertemporal discount rate will correspond to that of the representative individual, and his or her trade-offs across time would be given by the market rate of interest. But these assumptions are not generally satisfied, as evidenced by the marked discrepancy between the lower interest rates on savings typically facing consumers and the higher rates earned on investments by producers.

Some of the disagreement arises from confusion about what is being discounted. The social discount rate approach discounts changes in consumption at different dates. The producer interest rate approach discounts direct cash flows from the project. The two need not be inconsistent.

If a government is comparing two projects of equal cost, producing a result in the same year, then a comparison of the rates of return would provide an appropriate basis for choosing among projects. Cline (1992) proposes using a shadow price of capital set equal to the present discounted value of an annuity paying equal annual installments over a lifetime of N years (set at 15 years for the lifetime of typical capital equipment), with a return of r equal to the rate of return on capital, and discounted at the SRTP. With plausible ranges for N, r, and SRTP, the shadow price of capital can range from 2 to over 10 units of consumption equivalent per unit of capital (Lyon, 1994).

If a public project were to displace a private project of equal cost, the same reasoning would imply that the government should only undertake the public project if the rate of return exceeded the rate of return in the private sector (Stiglitz, 1982). More generally, when the government undertakes a project, complex general equilibrium effects can be expected. The full consumption effects of these changes (or their consumption equivalents) need to be calculated, and then discounted using the SRTP (Arrow and Kurz, 1970; Feldstein, 1970; Bradford, 1975; Stiglitz, 1982). This approach uses a shadow price of capital to convert all investment effects into their consumption equivalents, and then uses the SRTP to discount the resulting stream of consumption equivalents (Lind *et al.*, 1982; Gramlich, 1990).

For some projects, an adjusted discount factor, the public sector discount rate, is appropriate. A large literature addresses how the adjustment is to be made. One approach emphasizes the effects on consumption versus investment, deriving a weighted average of the consumption and investment rates of return, with weights depending on the respective importance of the sources of finance (Sandmo and Dreze, 1971).

4A.7 The environment and discounting

The essence of social discounting is to convert all effects into their consumption equivalents at the proper relative prices and then to discount the resulting stream of consumption equivalents at the social rate of time preference. Incorporating environmental effects thus does not change the discount rate itself, but does require special attention to the proper relative pricing of environmental goods over time. Although there is a generally accepted approach to valuing goods, there is less consensus concerning valuation of environmental impacts, other than those valued solely for their impacts on the production of goods.

The question is addressed within the public finance literature in terms of the valuation of public goods. Assume consumers have utility functions of the form $U = U(c,G)$ where G is some public good (e.g., quality of the environment). Then marginal rates of substitution between different values of c at different dates may bear no correspondence to marginal rates of substitution between different values of G at different dates. This implies that there is no justification for discounting environmental degradation at market rates of interest. The appropriate procedure entails converting the environmental change into equivalent contemporaneous consumption benefits and discounting those.

Technical progress and structural change over the past several decades have resulted in improvements in several measures of environmental quality in the developed countries. Moreover, recorded reserves of many "exhaustible resources" have actually increased over the past century, accompanied by a fall in their real prices. This provides evidence that continued growth in per capita incomes will result in improved environmental quality in at least some dimensions. Some have supposed, however, that environmental degradation will occur as society grows (Weitzman, 1993). If this occurs or if the environment is an income elastic good on which people are willing to spend relatively more as their income rises, then the marginal rate of substitution between environmental quality and private goods will systematically change over time, towards a higher relative marginal value of the environment. The result is equivalent to using a low (or even negative) discount rate for environmental amenities with prices unchanged. However, this process involves properly valuing future environmental benefits in arriving at the future flow of equivalent consumption, and does not change the discount rate to apply to the consumption stream.

Much of the environmental literature critical of cost-benefit analysis, in contrast, argues for a zero discount rate without seeming to recognize the distinction between a zero rate of pure time preference (ρ) and a zero discount rate (see, e.g., Daly and Cobb, 1989). But from equation (4.1), so long as consumption growth is positive there will be a nonzero SRTP. Similarly, some modern philosophers seem to make the same mistake (e.g., Parfit, 1983; Cowen and Parfit, 1992).

Finally, there has been considerable discussion about the proper discounting method for environmental projects of institutions such as the Global Environmental Facility of the World Bank (see, e.g., Munasinghe, 1993). The method that follows from the social cost-benefit approach is to obtain consumption equivalents of the environmental effects over time and then apply the appropriate discount rate. Within a fixed institutional investment budget, it may be that the collection of potential projects that successfully passes a cost-benefit test on this basis more than exhausts available funds. If so, efficient trade-offs within the menu of projects will appropriately involve cutoffs at a higher shadow price in funds drawn from the institutional budget – but always with benefit evaluation based on the consumption equivalence principle just outlined.

4A.8 Discounting and sustainable development

The Brundtland Commission called for "sustainable development," defined as economic activity that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations, 1987). Similarly, Brown-Weiss (1989) argued from the standpoint of international law that "each generation is entitled to inherit a planet and cultural resource base at least as good as that of previous generations."

A consensus exists among economists that this does not imply that future generations should inherit a world with at least as much of *every* resource. Such a view would preclude consuming any exhaustible natural resource. The common interpretation is that an increase in the stock of capital (physical or human) can compensate for a decline in the stock of a natural resource. Under most calculations, given the savings rates of all but the lowest-saving countries in the world, most countries now pass this test of sustainability.

Economics has recognized the concept of sustainability for some time. Hicks (1938) used the idea in defining net national income. Neoclassical growth theory (Phelps, 1961; Robinson, 1962) advanced the idea of sustainability in its formulation of the "Golden Rule," which is that configuration of the economy giving the highest level of consumption per head that can be maintained indefinitely. A recent extension has proposed the "Green golden rule" (Beltratti *et al.,* 1993). The recent economic debate on sustainable development has focussed on two issues: (1) intertemporal equity and (2) capital accumulation and substitutability. The extent to which natural and cultural resources are substitutable is critical to this analysis and is contentious. Many economists (for example, Pearce and Turner, 1990) stress the need for sustainability limits on the use of resources that future generations will need but cannot create.

Robert Solow's definition of sustainable development (Solow, 1992) focusses on intertemporal equity: Sustainable development requires that future generations be able to be at least as well off as current generations. Sustainable development does not preclude the use of exhaustible natural resources, but requires that any use be appropriately offset. Likewise, any environmental degradation must be offset by an increase in productive capital sufficient to enable future generations to obtain at least the same standard of living as those alive today.

Solow's definition, and much of economic theory to date, implicitly assumes that substitutes exist or could be found for all resources. If substitution possibilities are high, as most evidence from economic history indicates, then no single resource is indispensable, and intertemporal equity stands as the only crucial issue (Pearce and Turner, 1990). If, on the other hand, human and natural capital are complements or only partial substitutes, then different classes of assets must be treated differently, and some assets are to be preserved at all costs.

In many developing countries, Solow's definition would not be viewed as acceptable, since it seems to place no weight on their aspirations for growth and development. Further, formal models analyzing optimal development paths using a max-min (Rawlsian) criterion would focus exclusively on the welfare of the less developed countries. (Note that in Rawls' formulation, $\theta = \infty$.) But the remedy would be simple: immediate massive redistribution from the developed to the developing countries, with no environmental justification required. Even if there were limits on the transfers, this remedy would suggest that all the costs of mitigation – including those occurring within the developing economies – be borne by the developed countries.

Even the utilitarian approach ($\theta < \infty$) would tend to lead to higher general income transfers to poor countries than presently observed. Adherents of the descriptive approach might ask why the utilitarian construct is appropriate when considering intergenerational equity (as in the identification of the SRTP suggested in equation (4.1)) if it is not applied in practice across or even within countries now. In one sense, this question is another application of the principle suggested above, that in the absence of optimal redistribution intervention by government, observed market rates (in this case of transfers from rich to poor nations) will not necessarily or likely equal social rates. Alternatively, the equity norm suggested here may not be widely shared by governments or voters.

Despite the political constraints on present-day transfers from rich to poor countries, the time-discounting concepts of the utilitarian approach (and the SRTP in particular) remain valid. Thus, consider a matrix with two rows, developed nations and developing nations, and two columns, present and future. The SRTP can appropriately be applied between the two columns along each row, even if there is a barrier to its application between the two rows. Leaders and electorates in developing countries have cause for concern about their descendants just as do their counterparts in developed countries. As noted above, however, the value of the SRTP is likely to be higher for the developing nations than for the developed.

Endnotes

1. Identifying the appropriate discount rate has been discussed in the context of general cost-benefit analysis (Chapter 5) for many years (Dasgupta *et al.*, 1972; Harberger, 1973; Little and Mirrlees, 1974; Sen, 1967; Stiglitz, 1982). More recently, social scientists have debated the precise rate to use for global climate analysis (Broome, 1992; Cline, 1992; Nordhaus, 1991).

2. Direct intergenerational transfers could be made through a fund to compensate future greenhouse victims; without some such mechanism, however, there is no guarantee that such transfers will be made. Compensation will occur indirectly, however, if we bequeath a richer economy to our children and grandchildren.

3. In particular, an efficient policy is unequivocally better than an alternative only if those who are made better off under the efficient policy actually compensate those made worse off. More general treatments of cost-benefit analysis do incorporate distributional considerations.

4. When applied to discounting the utility of different generations, ρ is referred to as the social rate of pure time preference.

5. The *certainty equivalent* is the certain result that would make an individual indifferent between it and the uncertain outcome. Issues of equity can be treated analogously through the use of "equity equivalents" (Atkinson, 1970; Rothschild and Stiglitz, 1973).

6. The alternative view, which could be called environment-specific egalitarianism, says that each good must be valued in isolation from all others. This view stresses the need for limits to the use of resources that will be needed or desired, but cannot be created, by future generations (Pearce and Turner, 1990). In the extreme, this belief, known as specific egalitarianism, argues that environmental goods (and in some cases, each environmental good) must be treated separately from all other goods and that each generation should enjoy the same level of environmental benefits as previous generations.

The mainstream view in economics holds that future generations can be compensated for decreases in environmental goods by offsetting accumulations of other goods (though increasing scarcity of some environmental goods will require increasing amounts of capital to offset the loss of an additional unit of the environmental good). Environmentalists may favour restricting the use of nonreproducible environmental resources in a way entirely consistent with the mainstream view, in that risk aversion in the matter of environmental quality will affect the rate at which society trades environmental goods for other goods. Only in the limiting case of infinite risk aversion will no trade-offs be made. Thus, adherents of environment-specific egalitarianism may back the same policies as risk-averse adherents of the mainstream view.

A related issue is whether decision makers should accept the current generation's valuation of the future benefits of environmental goods, as reflected in the market. Even those who believe the answer is no may accept trading off environmental for other goods, though those trade-offs may not be well reflected in current market prices.

7. The economist Thomas Schelling (1993) argues against the way discounting is generally applied to climate change projects. Schelling notes that discussions of discounting within the context of climate change policy often confuse three ideas: (1) discounting for consumption enjoyed in the future; (2) discounting for risk; and (3) discounting for consumption by others.

Schelling points out that one thinks differently about one's own consumption than about the consumption of others, and that a key feature of the climate change problem is that those likely to bear the cost of mitigation (the developed countries) differ from those likely to enjoy the benefits (the currently developing countries). Thus, says Schelling, we should recognize that climate change mitigation is more like foreign aid than it is like the usual public investments to which we apply discounting. Foreign aid budgets are low because the donors do not have strong feelings of concern for the beneficiaries. In the absence of evidence to the contrary, says Schelling, there is no reason to impute much stronger moral sentiments to those who will be paying for climate change mitigation.

8. The empirical problem of uncertainty in forecasting g, the growth rate, has yet to be resolved. The post-1973 slowing of productivity increases in many OECD countries suggests the need for a reexamination of historical trends and perhaps a reduction in the recommended discount rate. These considerations have become particularly important with the addition of intergenerational distributional effects. Low-income groups within developed countries have seen a sharp reduction in per capita income growth; this would lead to lower discount rates. On the other hand, some developing countries now enjoy high per capita income growth, suggesting a higher discount rate. At 7% per capita income growth, and with $\theta = 1.5$, the discount rate would exceed 10% even with ρ set to zero.

9. Optimal tax policy is intertemporally and distributionally optimal.

10. Standard estimates put this elasticity between one and two. Such estimates are based on an additive social welfare function using elasticities of marginal utility revealed by behaviour toward risk. Though specialists debate the appropriateness of the assumptions, no generally accepted view supports a different value of θ.

11. Other factors, however, might push the calculations the other way, such as the likelihood of higher relative future damage from global warming for the developing countries (see Chapter 6).

12. This will be the path that satisfies the intertemporal efficiency conditions (Lind *et al.*, 1982):

(1) Production: the marginal rate of transformation in production between one period and the next, and thus the marginal product of capital, equals the producer rate of interest for all goods: $MRT_j(t,t+1) = i$, that is, the marginal rate of transformation for any good j from period t to period $t+1$ equals the producer rate of interest i.

(2) Consumption: the ratio of the marginal utility of consumption in period t to the marginal utility of consumption in period $t+1$ equals 1 plus the consumer interest rate r, or $MUC_k(t)/MUC_k(t+1) = 1 + r$.

(3) Overall: the consumer interest rate equals the producer interest rate for all goods, for all consumers, in all time periods; that is, $r = i$.

13. Critics have noted (a) that is is not in general the case that mitigation expenditures displace other forms of investment on a dollar-for-dollar basis; (b) that the second argument can be read as a statement of the compensation principle, which holds that one need not ask if compensation has actually been paid, only whether it could be paid, so that questions of distribution and efficiency can be separated; and (c) that the third argument assumes the presence of lump sum redistributive mechanisms (in the absence of which the social marginal rate of substitution may not equal the opportunity cost of capital) and a degree of rationality in collective decision making that may not be plausible. Society may not engage in optimal intergenerational redistribution; yet in evaluating a policy, it may still wish to consider explicitly intergenerational effects. Taken to an extreme, argument (c) would suggest that the social marginal utility of the rich must equal that of the poor; otherwise, governments would have redistributed income already.

14. It might be argued that resources could still be channelled to the best projects using a lower discount rate, by employing a *shadow price of capital,* reflecting the scarcity of capital. The issues of the intertemporal price and the *current* scarcity price of capital can, in principle, be separated.

15. Technically, indifference to inequality between countries at a given time implies instead that the other key parameter, the elasticity of marginal utility (θ), is zero.

16. That is, if the social welfare function implied a 2% discount rate, and the government employed policies to maximize social welfare, then the savings rate would be very high.

Manne uses a standard growth model to examine the relation between discount rates and savings rates in the context of developed economies. He finds that discount rates of 1 or 2% imply an unrealistically rapid near-term increase in the rate of investment. Manne thus concludes that a discount rate this low is grossly inconsistent with observed or plausibly anticipated behaviour. On the other hand, prescriptionists might interpret Manne's analysis as showing simply that the intertemporal equilibrium established by market economies differs markedly from that corresponding to the solution of an intertemporal maximization problem based on a social welfare function derived from ethical considerations. But even if savings could be increased enough to drive the discount rate to 1 or 2%, climate change investments would still have to compete with many other public and private investments offering higher returns.

17. Some care must be taken in inferring the appropriate opportunity cost of capital from observed market rates of return. First, many standard measures reflect average rates of return rather than the relevant marginal rates. Second, most investments carry some risk. Cline (1992) observes that investors purchase both safe government bonds yielding about 1.5% real, and stocks, yielding 5-7% real; he argues that this suggests a risk premium of 3.5-5.5%. Thus, if the average observed return to capital is 7%, and if the marginal return is less than the average (as one would expect), then the certainty equivalent opportunity cost would be less than 3.5%. On the other hand, it has also been argued that this calculation holds only if it is assumed that households allocate assets efficiently (an assumption that prescriptionists deny in other contexts); that bonds have risks quite different from either stocks or climate mitigation investments; and, thus, that this comparison is invalid (Nordhaus, 1994).

18. In contrast, the predominant view fifty years ago held that a project should be considered desirable if the winners *could possibly* compensate the losers, whether or not this compensation actually occurred (Kaldor, 1939; Hicks, 1939). This "compensation principle" (which is no longer accepted) would support the view that the discount rate should be the producer cost of capital – the rate that investments would have earned elsewhere in the economy. If a dollar invested in education, research and development, or new factories yields a return of 10%, and climate mitigation yields 5%, then converting climate mitigation investment to something more productive would yield higher total returns, implying that everyone could be made better off. The compensation principle would be satisfied. But compensation may not actually be paid, and future generations will probably not benefit from knowing that they *might have been* made better off.

Economists consider two cases: (1) Pareto improvements – changes, including compensation actually paid, that make everyone better off; these are obviously desirable; and (2) changes that produce some winners and some losers. To address the second case, economists generally use a social welfare function, typically showing some preference for greater income equality (that is, increasing equality raises social welfare). A considerable literature, building on the work of Rothschild and Stiglitz (1973) has added precision to this idea. In choosing an SWF, economists also generally assume separability. That is, the SWF can be written $W = W(U_1, \ldots)$. The ethical idea underlying this assumption is that society's willingness to substitute consumption between individuals *i* and *j* does not depend on the utility or income of individual *k*, a form of the assumption of the independence of irrelevant alternatives. Economists also generally assume consumer sovereignty. That is, each individual's utility (entering the SWF) is determined by that person's own judgments, not the judgments of society more generally.

19. For an open economy, the elasticity-adjusted rate on foreign loans also enters the calculus. However, for analysis of a global issue, this extension is probably inappropriate, as globally the economy is closed.

20. Alternatively, these models may suggest that the problem lies in the assumption about technical change. If little or no technical change had been the rule in recent centuries, society might have evolved toward the high savings rates that seem so implausible given actual historical experience.

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