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The Social Evaluation of Intergenerational Policies and Its Application to Integrated Assessment Models of Climate Change*

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Abstract

Assessment of climate change policies requires aggregation of costs and benefits over time and across generations, a process ordinarily done through discounting. Choosing the correct discount rate has proved to be controversial and highly consequential. To clarify past analysis and guide future work, we decompose discounting along two dimensions. First, we distinguish discounting by individuals, an empirical matter that determines their behavior in models, and discounting by an outside evaluator, an ethical matter involving the choice of a social welfare function. Second, for each type of discounting, we distinguish it due to pure time preference from that attributable to curvature of the pertinent function: utility functions (of consumption) for individuals and the social welfare function (of utilities) for the evaluator. We apply our analysis to leading integrated assessment models used to evaluate climate policies. We find that past work often confounds different sources of discounting, and we offer suggestions for avoiding these difficulties. Finally, we relate the standard intergenerational framework that combines considerations of efficiency and distribution to more familiar modes of analysis that assess most policies in terms of efficiency, leaving distributive concerns to the tax and transfer system.

KEYWORDS: individual discount rate, social discount rate, intergenerational distribution, climate policy, integrated assessment models

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Evaluating climate change policies requires aggregating costs and benefits that accrue over long time periods and to different generations. The standard procedure in evaluating these costs and benefits is to discount future outcomes to a present value. Because of the large timescales involved, however, seemingly small changes in the discount rate can have dramatic impacts on policy choices. In a ranking of central uncertainties in evaluating climate policies, the Intergovernmental Panel on Climate Change (2007) (p. 823) listed two components of the discount rate as second and fourth in importance; only climate sensitivity ranked higher, and both discount rate factors outranked the estimated uncertainty surrounding the economic impact of a 2.5° temperature increase. Accordingly, it should not be surprising that the widely contrasting policy recommendations of different models, which range from prompt, aggressive action to little immediate response, are largely due to their different choices of discount rates.

The controversy over discounting in the climate context makes it useful to step back and consider intergenerational policy evaluation from its fundamentals before applying it to the specific case of climate change. The standard welfare economic framework for policy evaluation, which we analyze in section 1, holds that the optimal policy is that which maximizes social welfare. Social welfare is determined by a function W of the utilities, U, of all individuals in society. Utilities in turn are (under a simplification frequently employed in assessing climate change) a function of individuals' levels of consumption, c. How consumption affects utility is an empirical question. Observations of decisions that individuals make, especially decisions made under uncertainty, can be used to estimate the rate at which individuals' marginal utility falls with consumption. By contrast, how utility affects social welfare is a normative question, that is, a social judgment made by an outside evaluator.

These two distinct concepts, however, are frequently conflated both in actual policy evaluation and in discussions of the choice of the discount rate. Instead of separately specifying the social welfare function $W(U)$ and individuals' utility functions $U(c)$, analysts often use a single, reduced-form representation, $Z(c)$, under which social welfare is taken to be a direct function of consumption. There are a number of problems with using a reduced form that combines ethical parameters (those relating to W) and empirical parameters (those relating to U). This conflation of the ethical and the empirical makes discussions of the appropriate shape of $Z(c)$ confusing and sometimes misleading. For example, what many would take to be sensible parameter choices for the reduced-form, when combined with standard estimates of the underlying empirical evidence on individuals' utility functions, can imply ethical judgments regarding the social welfare function that most observers would, on reflection, reject. A related problem is that empirical arguments are sometimes mistakenly taken to be ethical and thus a matter that the outside evaluator is free to choose without regard to existing evidence.

In section 2, we extend this general welfare economic framework to the intergenerational setting, such as that involved in evaluating climate change policies. Corresponding to the two elements in social policy evaluation, there are two domains of discounting that should be considered separately. Individuals maximizing their utilities will discount their own future consumption. Their consumption and savings choices will be determined by the specification of the utility function U, by their expectations, and by government policies. For example, if a model is being used to evaluate a carbon tax or a cap on emissions, it must estimate how individuals will respond to such a policy. The pertinent features of the utility function are entirely an empirical matter. We will call this *predictive* discounting because the role of an assumption about discount rates is to predict individuals' behavior.

These utilities (themselves derived from individual maximizing behavior) are aggregated by social evaluators outside the model, reflected in the choice of W. W may (but need not) involve further implicit discounting because it weights increments to the utilities of individuals who are better off relatively less. A social welfare function also may (but need not) discount utilities simply because individuals live in the future (which is referred to as pure time discounting). We call any discounting based directly on the social welfare function *evaluative* discounting. Evaluative discounting is an ethical exercise, and one of a particular sort that indicates what types of argument are appropriate and what sorts of considerations are not.

After developing these arguments in sections 1 and 2, we apply this analysis in section 3 to discounting practices in the context of integrated assessment models (IAMs). IAMs are the central tool used in climate policy to estimate future costs and benefits of policies. Moreover, it is common in these assessments to present results in terms of an overall present value welfare equivalent. Accordingly, it is important to understand how discounting has been used in IAMs. To illustrate our main arguments, we discuss the widely known models used by William Nordhaus (Nordhaus (2008)) and Nicholas Stern (Stern (2007)) and show how each of their analyses conflates empirical and ethical parameters, making interpretation of their results difficult and potentially misleading. Clear separation between the two domains in which discounting is performed, between the empirical, predictive roles of IAMs and the ethical judgments about the predictions, would make model interpretation and discussion of appropriate discount rates more transparent.

The existing literature has two principal approaches to making the requisite separation. The first is to do sensitivity analysis with respect to the parameters of the social welfare function. The second is to directly present the time series of outcomes in terms of what each generation receives (without offering any social assessment). Although sensitivity analysis and the direct presentation of outcomes are standard in many areas of policy assessment, they are less common with respect to the discount rates in the integrated climate assessment literature.

In section 4, we return to a question that, although rarely asked in this context, is central to discounting and climate policy assessment: namely, why should analysts or evaluators focus on social discounting, which is concerned with the intergenerational distribution of income, rather than on efficiency? After all, in the intragenerational policy context, it is conventional to assess policy using cost-benefit analysis and largely leave distributive matters to the tax and transfer system. An analogous approach in the climate context has much to commend it, and following this different course would significantly affect the role of evaluative discounting in the analysis.

1 Framework for Social Assessment of Policies – The Single Generation Case

We consider in this section the welfare economic framework for assessment of policies that has been developed (implicitly) in the single-generation context, drawing on Kaplow (2010). To motivate the analysis, it is useful to remember why it is that social assessments of consumption increments to different individuals are needed. If all individuals had constant marginal utility of income and society was indifferent to the distribution of utility, simple cost-benefit analysis would suffice: projects should be adopted if and only if benefits exceed costs. Moreover, even when one or both of these conditions fail, so that distribution does matter to total social welfare, it would still be correct to employ cost-benefit analysis (and without any distributive weights) if policies were accompanied by tax adjustments that keep the overall distribution of income constant.[1] It is necessary to compare the social welfare contribution of consumption increments to different individuals only when distribution will not be held constant, including the important case of questions of pure income distribution, whether within or between generations.

Suppose that we are considering a project that increases consumption to some individual i by an increment, but reduces consumption to some other individual j. We should engage in the project if and only if the social welfare gain attributable to the former exceeds the social welfare loss due to the latter. To make this determination, we have to specify both how much individuals' utilities change because of an increment to consumption – determined by individuals'

[1] We will discuss this issue in more detail in section 4.

utility functions – and how society evaluates that increase – indicated by the social welfare function.

Let each individual's utility be a concave function only of consumption, $U(c)$. Social welfare is taken to be the integral of a concave function of utility, so we can write social welfare as:

$$SWF = \int W\left(U(c_i)\right) f(i)di, \tag{1}$$

where $f(i)$ is the density of levels of consumption (that is, the relevant fraction of individuals at each consumption level). The marginal change in social welfare from a change in individual i's consumption is:

$$\xi_i = \frac{\partial W}{\partial U}\frac{dU}{dc_i}, \tag{2}$$

which depends on both the U and W functions and, in general, on the consumption level c_i since the U and W functions, and accordingly their derivatives, are evaluated at the current levels of their respective arguments. Integrating expression (2) over all individuals gives us the change in social welfare from a given change in policy.[2] Therefore, our hypothetical policy is desirable if and only if the increment to i's consumption, weighted by ξ_i, exceeds the fall in j's consumption, weighted by ξ_j.

The marginal change in social welfare for an increment of consumption, ξ_i, ordinarily declines with consumption for two possible reasons: because marginal utility declines as consumption increases and because marginal social welfare (in some formulations) declines as utility increases. The overall effect depends on the curvature of both the utility function and the social welfare function. Because U and W depend on their arguments, these factors affect ξ_i differently: the faster marginal utility declines with consumption, the more equal utility levels will be for given differences in levels of consumption and, therefore, the less the curvature of the social welfare function matters. To illustrate, suppose that $U(c)=ln(c)$ and c=\$10,000 for a poor person and c=\$100,000 for a rich person. The ratio of their marginal utilities (equal to $1/c$) is then 10 to 1. If social welfare is linear (utilitarian), this is also the ratio of the ξ_i; a dollar is 10 times more socially valuable to the poor person than to the rich person. Now suppose instead that social welfare depends on the log of utility: $W(U)=ln(U)$. The ratio of the ξ_i increases to 12.5 to 1 (not to 100 to 1). Curvature of the social welfare

[2] Typically, projects are assumed to be small enough that the ξ_i's are assumed to be constant; in some cases, possibly including climate change policies, this may not be the case.

function does matter, but for many typically contemplated U and W functions, it matters less than that of individuals' utility functions.

Following Atkinson (1973), it is common to combine $W(U)$ and $U(c)$ into a single, composite function. To illustrate, consider the commonly used constant relative risk aversion (CRRA) utility function. These take the form

$$U(c) = c^{1-\alpha} / (1-\alpha), \tag{3}$$

where α is the coefficient of relative risk aversion.[3] Social welfare may be taken to have a similar form:

$$SWF = \int \frac{U(c_i)^{1-\beta}}{1-\beta} f(i)\, di, \tag{4}$$

where β can be interpreted as the coefficient of relative utility inequality aversion. A reduced form of the social welfare function that is a composite of (3) and (4) is:[4]

$$SWF = (1-\alpha)^{\beta} \int \frac{c_i^{1-\eta}}{1-\eta} f(i)\, di, \tag{5}$$

where $\eta = 1-(1-\alpha)(1-\beta)$. We might then interpret η as a measure of the social aversion to inequality in consumption.[5]

There are several problems with this approach.[6] One difficulty is that expression (5) is not well defined if α exceeds 1 because the first term before the

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[3] Throughout, for all such functions considered, we will set aside without further remark the special case in which the curvature parameter equals 1, in which event one substitutes the natural log functional form, as in our preceding example.

[4] Most analysts who use a constant-elasticity reduced form do not include the expression before the integral.

[5] We find this manner of expression most transparent in suggesting the origin of η. One could instead write $\eta = \alpha + \beta - \alpha\beta$. The presence of the latter term is strongly suggestive of some of the points that follow.

[6] An additional serious difficulty is that, strictly speaking, equation (5) is a violation of welfarism because what matters for social welfare assessments are not just individuals' utility levels but also how they come about. For example, changing someone's coefficient of relative risk aversion and their consumption simultaneously so as to leave utility constant will nevertheless change the social valuation of that utility; hence, social decisions do not depend solely on individuals' utility profiles. Kaplow and Shavell (2001) show that this sort of violation of welfarism implies Pareto violations.

integral then involves raising a negative number to a non-integer exponent.[7] More centrally, η is not the sum of, or similar combination of, α and β. For example, suppose that η is taken to be 2, and α is determined, through observation, to be, say, 0.9. The implied value of β is 11, a very high level of aversion to utility inequality. If others interpreting the data favored a slightly higher estimate of α of 0.99, then the implied value of β would rise to 101. But if new observational data show that α is even higher, actually 2, taking η to be 2 implies that we are now utilitarian, implying that β must be 0. Furthermore, if, as many economists believe, we have α greater than 1 but less than 2, say 1.5, β is !1, which seems to mean that we would actually have a preference for inequality. Figure 1 shows the implied value of β for η=2 and a given observation of α.

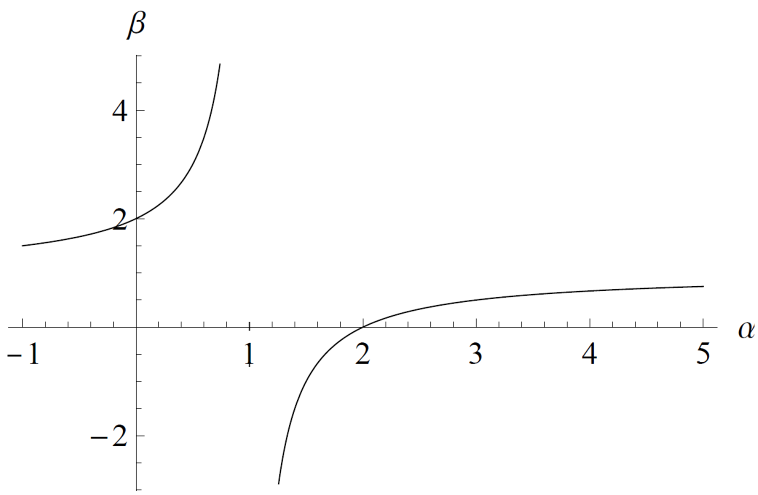

Figure 1 – Implied β for a given observation of α, when η=2

As is evident, we cannot simply chose η through ethical reflection on aversion to consumption differences and expect the resulting curvature of the social welfare function to make sense.

As mentioned, utilitarians take social welfare to be the unweighted sum of utilities, so β=0. In that case, $\eta = \alpha$, and the composite form in this case is unproblematic. However, the value of η in this case is a purely empirical matter (because, after all, α is an empirical parameter), its value having nothing to do with ethical reflection.

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[7] The same problem arises in expression (4) if U is negative, which occurs, again, when α exceeds 1 and the utility function takes the form in expression (3). For further discussion, see Kaplow (2010) (p. 34).

This point about the utilitarian case has larger implications. Specifically, it indicates that there is something fundamentally mistaken about any notion that social welfare can be taken to depend directly on consumption inequality rather than on utility inequality. Social welfare functions are functions of utility, after all, and there is good reason for this: individuals' utilities are taken to be of normative importance, whereas consumption is purely a means to an end, that end being utility. For example, if at some point further consumption reduced utility rather than increased it, consumption beyond that level would be socially undesirable, and a formulation that deemed it socially beneficial regardless of its adverse consequences for individuals' utility would make no ethical sense. The same reasoning indicates that the *extent* to which consumption should be seen to augment utility is an empirical, pragmatic question, one that depends on the fact of the matter (however difficult it may be to discern) rather than on a priori ethical reasoning.[8] The reduced-form parameter η in the composite functional form (5), which is a direct measure of our aversion to consumption inequality, can only be given ethical meaning if it is *derived*, taking as the two key inputs the manner in which consumption actually affects well-being, an empirical matter indicated by the utility function, and the manner in which utility is deemed to affect social welfare, a legitimate subject for ethical reflection by an outside evaluator.

2 Framework for Social Assessment of Policies – Future Generations

To assess problems of climate change, we need to extend the framework of section 1 to encompass future generations. For concreteness, suppose that a project produces an increment of consumption for future generations and the question is what reduction in consumption the present generation should appropriately be expected to incur to generate that benefit. The analysis would in many ways be similar to that in section 1. We still need to specify the individual utility function and the social welfare function so that we can determine the marginal social value of an increment of consumption to individuals in different generations. To keep matters simple, we will adopt the common practice of using a representative agent for each generation, a simplification that is not innocuous.[9] In that case, the social maximand is:

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[8] Put another way, it seems difficult to defend the view on ethical grounds that the empirical relationship between consumption and utility can be ignored so long as marginal utility is positive, but that it would become central if marginal utility ever fell slightly below zero rather than staying infinitesimally above zero.

[9] Following the analysis in section 1, it will matter which individuals within a generation are affected by the consumption increments since, in general, each will have a different effect on social welfare. One might make generalizations about intragenerational distribution, but in that

$$SWF = \int_{t=0}^{\infty} W\left(U(c_t)\right) dt, \tag{6}$$

where c_t is the consumption (of the representative individual) at each time period (generation) t. Equation (6) is the same as equation (1) except that we are now integrating over time. As in the single-generation case, we still must separately specify U and W. The former is empirical and the latter is ethical, and their curvatures affect the social evaluation of outcomes differently.

Expression (6) does not allow pure time discounting of utilities. (Discounting, if any, arises in (6) because of the curvature of W, as we elaborate below). We can introduce pure time discounting of utilities by altering expression (6) as follows:

$$SWF = \int_{t=0}^{\infty} W\left(U(c_t)\right) e^{-\delta t} dt. \tag{7}$$

The discount rate in this case, δ, is an element of the social welfare function and is determined through ethical reflection.

What does the social welfare function (7) imply about how *consumption* is discounted? Beginning with the first term in the integrand, we can see that, as before, the weight on increments of consumption in any generation t will depend on the curvature of both U and W. Then, when that weight is determined (using consumption levels, c_t, for generation t), the result is further discounted, to an extent determined by δ, to produce the overall impact of the increment in generation t on social welfare. (This combination of factors will be further elaborated below, when we discuss the Ramsey equation.)

Expression (6) also did not explicitly include discounting by individuals as they choose their savings patterns to maximize their utilities. Suppose that instantaneous utility (the felicity function) at time τ is $u(c_\tau)$, and the individual discounts future utility at a constant rate θ. (Individuals might discount future utility because, for example, they are uncertain about when they will die or they are impatient.) Suppose that each individual lives for n periods and that utility is time-separable. Then an individual maximizes:

case any summary would itself reflect some combination of a social welfare function and individuals' utility functions, whereas the standard representative individual framework takes the summary to be a utility function. Such complications are not considered further here, but in light of the large intragenerational disparities in consumption, especially across countries (if the maximization is in terms of global welfare), this complication warrants further attention. (The analysis in section 4 does, however, bear on how this problem might best be addressed.)

$$U = \int_{\tau=0}^{n} u(c_\tau) e^{-\theta\tau} d\tau, \tag{8}$$

subject to that individual's lifetime budget constraint. (It might be helpful to think of the representative individual in each generation t living for n subperiods, denoted by τ, which would be appropriate in a non-overlapping-generations model.) Analogous to our discussion of expression (7) for the social welfare function, we can now ask what the representative individual's utility function (8) implies about how *the individual* discounts consumption over a lifetime. The answer is similar. The first term in the integrand indicates that the weight on an increment of consumption in time period τ will affect utility by an amount that reflects the magnitude of c_τ in a way that depends on the curvature of u. This weight is then further discounted, to an extent determined by θ (not δ) to produce the overall impact of the increment in year τ on the representative individual's utility, U. (This combination of factors will likewise be examined below in connection with our discussion of the Ramsey equation.)

The social optimization problem is to maximize (7) given that individuals maximize (8) under the policy being evaluated. An important point is, as just mentioned, that the pure time utility discount rate used by individuals when maximizing utility, θ, is not the same as the pure time discount rate used by the outside evaluator when aggregating utilities, δ. For example, one may plausibly believe that θ is a positive number based on empirical studies while setting $\delta=0$ based on the ethical view that all individuals should be weighted equally. One discount rate, θ, is empirical, while the other, δ, is ethical. (Note, however, that, depending on the ethical basis for δ, it may depend in whole or in part on empirical evidence.[10])

Unfortunately, analysis usually proceeds without attention to the difference between utility functions and the social welfare function and, relatedly, between empirical and ethical discounting. Specifically, it is common to use a reduced form similar to equation (5):

$$SWF = \int_{t=0}^{\infty} Z(c_t) e^{-\delta t} dt. \tag{9}$$

[10] For example, following Parfit (1984), one might hold that the only legitimate basis for pure discounting of future utility is to reflect the less-than-certain probability that future individuals will exist. In that case, δ would be determined purely empirically (in this instance, rather speculatively).

$Z(c)$ is a measure of social aversion to consumption inequality. As in the single-period case, analysts often take Z to be an isoelastic function of consumption, which yields:

$$SWF = \int_{t=0}^{\infty} \frac{c_t^{1-\eta}}{1-\eta} e^{-\delta t} dt. \tag{10}$$

For example, Stern's discussion of discounting, which we review in section 3B, uses this functional form (which can be seen by combining equations (3) and (6) in Chapter 2A of the Stern Review, Stern (2007)). Similarly, the IPCC's only substantial discussion of discounting, found in Arrow et al. (1996), uses this form (represented by combing their equations 4A.1 and 4A.3). Partha Dasgupta (2008) also uses this form, although in discrete time (his equations 2 and 3). Nordhaus (2008) (equations A.1, A.2, and A.3) likewise appears to use this form.

Equation (10), however, has the same problems as does equation (5), the reduced-form maximand in the single-generation case. As before, we cannot readily interpret η because it is a complex composite of the coefficient of relative risk aversion from individuals' utility functions and of society's aversion to utility inequalities from its social welfare function. Just as in the single-generation case discussed in section 1, it combines empirical facts and ethical views in an opaque and unintuitive manner. For a given reduced form parameter η, small changes to empirical facts imply dramatic and in some cases seemingly bizarre changes in ethical views, as we illustrated for the case in which η was taken to equal 2.

An additional complication is that the individual discount rate, θ, does not appear in equation (10). It is not clear whether θ is arbitrarily set to zero or whether it is now included in the value of δ. If θ is included as part of the value of δ, then δ, like η, embodies both empirical and ethical components and cannot be set based solely on either empirical measurements or ethical reflection.

One explanation for the prevalence of equation (10) is that it was adopted from growth models: it is the same as the maximand in the canonical neoclassical growth model with δ representing the net-of-population-growth discount rate of an infinitely-lived, representative household.[11] Barro and Sala-I-Martin (1995)

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[11] The justification for the use of an infinitely-lived individual requires two steps. First, we must believe that the conditions are met for the use of a representative individual at any given time. So-called Gorman preferences are sufficient to ensure that maximizing (10) produces a Pareto outcome. Acemoglu (2009) (chapter 5). Second, we must believe that it is appropriate to treat the representative individual as infinitely lived. The framework is justifiable only if either of two conditions hold: (i) the likelihood of death is a constant probability, or (ii) there are multiple generations but each is purely altruistic with a constant weight on future utility. Both of these conditions are in principle empirically testable. If they hold, θ cannot be chosen freely but should have the value that best captures the justifying conditions. For example, if we believe altruism is

(Equation 2.1), Acemoglu (2009) (Equation 8.49). If the individual is fully informed and there are no externalities, the individual will make the appropriate trade-offs over time to maximize equation (10). In this framework, no valid social welfare function would choose anything other than what the infinitely-lived individual would choose. That is, η and δ in expression (10) become α and θ respectively as they now are parameters of the utility function, not the social welfare function. Adjusting the notation, if there is a representative infinitely-lived individual, expression (10) becomes:

$$SWF = \int_{t=0}^{\infty} \frac{c_t^{1-\alpha}}{1-\alpha} e^{-\theta t} dt. \tag{11}$$

Suppose that the representative individual for some reason fails to maximize his utility – say he fails to fully consider the future and therefore sets his personal discount rate, θ, too high. We cannot simply adjust θ to a preferred value because θ is empirically determined. In this case, we must instead consider the full model represented by expressions (7) and (8). For purposes of predicting individuals' behavior, we cannot change the empirically determined utility function in (8) to reflect some normative view of correct behavior because the model's results will no longer conform to reality. Treatment of the social welfare function in this case is more controversial with regard to the representation of individuals' utility to be employed in the W function in (7), although not regarding the functional form of W itself.[12]

The interpretation suggested by some analysts is that expression (10) is a utilitarian social welfare function with the addition of pure time discounting (i.e., as part of the social welfare function, not as part of the utility function).[13] That is, in the notation used above, β=0. This view implies, as noted previously, that $\eta = \alpha$. In this case, η is then properly understood to be (entirely) a parameter of the utility function. Therefore, it must be determined empirically, not posited by stipulation according to the ethical views of a social evaluator. Nevertheless, authors suggesting that expression (10) is utilitarian sometimes also suggest that η is an ethical parameter rather than an empirical parameter, which is internally inconsistent.[14] For example, Dasgupta (2008) explicitly states that he is adopting

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the appropriate justification for using an infinitely-lived representative individual, θ should represent that altruism.

[12] However, if behavioral utility differs from normative utility (say, due to self-control problems), many would deem it appropriate to substitute the normative utility function's assessment of the individual's situation when aggregating utilities in the social welfare function.

[13] Stern (2007), Heal (2005), Dasgupta (2008), Arrow (1982), Stiglitz (1982).

[14] A partial reconciliation is that the term "utilitarian" is sometimes used loosely to refer to the general class of social welfare functions of the sort in expression (4), thus encompassing as well

a utilitarian interpretation of η but then devotes much of his article to ethical arguments about the correct value of η.[15] (For further examples, see section 3.)

Moreover, unlike in the single-generation case, where viewing expression (5) as utilitarian resolved the problems with using the composite form, a discounted utilitarian reconciliation raises some problems in the multiple-generation case. The reason is that, if δ in expression (10) is part of the social welfare function, we have implicitly made the empirical assertion that θ=0. Unless individual time preferences can be explained solely through an empirically plausible choice of α, however, this is not a good interpretation of (10). Put another way, viewing (10) as a discounted utilitarian social welfare function is not simply a matter of interpretation; it also requires making an empirical claim that may or may not true.[16]

An additional problem with interpreting (10) as embodying discounted utilitarianism is that the use of a utilitarian social welfare function is a substantial restriction on the social welfare function being imposed by the modeler. Some readers will not agree with this form of the social welfare function or, perhaps more importantly, even realize that it is being prescribed.[17]

It is useful to apply the foregoing analysis to the so-called Ramsey equation for the discount rate since this equation is so commonly used in analyses of discounting in the climate context. The Ramsey equation, which derives from the neoclassical growth model, is an expression for the equilibrium return ρ demanded by consumers as they optimize their consumption patterns over time. It is derived (in the case of CRRA utility) by taking expression (11) as the social maximand, subject to the budget constraint and the laws of motion for capital. If we make use of pertinent first-order conditions, we can produce:

$$\rho=\alpha\dot{c}+\theta, \tag{12}$$

all those in which $\beta > 0$. However, in that case we are back to the problems with which we began (and which are only avoided by a social welfare function that is utilitarian in the formal, literal sense).

[15] Heal (2005) asserts that, in a full CGE model, we only need to specify δ because the other parameters of the social optimization are determined internally to the model; the model produces utility flows that we then simply aggregate according to the social welfare function which is specified through the choice of δ. We take Heal to be saying that the only *ethically* chosen parameter is δ because in a CGE model, the parameters of the utility function (in the case of CRRA utility, α and θ) must still be specified, albeit, empirically. Heal is explicitly operating in with a discounted utilitarian social welfare function so he is, in fact, choosing β (by setting β=0) as well as δ. By contrast, Heal (2009, p. 281) asserts that the choice of form for the utility function (in our notation, α) is an ethical choice, creating problems similar to those discussed in the text.

[16] If expression (10) is taken to be undiscounted utilitarian, so that both η and δ are elements of the utility function, this problem does not arise.

[17] A utilitarian social welfare had both strong adherents and detractors. See, for example, the competing views in Sen and Williams (1982) and Kaplow (2008) (chapter 14).

where $\dot{c}$ is the growth rate of consumption. This equation says that households allocate consumption over time so that the rate of return is equal to the rate of decrease in the marginal utility of consumption due to consumption growth, plus the representative individual's pure rate of time preference (θ). Note that this equation and explanation maps directly to our discussion of how expression (8) for the representative individual's utility relates to discounting. In the climate policy assessment literature, it is common to discuss the proper discount rate by considering the appropriate values for the parameters on the right side of expression (12). That is, numerous authors skip equation (7) for social welfare (or analogues thereto) and instead go directly to the Ramsey equation. Prominent examples include Nordhaus (2007) and Weitzman (2007).

The Ramsey equation originates with growth models that consider a representative, infinitely-lived individual. The parameters α and θ are parameters of the utility function of that representative individual. To consider distributional issues, however, we need to have more than a representative individual and incorporate a separate social welfare function that, if appropriate, includes the pure discounting of utilities. To illustrate, if we treat equation (10) as the social maximand rather than equation (11), the Ramsey equation becomes:

$$\begin{gathered} \rho = \eta\dot{c} + \delta, \text{ or} \\ \rho = \big(1-(1-\alpha)(1-\beta)\big)\dot{c} + \delta. \end{gathered} \tag{13}$$

Not surprisingly, the problems with using the reduced form expression (10) arise when one works with the Ramsey equation, since, after all, the latter is derived from expression (10). (This encompasses the point that including δ while omitting θ implies that θ=0, which may be inconsistent with empirical evidence.)

Whether operating through the Ramsey equation, an infinitely-lived representative individual framework, or otherwise, we have emphasized the difference between $U(c)$ and θ, on one hand, and $W(U)$ and δ, on the other hand, in policy evaluation. The overall discount rate on the representative individual's consumption implied by $U(c)$ and θ (and the set of policies) is the discount rate used by such individuals to compare their own consumption in different periods of their lives when they are maximizing their own utilities. The discount rate implied by the choice of $W(U)$ and δ, by contrast, is the discount rate an outside evaluator applies to the utility of representative individuals of different generations when aggregating their utilities to assess the outcome of a policy. Aggregating $U(c)$ and $W(U)$ into a single composite creates confusion between the empirical selection of the parameters of $U(c)$ and the ethical choice of the parameters of $W(U)$. Likewise, the pure time discount rates, θ for individuals' discounting of their own utilities during their lifetimes and δ for society's discounting of each generations' utilities, need to be clearly distinguished.

3 Discounting in Integrated Assessment Models

The evaluation of policies aimed at mitigating climate change is a particular case of an intergenerational policy evaluation as described in section 2. Those IAMs that solve for optimal policies are, in theory, maximizing equation (7) for social welfare subject to the individual's utility-maximizing behavior (8).[18] Therefore, conflation of parameters of the social welfare function and of the individuals' utility functions in these models, and in climate policy evaluation generally, introduces precisely the problems discussed thus far. In particular, policy evaluation in the IAM context requires both the specification of the utility function and an evaluation of outcomes by aggregating utilities. Individuals in the model will discount as they allocate consumption over time. Evaluation of model output may separately involve discounting of different generations' utilities as part of the social aggregation process. Discussions of "the discount rate" in an IAM are often ambiguous – referring to either or both individuals' (predictive) discounting and social (evaluative) discounting, and for each of them referring to the discounting implied by the curvature of the pertinent function (utility function or welfare function), to pure time discounting (θ and δ, respectively), or to some sort of aggregate of these four distinct components. As a consequence, it is often difficult to interpret the models and the debate about the correct discount rate to use in the models.

We illustrate this problem by considering two models that have been prominent in the recent debates over discounting: Nordhaus's DICE model (Nordhaus (2008)), and the model used in the Stern Review (Stern (2007)), which is a modification of the PAGE2002 model found in Hope (2006). Neither cleanly separates predictive from evaluative discounting.

Once predictive and evaluative discount rates are appropriately separated in policy analysis, another question arises: should modelers be choosing evaluative discount rates and embedding them in bottom-line results or policy prescriptions? While specifying predictive discount rates is a necessary part of the modeler's task if the model is to predict outcomes based on individuals' maximizing behavior, choosing an evaluative discount rate is an ethical exercise that could well be left to the reader. We discuss two procedures that allow modelers to avoid choosing evaluative discount rates: sensitivity analysis on the parameters of the social welfare function and direct presentation, by which we

[18] Not all IAMs attempt to solve for optimal policies. Some merely simulate policies chosen by the modeler and do not attempt to provide any assessment of the estimated results.

mean the display of the time series of model outcomes in terms of welfare in different periods without any attempt to apply intergenerational weighting to those values. Neither of these procedures is novel and both are sometimes used in the climate IAM context as well as being regularly employed elsewhere. Our suggestion is that more consistent and prominent adoption of these procedures in IAMs would help clarify the issues and reduce some of the disagreements over discounting.

A. DICE

The DICE model, a standard in climate policy analysis since the early 1990s, is essentially a neoclassical growth model coupled with a climate module.[19] Production creates emissions that (via the climate equations) cause a change in global mean temperature, which in turn causes damages, reducing production. The model finds the optimal policy by maximizing:

$$\omega = \sum_{t=1}^{T\max} \frac{c_t^{\,1-\eta}}{1-\eta}(1+\delta)^{-t}. \tag{14}$$

This expression is a combination of equations A.1, A.2, and A.3 in Nordhaus (2008), with the notation modified to match ours. It differs from our formulations by using discrete time and having a finite endpoint, neither of which are consequential for present purposes. We do not account for population growth, which is included in DICE.

In expression (14), we use ω instead of *U* or SWF on the left side because it is unclear how to interpret expression (14) in light of the analysis in sections 1 and 2. Is ω an individual utility function, a social welfare function, or a composite and are the parameters accordingly empirical, ethical, or some combination? The answer appears to be that it varies and in ways that are possibly inconsistent.

On one hand, a representative individual in DICE optimizes the savings rate to maximize (14).[20] Under this view, expression (14) is a utility function, which implies that the parameters are entirely empirical. If they were ethical and the empirical parameters were different, the behavior in the model would be different.

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[19] A model description can be found in Nordhaus (2008). The model itself can be downloaded at http://nordhaus.econ.yale.edu/DICE2007.htm.

[20] More precisely, individuals find the constant savings rate that maximizes expression (14). In a more complete optimization, of course, they might vary their savings rate over time.

On the other hand, Nordhaus (2008) explicitly posits that the parameters in expression (14) are normative. For example, he states (p. 33) (emphasis added):

> In the DICE model, the world is assumed to have a well-defined set of preferences, represented by a '*social welfare function*,' which ranks different paths of consumption. The social welfare function is increasing in the per capita consumption of each generation, with diminishing marginal utility of consumption. . . . The relative importance of different generations is affected by two central *normative* parameters: the pure rate of time preference and the elasticity of the marginal utility of consumption (the 'consumption elasticity' for short).

Further, he cautions (p. 172):

> It must be emphasized that the variables analyzed here apply to comparisons of the welfare of different generations and not to individual preferences. The individual rates of time preference, risk preference, and utility functions do not, in principle at least, enter into the discussion or arguments at all. An individual may have high time preference, or perhaps double hyperbolic discounting or negative discounting, but this has no necessary connection with how social decisions weight different generations. Similar cautions apply to the consumption elasticity.

Given these sharp, unambiguous statements and the fact that he uses expression (14) to undertake social evaluation, the parameters have to be normative. It is not clear, if this is the case, what the individual utility function is or why the parameters of (14) would affect savings rates.

One might partially reconcile these conflicting interpretations by supposing that expression (14) represents discounted utilitarianism (i.e., $\eta = \alpha$, δ is part of the social welfare function, and θ=0). As we noted, this interpretation necessarily includes an empirical assertion (θ=0) that may not be true. An alternative reconciliation is that the integrand in expression (14) is the composite function $Z(c)$. For the reasons we discuss at length in sections 1 and 2, this interpretation is problematic for different reasons.

A reconciliation of these two conflicting views is to take expression (14) be an *undiscounted* utilitarian social welfare function with a single, infinitely-lived representative individual (i.e., with individual discounting but *without* discounting as part of the social welfare function). Nordhaus himself at one point explicitly adopts this interpretation, stating that "the social welfare function is taken to be an additive separable utilitarian form, $W = \int_0^\infty U[c(t)]e^{-\rho t}dt$" (p. 172). (Under this interpretation, Nordhaus's ρ would, in our notation, be θ.) In that event, his expression (14) should be interpreted to be the same as our expression (11). Its parameters are then components of the representative individual's utility function and, as such, are entirely empirical; $\eta = \alpha$ and $\delta = \theta$. This view, however, flatly contradicts the above quotations. Moreover, as we noted, this view is restrictive. Some readers may not agree with this choice of a social welfare function and, given the language used to describe (14), many will not realize that it is being imposed. Also, some may accept Nordhaus's posited pure time preference as empirically representing individuals' actual discount rates but reject it as a social discount rate (or conversely) but not appreciate what is being assumed. Finally, as we noted, the infinitely-lived representative individual framework is applicable only under certain conditions and the discounting parameters used must be tied to the justifying conditions (see footnote 11).

B. Stern/PAGE2002

The integrated assessment model used in the widely known Stern Review (Stern (2008)) is a modification of PAGE2002.[21] PAGE2002 is a partial equilibrium model. It assumes an exogenous GDP growth rate; computes the resulting damages, adaptation costs, and, for a chosen policy, mitigation costs; and then calculates the present value of GDP for the chosen policy. Baseline emissions appear to be (otherwise) exogenous, but spending on mitigation reduces emissions, which in turn reduces damages.

Note that because PAGE2002 is a partial equilibrium model that uses exogenous GDP as an input, there are no individuals, no individual utility functions, and no individual maximization, discounting, or savings choices. Instead, these are implicit in the assumed GDP growth rate and the overall structure of the economy. We might imagine that, if the implicit utility function that is consistent with the assumptions about GDP growth were isoelastic, there would be an implied α and θ, but these parameters are not (and probably cannot easily be) specified.

[21] Stern refers to Hope (2003) for a description of the model. This paper does not have the model equations, however. We use Hope (2006), which describes the PAGE2002 model as of 2003 and which does have the model equations. Because the 2003 paper might describe an earlier version of the model, there could be some differences between our description and the model Stern actually used.

Stern uses PAGE2002 to compute optimal climate policy.[22] To do this, he divides annual GDP produced by the model by exogenous annual population to get GDP per capita. He then imposes a CRRA utility function (with exponent η) and an assumed, fixed savings rate of 20% to compute utility per capita. He sets η=1, based on his view of the empirical data (pp. 183-184).

This methodology seems problematic because he is imposing a utility function on the model ex post when there is no reason to suppose that it is consistent with the (unspecified) utility function that implicitly generates the model's results. That is, he is choosing empirical parameters for the utility function (both a value of α and of θ), which involves predictive discounting, but is not attending to whether the resulting predictions are in line with his results (which would seem to be true only by coincidence given how each was generated).

The conflict between empirical and ethical parameters arises in connection with Stern's statement of his social welfare function. He specifies a social welfare function that is explicitly utilitarian, with discounting of utilities only for the possibility of extinction. Adjusting his notation to conform to ours, he maximizes:[23]

$$SWF = \int_{t=1}^{\infty} \frac{c_t^{1-\eta}}{1-\eta} e^{-\delta t} dt. \qquad (15)$$

This representation is the same as our expression (10) where, because the social welfare function is utilitarian, β=0, which implies that $\eta = \alpha$. Furthermore, based on ethical reasoning, Stern takes the view that δ should be set equal to zero with the exception of the possibility of extinction. He estimates this possibility to be such that δ=0.1.

Stern's interpretations of both η and δ are problematic. Stern repeatedly states that the value of η is an ethical variable, contradicting the claim that (15) is a utilitarian social welfare function. For example, he states: "η which is the elasticity of the marginal utility of consumption [in] this context . . . is essentially a value judgment." Stern (2007) (p. 52). He confirms this view in Stern (2008), stating that "η is the elasticity of the *social* marginal utility of consumption. . . . Thinking about η is, of course, thinking about value judgments – it is a prescriptive and not a descriptive exercise" (pp. 14-15) (emphasis added). The subsequent discussion in the article (pp. 15-17) is then devoted to ethical reflections on the proper value of η.

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[22] Our sources for the following discussion are, in Stern (2007): box 6.3, where he describes his modifications to PAGE2002, and chapter 2A, where he describes his approach to discounting.

[23] This is a combination of equations (3) and (6) in chapter 2A.

The difficulties with this view should, at this point, be relatively clear. If his η is truly ethical, then $\eta = \beta$ and $\alpha = 0$, which is empirically implausible and contrary to his claim that the social welfare function is utilitarian. He could be using the composite form $Z(c)$, but this is contrary to his statements and introduces the problems of interpretation described in section 1. Moreover, if one accepts his apparent view in favor of a social welfare function that is strictly concave – and notably more egalitarian than a utilitarian SWF – and combines this judgment with an empirically plausible estimate for α, individuals' coefficient of relative risk aversion, it seems that one would then be endorsing a significantly higher overall social discount rate on future generations' consumption. If so, one who agreed with both the Stern Review's predictions and Stern's value judgments would reach significantly different policy conclusions, notably, ones favoring much less immediate action to address global warming.

Problems also arise in interpreting (15) because of the omission of θ (the individual pure time discount rate). Stern takes δ to be purely ethical, which implies that $\theta=0$. This implication, however, entails an empirical assertion that may not be borne out.

The tension between the empirical and the ethical is illustrated when Stern discusses savings rates. Some authors, notably Arrow (1999), have criticized setting δ equal to *0.1* because they claim it implies an implausibly high savings rate. Stern (2007) (p. 54) responds to this criticism by arguing that the model on which it is based is restrictive and that in reality many things affect savings. Likewise, Stern (2008) (p. 16) points to the possibility of technical progress as reducing the savings rate implied by a pure time discount rate of (or near) zero. It is not clear, however, how to make sense of any of this discussion because it suggests that a parameter of the social welfare function can affect savings rates. But δ can only affect savings rates if it is part of individuals' utility functions, that is, if it is really what we are calling θ. But in that case, the parameter would be purely empirical and thus properly determined in an entirely different manner.[24]

Both DICE and Stern's use of PAGE2002 make valuable contributions to our understanding of the policies that might be adopted to address the consequences of greenhouse gas emissions. Unfortunately, in each model and presentation, confusion about what is in the utility function and what is part of the social welfare function impedes our understanding of these models and their implications. It is difficult to relate competing views about discount rates to each other given the mix of the empirical and the ethical – of the predictive and the evaluative – as well as discounting of consumption that arises from curvature (of the utility or social welfare function) on one hand and pure time discounting (of

[24] The shape of the social welfare function might indirectly affect savings because it might affect government policy toward savings. Stern does not seem to have this in mind.

consumption or of utility, respectively) on the other hand. Regardless, the difficulties in interpretation that we identify may help explain how modelers with otherwise similar analyses can nevertheless end up choosing widely different discount rates, resulting in large differences in policy prescriptions.

C. Separating Predictive and Evaluative Discounting

An essential first step in avoiding the interpretative difficulties just discussed is for modelers to state clearly the empirical parameters used for their utility functions and the ethical parameters employed in their social welfare functions. The former are necessary for any predictions that are based on individuals' maximizing behavior, and both are essential for offering social evaluations or for deriving an optimal policy path. Because ethical parameters are more controversial and because their choice is not particularly within the expertise of climate or economic modelers, it is helpful if these parameters are either left unspecified or are presented in a manner that allows readers to apply their own value judgments. Accordingly, in this section we suggest how this goal might be accomplished, following the familiar tradition of policy analyses in other areas. In particular, we examine the use of sensitivity analysis and the direct presentation of time series results as useful ways of separating the unavoidable specification of empirical parameters from the more discretionary selection of ethical parameters.

Sensitivity analysis

Sensitivity analysis is, of course, widely used to examine how results change in response to changes in parameters.[25] Typically, sensitivity analysis is used when empirical parameters are uncertain. It can also be used for ethical parameters. That is, modelers would show how optimal results change or how results of a given policy are assessed differently as the parameters of the social welfare function are altered. This type of presentation allows readers to see directly how the choice of ethical views affects policy decisions. Sensitivity analysis on the parameters of the social welfare function is distinct from sensitivity analysis on parameters that affect the discounting employed by individuals when maximizing utility. As one changes the parameters of the utility function, individuals in the model will change their behavior because they are now optimizing a different function. The social welfare function remains fixed, but it will evaluate the results of a given policy differently because the predicted behavior has changed

[25] There are numerous references on the topic, including books such as Saltelli, Chan, and Scott (2000). In the environmental context, the EPA recommends sensitivity analysis for its environmental models. Council for Regulatory Environmental Modeling (2009).

(and because the level of individual utility associated with a given outcome changes). Contrariwise, as one changes the parameters of the social welfare function, behavior and utility will remain fixed but the evaluation will nevertheless be different.

We are not aware of any sensitivity analysis that cleanly separates the sensitivity of predictive discounting from the sensitivity of evaluative discounting. Sensitivity analysis confined to the implied discount rate in composite function $Z(c)$ is difficult to interpret because we cannot tell which parameters, the ethical, empirical, or both, are being changed. Nevertheless, even sensitivity analysis on composite discount rates is not common. Ferenc Toth, in a 1995 survey of discounting in integrated assessment models of climate change, concluded that "the majority of integrated assessments do not include sensitivity tests for the discount rate, or do not hold it sufficiently important to report them in the literature." Toth (1995) (p. 408) Fifteen years later, this unfortunately remains the case.[26]

There are, however, some examples. Tol (1999) analyzes the marginal damages from emissions using the FUND integrated assessment model. FUND estimates a time series of damages from greenhouse gasses in a number of sectors and then aggregates them into a single, monetized amount to estimate the marginal cost of emissions. In presenting results, he displays calculations for varying discount rates, ranging from 0% to 10%. Anthoff and Tol (2009), reporting additional results from FUND, follow a similar procedure. In both cases, these appear to be aggregated discount rates, representing some combination of predictive and evaluative rates.[27]

Nordhaus (1994) performs sensitivity analysis on the results of the 1994 version of DICE for changes to both η and δ. In his more recent book (Nordhaus (2008)), however, he does not do sensitivity analysis on the parameters of the discount rate. He does do sensitivity analysis for other variables, and also presents a comparison of his results to Stern's results by running DICE with Stern's discount rates (showing that the choice of discount rates is the primary driver of the differences in policy recommendations from the two models), but he does not consider other values. As with Tol, however, we still have the difficulty of untangling predictive and evaluative discounting.

A number of papers are devoted to exploring the sensitivity of IAM results to parameters of the discount rate. Anthoff, Tol, and Yohe (2009), Hope (2008),

[26] Dasgupta (2007) (p. 6), commenting on the Stern Review, also calls for more sensitivity analysis: "What we should have expected from the [Stern] Review is a study of the extent to which its recommendations are sensitive to the choice of eta. (Many economists would expect a sensitivity analysis over the choice of delta too.)"

[27] Not all papers presenting results of FUND, however, follow this practice of sensitivity analysis. E.g., Tol (2007).

Nordhaus (1997), Nordhaus (1999) and Gerlagh and van der Zwaan (2004). These papers are valuable because they suggest the direction and magnitude of change we might expect from changing various discounting parameters. Like the other papers we discuss, however, they mix up the parameters of the social welfare function and the parameters of the utility function, making interpretation difficult. Moreover, our suggestion here is for more sensitivity analysis with respect to ordinary use of IAMs; when reporting the results of a study, say about the effect of technology subsidies, border taxes, or any other object of analysis, authors should report how those results are sensitive to the parameters in the social welfare function used in the model. Studies focused primarily on the discount rate are not a substitute for this.

Direct presentation

Sensitivity analysis of particular components of discounting allows one to compare bottom-line assessments under different social welfare functions. An alternative to sensitivity analysis is to forgo such assessments. Rather than aggregating model results into a single number, one can instead display a time series of model results (i.e., the resulting time path of consumption or utility across years or generations). This procedure avoids any ethical choice by the modeler, leaving the ultimate assessment to the reader.[28] By presenting the model's predicted outcomes of a policy, the analyst gives his or her audience the full information content of the modeling effort – who gets what, when – rather than effectively compressing that information into a single policy recommendation in which the analyst's choice of ethical parameters plays a major

[28] Many may be concerned about the difficulty of choosing an evaluative discount rate because of the unintuitive power of exponential discounting to the uninitiated. For example, few (non-economist) readers of IAM reports understand that doubling the discount rate from 2% to 4% changes present values over a 100 year period by almost sevenfold and that doubling them again from 4% to 8% means a further change by a factor of 43. In addition, these multiples change in nonlinear ways with the time period. Koopmans (1965) (p. 226) noted "[T]he problem of optimal growth is too complicated, or at least too unfamiliar, for one to feel comfortable in making an entirely a priori choice of [a time discount rate] before one knows the implications of alternative choices." However, our analysis of the foundations of evaluative discounting in section 1 suggests another view on this problem, one that derives a social welfare function, much as in the single-generational context, from first principles. For example, one might use arguments that ground welfarism to adopt a social welfare function of the form in expression (7); adopt the reasoning of Parfit (1984) and others to suggest that pure time discounting of utility should reflect only the probability of extinction, which (along with difficult-to-ascertain empirical evidence) determines δ; and then engage in further ethical analysis to choose the curvature of $W(U)$, perhaps adopting the utilitarian (linear) form, following the argument of Harsanyi. The resulting overall discount rate of utility, or of consumption, then just is what it is. No choice of a composite discount rate, which implicitly incorporates numerous value (and empirical) choices is involved.

role. Predictive discounting will still be involved in model calculations since outcomes depend on individuals' maximizing behavior (unless, e.g., savings behavior is stipulated), but there is no evaluative discounting since there is no evaluation. By avoiding the choice of a social welfare function altogether, this method eliminates the possibility of confusion over what is empirical and what is ethical.

This procedure is not uncommon: it is used frequently in policy analyses outside the climate context and also appears in some climate IAMs.[29] Results from MIT's integrated assessment model, EPPA, are most often stated as a time series of changes to either utility or consumption.[30] For example, Paltsev et al. (2009) uses the EPPA model to analyze the costs of meeting specified emissions reduction targets. Rather than presenting an aggregate evaluation of their results, they present the change in utility in various time periods as a result of the policies being simulated. The IPCC presented results this way in its Third Assessment Report, which shows the percent change over time in world GDP under a business-as-usual scenario for three different IAMs. Smith, Schellnhuber, and Mirza (2001). The Stern Review also presents some results in this format, showing changes in per capita GDP under various scenarios. Stern (2007) (p. 178).

There are some limitations to this approach. One is that, without specifying a social welfare function, one cannot optimize policies. To address this problem, one might employ a compromise procedure under which one chooses the ethical parameters of the social welfare function in order to perform optimization and then displays the raw results for the optimal policy and for other regimes, such as some status quo baseline. One might also perform sensitivity analysis, deriving multiple optimal policies for different ethical parameters and displaying the raw results for each.

Another problem is that it may be difficult for a decision-maker to come to a policy conclusion from a visual inspection of different paths of consumption or utility over time unless there is a near dominance relationship among them. As a consequence, the decision-maker would ultimately have to employ some particular social welfare function in order to compare policies. Nevertheless, the separation of these processes – prediction and evaluation – will achieve great clarification, and there is substantial benefit of allowing one to choose which

[29] Examples in the general context include Altig et al. (2001), Heckman, Smith, and Clements (1997), and Fullerton and Rogers (1993).

[30] Paltsev et al. (2005) provides a model description. They use the term welfare, but they do not mean social welfare as we use the term here. Instead, welfare in their model description refers to utility. The use of direct presentation rather than sensitivity analysis might be connected to model structures. For example, EPPA does not attempt to estimate damages from climate change, so it could not easily be used for optimization. For broad descriptions of model types, see Weyant et al. (1996), Weyant and Hill (1999), and Hope (2005).

integrated assessment seems most credible, independently of particular modelers' ethical beliefs, and then to debate which is the proper mode of social evaluation, independently of particular evaluators' assessment models.

4 Intergenerational Distribution versus Efficiency

As we note at the outset of section 1, distributional issues are assumed to be implicated in the climate policy literature and in the discounting debate in particular. Indeed, this distributive dimension motivates our framework that explicitly and systematically derives discount rates using a social welfare function that depends on individuals' utility functions. We also remarked that, in economic policy assessment, it is far more common to perform cost-benefit analysis (without distributive weights) and leave distributive concerns to the tax and transfer system. This familiar separation of efficiency and distribution has much to commend it in general: notably, the pursuit of efficiency in the domain under consideration leads to a larger pie that can be distributed, for example, to make all income groups better off.[31] In this section, we briefly sketch how the main ideas apply in the climate policy context, which involves distribution across generations.[32]

The problem in the context of cost-benefit analysis for climate change can be roughly approximated by a model in which the cost of reducing greenhouse gases is a fraction of GDP for all generations, but the benefits of that action – the damages that were averted by that action – rise over time. Undertaking immediate, aggressive abatement of greenhouse gases then involves the present generation sacrificing its consumption in order to benefit future generations. The intergenerational distribution problem is commonly framed by considering costs borne in a single present period and benefits in a single future time period. Suppose that the marginal dollar of present sacrifice provides a benefit of B dollars at future time t. According to expression (7), this marginal sacrifice is socially desirable if and only if:

$$W'\big(U'(c_t)\big)e^{-\delta t}\cdot B > W'\big(U'(c_0)\big). \tag{16}$$

However, it is also natural to ask whether the return of B at time t is a good payoff relative to other ways to invest the funds. Alternatives include other public projects (e.g., infrastructure), R&D, human capital, or conventional private sector investments. If the return at time t on any alternative is greater than B, then

[31] See, for example, Kaplow (2004) and Kaplow (2008) and, for formal analysis in the context of controlling externalities, see Kaplow (2006).
[32] See Kaplow (2007) and Samida and Weisbach (2007) for elaboration.

it would be better (regardless of whether the social criterion (16) is satisfied) to invest in such alternative instead of in additional greenhouse gas mitigation. Indeed, this strategy is Pareto superior, and it can be made strictly so. If the present generation invests slightly less, making itself better off, yet still invests enough that the future generation is also better off, both generations gain. Similarly, if the return on another alternative is less than B, both generations could be made better off (again, regardless of whether the social criterion (16) is satisfied) by reducing the investment in that alternative and shifting the resources to greenhouse gas reductions.

In other words, it is in principle socially best to choose the level of control of greenhouse gas emissions that equates the marginal return to those of all alternative investments. This decision rule is based entirely on the rates of return on other investments and depends not at all on the social criterion (16) that (in some form) constitutes the standard basis for assessment for climate policy.[33] One should also note that, although framed in terms of rates of return, the underlying idea is familiar from analysis confined to a single period, where it is optimal to allocate scarce resources to their highest-valued uses.

There are a number of complexities and subtleties associated with determining the rate of return on other investments that it is appropriate to employ. One important point is that the rate of return is endogenous when nonmarginal policies are under consideration. Because of the large potential impact of climate change as well as the possible magnitude of mitigation strategies, the market rate of return is endogenous to climate policy. It nevertheless remains true that we should invest in climate change mitigation up to the point where the marginal return is equal to that on other projects. For example, the initial benefit from mitigation might be very high but subject to diminishing returns. It is also possible that, as mitigation efforts increase and thus climate damages to the economy are reduced, the returns on other projects will be boosted. (And they may also rise for the simple reason that, as more resources are shifted away from alternative projects toward climate mitigation, the now-marginal projects will be more productive ones.) At the optimum, we would invest in climate mitigation up to the point where the marginal returns are equal to those available elsewhere.[34]

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[33] Important relationships between these concepts do exist. Notably, individuals' own discount rates for consumption guide their savings behavior, producing an equilibrium relationship between personal discount rates and the market interest rate. Moreover, to the extent that society has intergenerational distributive preferences that determine policy, the resulting intergenerational distribution will itself influence market returns.

[34] There are other important complications that may be pertinent. For example, looking to historic market rates of return may not well predict future rates of return if temperatures rise significantly (because the resulting damages may nontrivially alter average returns to other investments). Rates of return should in principle be calculated within the model based on estimates of market

Another controversy concerns whether to use a before- or after-tax rate of return when discounting returns on public projects. Indeed, some analysts have argued that discount rates should be chosen on the basis of ethical reflection because of divergences between the market and social discount rates. Stern (2008) (pp. 12-13). Similarly, appropriate adjustments for risk must be made because the benefits of emissions reductions are uncertain. These issues and many others are beyond the scope of the present investigation.[35] For present purposes, we emphasize that the previous logic is nevertheless sound; various complications or subtleties call for appropriate adjustments, not abandonment of the valid core idea. For example, if there is a positive externality so that some project has a greater social return than its market return, that greater social return should be employed; indeed, this case is precisely the justification for government action to reduce greenhouse gases. But, once it is determined that the full social return in generation t is B, we should still wish to know whether this return exceeds or falls short of the full social return on alternative projects.

Relatedly, it is difficult to understand how distortions or other factors affecting the market rate of return are best addressed by ethical reflection that leads to choosing different behavioral parameters (notably the values of α or θ), as these are empirically determined, or how changing the shape of W, the method of aggregating utilities, is a coherent response. In the single-generation setting, no one would suggest that the existence of monopoly, tariffs, tax wedges, or other distortions should be addressed in whole or in part by employing different utility functions from those that would otherwise be used or a different social welfare function from that otherwise deemed proper. This point reinforces the broader theme of this section: although adding an intergenerational dimension introduces interesting and important complications, it is not a reason to abandon well-established and justified techniques of policy assessment, replacing them with methods that, when simplified to the single-generation context, would not make sense. Climate change is a particularly complex setting, involving long time horizons, irreversibilities, high levels of uncertainty, and economy-wide effects. The appropriate response to those complications is increased care and transparency.

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conditions, including climate damages. Similarly, climate change may affect sectors of the economy differently, for example, making agricultural production more expensive relative to other sectors. Proper estimation of these effects – adjusting the relative price of goods because of climate damages – is also needed.

[35] See, for example, Arrow et al. (1996) and Lind et al. (1982). These and other issues are addressed further and related to the present argument in Kaplow (2007).

5 Conclusion

The choice of the discount rate for integrated assessment models is one of their most consequential decisions, one that can readily sway the policy prescription from near inaction to immediate, aggressive, and costly intervention. Unfortunately, agreement ends there. Furthermore, much of the debate over the discount rate resembles ships passing in the night. In order to advance understanding, improve analysis, and foster intelligent policy-making, we present a conceptual framework that clarifies a number of issues by unpacking the concept of discounting into qualitatively distinct components.

The central distinction is between features of individuals' utility functions and of the social welfare function. Utility functions must be specified both for purposes of what we call predictive discounting – that is, to analyze models in which individuals' maximizing behavior determines outcomes – and for purposes of ultimate social welfare assessments since social welfare is taken to be a function of individuals' utilities. For this latter purpose, which includes what we label evaluative discounting, the social welfare function must be specified as well.

To further complicate matters, each of these domains – specification of utility functions for predictive discounting and of the social welfare function for evaluative discounting – involves two dimensions. First, discounting depends on the curvature of the pertinent functions, how utility depends on consumption, $U(c)$, in the former case and how social welfare in a given generation depends on utility, $W(U)$, in the latter case. As we explain and demonstrate through examination of some of the leading models and writings on climate change, the common use of a single reduced form, $Z(c)$, often leads to conflating these distinct phenomena, one (utility) empirical and the other (social welfare) ethical.

Second, each domain can also involve pure time discounting: for predictive discounting, the rate at which individuals discount their own future utility, which we denote by θ; and for social evaluation, the rate at which an outside evaluator discounts the contribution of a generation's utility to social welfare, which we denote by δ. Again, the former, involving individuals' utility functions, is empirical, and the later, regarding the social welfare function, is ethical.

We examine some of the most notable contributions in the IAM literature and find that discussions frequently conflate the two domains, individual utility (empirical) and social welfare (ethical). Sometimes the result is ambiguity, and at other times, arguments are affirmatively off base, such as in attempting to offer ethical arguments over what are, in principle, empirical parameters (matters of fact) or suggesting that certain empirical facts call into question choices of ethical parameters.

We advocate that consistent and sharp distinctions be drawn between these two domains (utility and social welfare) and between the two sources of discounting (curvature and pure time preference) that can arise in each. Ceasing altogether the use of the term discounting without further modifiers might be a good place to start. Additionally, to avoid modelers' imposition of ethical views on consumers of their work, often in ways that are opaque, we suggest more widespread use of techniques familiar in other realms: sensitivity analysis (here, to the choice of ethical parameters of the social welfare function) and direct presentation of the time series of outcomes of IAMs, to permit readers to perform their own assessments.

Conceptual clarification is an important goal of economists and other analysts attempting to inform policy-making. It should also aid future work unrelated to discounting issues per se by making IAMs – and, in particular, the bases for different conclusions – more transparent to other investigators. Finally, by focusing debate about components of "the discount rate" so that empirical questions are separately identified and then resolved using appropriate evidence, with ethical argument confined to and more sharply focused on determination of an appropriate social welfare function, disagreement may or may not subside, but at least it will be concentrated on the right questions and lead to proposed methods of deriving answers that are appropriate.

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