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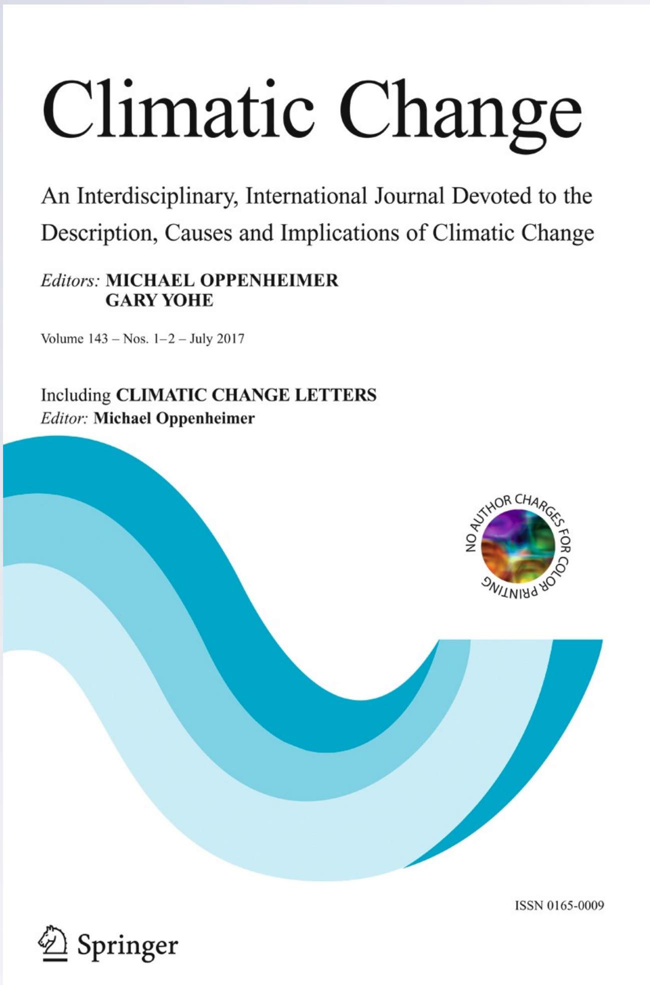

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An intergenerationally fair path towards 2 °C

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Abstract In this paper, we argue that important questions of the intergenerational distribution of the costs of climate change remain even if a temperature target 2 °C is assumed because the target can be pursued in ways that assign costs differently across generations. Moreover, the discounted utilitarian approach that is standard in the economics literature is suspect in light of an a priori argument about its fairness. We also compare the results of modeling Nordhaus's version of discounted utilitarianism, constrained by a 2-degree warming parameter, with a similarly constrained version of a principle that requires minimizing the accumalted differences in the burdens of climate change costs across generations. The model comparison demonstrates that the a priori worry about discounted utilitarianism is largely born out. Nordhaus's version of discounted utilitarianism assigns poorer generations a heavier burden because it is optimific to do so. These arguments call into question the tremendous credibility that discounted utilitarianism enjoys in climate policy. The most important policy implication of the paper is that in order to pursue a fair path towards limiting warming to 2 °C, policy should be directed to increasing the price of carbon over the short term significantly more than what is called for by Nordhaus's model.

At the meeting of the UN Framework Convention on Climate Change (UNFCCC) in Copenhagen in 2009, parties expressed a commitment to limit mean surface temperature warming to 2 °C above pre-industrial levels (UNFCCC 2009). That aim was re-affirmed the following year in Cancún (UNFCCC 2010). In June of 2015, the G7 also affirmed the 2 °C limit. At the Paris meeting of the UNFCCC, parties agreed to limit warming to well below 2 °C (UNFCCC 2015). There is durable and broad international support for the aim of limiting warming to 2 °C or less. It is, of course, unclear whether limiting warming to 2 °C would suffice to prevent various climate change catastrophes, the probabilities of which are uncertain.

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What counts as dangerous climate change is a normative judgment that is not settled by risk analysis alone (Moellendorf 2011 and 2014). But there is now an impressive consensus around limiting warming to 2 °C or less that is driving policy efforts.

Deliberating about a temperature target requires considering present costs in light of future risks and uncertainties. Getting the goal right, or nearly so, is a hugely important concern of intergenerational justice. Our claim, however, is that settling that question does not exhaust the concerns of intergenerational justice. One remaining issue is how to distribute across time the costs of limiting warming at any particular temperature target. Assuming the parameter of limiting warming to 2 °C, we consider two different principles for assigning costs across generations. One principle is familiar in the economics of climate change. It seeks to optimize consumption within the 2 °C constraint. Optimization is a normative goal that derives from the tradition of utilitarian moral theory. The economics of climate change is largely implicitly utilitarian in that regard. We contrast optimizing consumption with an alternative principle that assigns generations approximately equal burdens. Both principles are introduced in Section 1. Section 2 makes the initial case for the egalitarian principle negatively by raising fairness problems for any principle seeking intergenerational optimization. Section 3 explains the model framework used to project the consequences of following the two principles; and it makes the initial comparison of the two principles both constrained by the 2 °C limit. That comparison furthers the case for the egalitarian principle over discounted utilitarianism on grounds of fairness. Section 4 further compares the two principles according to differential cost assignments. Section 5 considers and rejects a criticism of the egalitarian principle as being insufficiently egalitarian. We argue against the familiar principle of discounted utilitarianism and on behalf of the alternative principle that equalizes burdens. The implication of this conclusion for policy is that measures that would increase price of carbon significantly more over the short term than are often proposed should be adopted.

1

Let us begin with the familiar. Discounted utilitarianism is widely employed in the economic modeling of climate change. The proxy for utility in these models is consumption. The costs of adapting to climate change, of repairing damages due to climate change, or of investing in mitigation strategies are diminutions of consumption. The aim is to pursue an intergenerationally optimal mix of costs and consumption. But it is not optimal consumption per se that is sought, rather in standard forms of the model, a discount rate is applied to consumption, reducing the value of consumption according to three factors, economic growth, the diminished value of marginal consumption increases to those who consume more, and how much farther into the future the consumption occurs.[1] What counts as optimal will then depend upon the discount rate applied.

One of the best known and most thoroughly worked out versions of discounted utilitarianism is articulated by William Nordhaus in his DICE 2013R model.[2] Because Nordhaus has made the

[1] This standard conception of the social discount rate derives from Ramsey (1928).

[2] See Nordhaus and Sztorc (2013)

DICE framework available for other researchers, it is relatively easy to make comparisons of principles isolating for their distributive consequences by simply adopting all of the background assumptions of the DICE 2013R model, but changing the input principles.[3] It will help then to lay out some of the background assumptions of this model that we hold fixed in order to keep our focus on fairness. The model follows standard economic growth theory, according to which increasing population, investments in capital, technology, and education allow for economic growth. Population growth and technology are exogenous variables projected according to historical data. Population growth follows UN projections and peaks at about 10.5 billion in 2100. Total factor productivity, reflecting technological change, allows for annual increases in per capita consumption of about 2% up to 2100 and 1% thereafter. To account for a broad range of impacts of climate change, economic output is decreased with reductions of natural capital. As CO_2 concentrations are presumed to reduce natural capital, mitigation efforts can be considered investments into natural capital. Finally, the model further presumes that preferences are well-defined and that collective welfare W derives from aggregated discounted utility according to Eqs. (1) to (3):

$$W = \sum_{t=0}^{T_{max}} U[C(t), L(t)]R(t) \tag{1}$$

Utility U is a concave function of per capita consumption over time ($C(t)$) and population ($L(t)$) according to Eq. (2) and $R(t)$ denotes time-based discounting (Eq. 3).

$$U[C(t), L(t)] = L(t)\frac{C(t)^{1-\eta}}{(1-\eta)}, \eta = \text{elasticity of marginal utility} \tag{2}$$

$$R(t) = (1+\delta)^{-t}, \delta = \text{rate of time preference.} \tag{3}$$

The optimization calculus then allows for comparing the impact of different climate policies on social welfare in a competitive market-based system. The outcome is Pareto optimal but is insensitive to the distribution of wealth over space or time.[4]

Most of the scientific debate on the discounted utilitarian approach concerns two issues. A considerable body of literature concerns the value of the factors in the discount rate. We are not interested in debates internal to the account in this paper (For discussions of the discount factors see Moellendorf 2014 and Moellendorf and Schaffer 2016). Other papers address problems of capturing the normative aim of sustainable development. Graciela Chichilnisky, for example, argues that the discounted utilitarian approach conflicts with the idea of sustainable development, as the sum of discounted utilities amounts to a dictatorship of the present (Chichilnisky 1996). She proposes to augment discounted utilitarianism with a second criterion that requires choosing the intergenerational consumption stream with the highest average utility. Taken on its own, this criterion would be an unacceptable dictatorship of the future, but in combination with the optimal sum of discounted utilities, neither the present nor the future plays a dictatorial role. Francisco Alvarez-Cuadrado and Ngo van Long follow this line of thought but argue for replacing the criterion requiring the highest average utility with one that requires maximizing the utility of the least advantaged generation.[5] Both approaches have a strong Pareto property

[3] See Nordhaus and Sztorc (2013)

[4] Ibid.

[5] See Alvarez-Cuadrado and Van Long (2009). The maximin criterion, employed by Alvarez-Cuadrado and van Long to supplement the discounted utilitarian welfare criterion, is often proposed as a more just alternative to the maximization of the sum of discounted utilities. This criterion is likely to approximate equality, but it is insensitive to the welfare of all generations but the least advantaged one. Roemer's (2007) proposes to maximize the lexicographic minimum.

and satisfy non-dictatorship of the present and the future. However, in contrast to the approach that we advocate below, they do not explicitly follow a substantive normative account of fairness among all generations.[6] In particular, both allow trading off utilities among generations, if overall welfare can be increased.

We compare Nordhaus's version of discounted utilitarianism (NH) with an alternative that we have developed in other work and that we refer to as intergenerational equality (IE) (Schaffer and Moellendorf 2014 and Moellendorf and Schaffer 2016). IE forgoes the aim of optimizing (discounted) utility or consumption. Instead, the guiding principle of intergenerational equality is the equalization of the ratio of climate change costs, as defined at the beginning of this section, to global GDP across generations. If a particular generation, such as the present one, has very little to pay in climate change damages, then it will have to invest in mitigation and adaptation in order to assume costs that might be proportional to the damage costs that will be borne by subsequent generations.[7]

Why should an equal ratio of costs to benefits be pursued? The idea is that climate policy creates both benefits and costs. The benefits come in the form of the various goods that constitute development. These are enjoyed by present generations and passed on to future generations. The costs—in particular the damages of climate change—of present energy policy are mostly deferred to subsequent generations. That people in the present should enjoy the benefits and not the costs and that people in the future will experience a mixture of costs and benefits seem patently unfair. But assuming economic growth, as the model does, people in the future will also be wealthier. So, simply equalizing costs across generations also seems unfair. Burdens can be thought of as costs in relation to the ability to pay them. In order to equalize burdens between people, higher costs must be assigned to those more able to bear them. Equalizing the ratio of costs to GDP has the attraction of equalizing burdens across generations.

NH assumes that unborn future person make valid claim on our action—they factor into the optimization calculus. In offering an alternative to NH, we accept that assumption, which in any case we think, is plausible. NH and IE differ in degree, with respect to burdens now assumed, but not on the fundamental matter that future persons make valid claims on our actions.

2

Our interest in this paper is to focus on the fairness of following NH in comparison to IE in pursuit of the 2 °C warming limit. Our claim is that IE is superior. Our argument will benefit from the use of computer modeling to understand better how the two approaches would assign costs across generations. But in the present section, we sketch an a priori argument about the weaknesses of discounted utilitarianism.

Ever since the publication of John Rawls's pioneering work, *A Theory of Justice*, the credibility of utilitarianism on grounds of fairness has been suspect. At the very least, Rawls succeeds in offering a powerful and comprehensive alternative to utilitarianism for justice

[6] This is also true of Gordon and Varian's (1985) from our approach.

[7] We have not been guided by Chichilnisky's concern to avoid the dictatorships of the present and the future. Rather, we aimed for an alternative that is superior to discounted utilitarianism on grounds of fairness. But, approximating an equal ratio of climate change costs to GDP across generations would seem put neither the present generation nor some future one in a dictatorial position.

within states, which alternative must be taken seriously as long as there is reason to believe that in principle utilitarianism allows laying crippling burdens on some individuals in order to generate comparatively small gains to a sufficient number of others. Rawls famously charges that this possibility is indicative of utilitarianism's failure to take seriously the distinction between persons (Rawls 1999). An analogous problem exists for an account of the distribution of intergenerational costs. Fairness seems to rule out justifications for the assignment of costs to a particular generation simply on grounds of the benefits that such an assignment would yield to other generations.

We are not claiming to offer a Rawlsian account of intergenerational justice although we do think that Rawls's basic criticism of optimization is powerful. And the issue of fairness can be approached in the first instance by employing a Rawlsian veil of ignorance for representatives of generations. If we imagine justifications of the intergenerational costs of climate change being made to representatives of generations, who did not know which generation they represented (and did not represent either the first or the last generation), and who were interested in reducing costs for those whom they represented, no representative would find satisfactory a principle which permitted laying crippling costs on a generation simply because it benefitted other generations. This is a very brief summary. But one of us has defended this approach at length elsewhere (Moellendorf 2009). The veil of ignorance consideration coheres with the distinction between persons criticism.

The problem for any principle that aggregates and optimizes benefits is that it allows in principle that a particular generation might have greatly diminished benefits because the small benefits to other generations outweigh those costs. Indeed, if it is optimal overall, a particular generation could carry very heavy burdens because of this. Nordhaus is, of course, aware of this problem. In fact, he discusses it under the name of *the climate wrinkle*. "Suppose that scientists discover a wrinkle in the climate system that will cause damages equal to 0.1 percent of net consumption starting in 2200 and continuing at that rate forever after. How large a one-time investment would be justified today to remove the wrinkle that starts only after two centuries?" (Nordhaus 2008) Precisely, because the benefits continue forever—by the assumption of the models, if not by physical reality—there is no limit to the one-time investment a society might be required to make in order to produce the benefit. Nordhaus takes this to be a reason to apply a social discount rate to consumption, and the particular factor of the social discount rate that would be directed exactly to mitigating problems of this sort is the rate of pure time preference. If the future consumption is discounted simply because it is in the future, then the cumulative benefits reduce; thus, the amount of the one-time hit justified by them reduces as well. How much the hit reduces will depend upon the rate of pure time preference employed.

By preventing the justification of an infinite cost assigned to some generation, a pure time preference might help to diminish the incredulity that otherwise would meet a proposal to optimize consumption across an infinite time horizon, but it does not address the underlying moral problem. A representative of a generation in the situation sketched above is not going to allow her generation to suffer diminished consumption simply because it benefits enough others. The moral problem seems to be with the kind of justification offered. If that is correct, without even looking at computer modeling, we have reason to be suspicious about the discounted utilitarian approach. In the next section, we argue that the modeling, however, makes another related reason perspicuous.

3

Because Nordhaus has made the DICE framework available for other researchers, we simply change the parameters of the model so that it conforms to IE in order to illustrate the different cost assignments of the two approaches.[8] How do we do that? The main issue here is that NH employs an optimizing calculus, but intergenerational equality is not an optimizing function. But because present climate change damages are so low in comparison to forecasted ones, strictly equalizing the ratios of costs to benefits is not possible in any case without assuming astronomically high mitigation costs initially. In light of that, the principle of equalization applied strictly looks unreasonable. Still, however, it can be reasonably approximated by minimizing the accumulated difference in the ratios of costs to GDPs across generations. Seeking to minimize accumulated differences also has the benefit of allowing us to use an optimizing function.

To be clear then: The form of intergenerational equality that we compare to Nordhaus's version of discounted utilitarianism is an approximation. We model not the strict equalization of the ratios of costs to GDP, but the minimization of the accumulated differences in the ratios across generations (Eq. 4).

$$\min\int_0^\infty abs\left(\frac{\Lambda(t-1)+\Gamma(t-1)}{Y(t-1)}-\frac{\Lambda(t)+\Gamma(t)}{Y(t-1)}\right) \tag{4}$$

$\Lambda(t)$ costs for mitigation in t
$\Gamma(t)$ climate-related damages in t
$Y(t)$ GDP in t

In line with NH, costs for mitigation, $\Lambda(t)$, depend on the rate of mitigation, $\mu(t)$, that ranges between 0 and 100%. The cost function in NH relates to the decreasing rate of the adjusted backstop price, $\theta(t)$, and is highly convex ($\nu = 2.8$). The adjusted backstop price, in turn, is a function of the backstop price, ρ(t) and the rate of ongoing decarbonization due to normal market effects (e.g., ongoing market penetration of renewable energy), $\sigma(t)$.

$$\Lambda(t) = \mathrm{Y}(t)\theta(t)\mu(t) \tag{5}$$

$$\theta(\mathrm{t}) = \frac{\rho(t)\sigma(t)}{1000\nu} \tag{6}$$

Decarbonization is largely driven by the development of carbon-saving technology. It is further pushed by increasing fossil fuel prices either due to the depletion of limited fossil fuel or specific climate policies (e.g., carbon taxes). The backstop technology could be one that removes carbon from the atmosphere, allows for a complete transition to renewable energy production, or a mix of both.[9]

[8] See Nordhaus and Sztorc (2013)
[9] Ibid.

In order to calculate climate damages, $\Gamma(t)$, and again in line with the DICE 2013R model, global output is multiplied by the fraction of output loss due to climate change,$\lambda(t)$, which, in turn, is a function of atmospheric temperature $T_{AT}(t)$.

$$\Gamma(t) = Y(t)\lambda(t) \tag{7}$$

$$\lambda(t) = \psi T_{AT}(t) + \psi[T_{AT}]^2, \psi = \text{calibration factor} \tag{8}$$

The atmospheric temperature in t depends on the carbon concentration that is driven by historic greenhouse gas emissions and subsequently by mitigation efforts.[10] The calibration factor is based on current estimates and an adjustment for non-monetized damages (such as loss of biodiversity). Though the damage function is indispensable for the model, it is not well-developed. It is riddled with uncertainties regarding temperature increases that have not been experienced so far.[11] Still, the principal relationship between mitigation expenses and future damages is clear. The stronger and the earlier the mitigation efforts, the lower future damages and vice versa. In the search of the optimal rate of mitigation driven by specific climate policy, $\mu(t)$, mitigation expenses are calculated endogenously by the model. Following the original NH approach, mitigation expenses increase in each period until marginal mitigation costs just equal marginal aggregated and discounted damages. Within the logic of the alternative IE approach, early mitigation expenses increase in the attempt to balance cost burdens among generations.

The corresponding optimal emission paths can then be calculated by Eq. (9).

$$E_{\text{ind}}(t) = \sigma(t)[1-\mu(t)]\ Y(t) \tag{9}$$

Industrial emissions, $E_{\text{ind}}(t)$ depend on the corresponding output, $Y(t)$, the rate of ongoing decarbonization due to normal market effects (e.g., ongoing market penetration of renewable energy), $\sigma(t)$, and the optimal rate of mitigation driven by specific climate policy, $\mu(t)$. Reduced emissions, $E_{\text{red}}(t)$, which also determine climate damages, then derive from the difference between the emission path based on ongoing decarbonization due to normal market effects and the optimal emission paths calculated above.

$$E_{\text{red}}(t) = \sigma(t)Y(t)-\sigma(t)(1-\mu(t))Y(t) \tag{10}$$

Finally the carbon price, $\kappa(t)$, that corresponds to the optimal emission paths is a function of the backstop price, $\rho(t)$, and the mitigation rate, $\mu(t)$:

$$\kappa(t) = \rho(t)\mu(t)^{\nu} \tag{11}$$

According to the DICE model, the optimum mitigation path requires modest initial reductions in greenhouse gas emissions followed by continuously increasing reductions over time. However, following this optimum path yields a temperature increase that is well above the 2 °C target. Given the impressive consensus in policy circles about the 2 °C limit, Nordhaus also identifies an optimal mitigation path under the exogenous constraint of limiting warming to2 °C (Nordhaus 2013). Under that constraint, Nordhaus identifies a single optimal

[10] The DICE 2013R model accounts for various additional factors, such as the radiative forcing and complex exchanges between the different atmospheric layers. Our aim is not to present the model in full, but to give a short overview of the equations that are most relevant for the presented paper.

[11] Nordhaus and Sztorc, *DICE 2013R.*

climate change mitigation and investment path. We compare a constrained version of NH to a constrained version of IE. We refer to these as NH2 and IE2.

Two further clarifications about IE2 are in order. First, NH2 yields not only an optimal mitigation path but also identifies one single optimal investment and subsequently growth path under the constraint of limiting warming to 2 °C. This is in contrast to IE2, which allows several mitigation paths approximately equalizing burdens, depending upon the (exogenous) trajectory of investments (and subsequent growth). Approximately, equal ratios of costs to GDP could be had on both no growth and high growth scenarios, and every scenario in between. Because we want to highlight the comparison with NH2 results, we assume the rate of growth that Nordhaus identifies as optimal. But that particular rate of growth is not a substantive commitment of the IE2 approach. Second, IE2 assumes that the rate of mitigation is at least equal to the rate of ongoing decarbonization due to normal market effects. It assumes that societies shall not reintroduce fossil-based production processes, once the industry is fully decarbonized.[12]

The following figures were generated by constraining both NH2 and IE2. For reasons of comparison, we also show the respective results for the unconstrained Nordhaus approach (NH). Figure 1 provides a comparison of the paths of emission reductions of NH, NH2, and IE2.[13] Due to the long residence of CO_2 in the atmosphere, and because warming is driven by atmospheric stocks, in order to limit warming, emissions must ultimately be reduced to zero. Therefore, the paths of NH, NH2, and IE2 ultimately converge and head to zero. Figure 1 shows the convergence occurring next century.

Figure 2 reveals a similar trend for the optimal carbon price over time. While prices differ in the early stage of the mitigation process, they converge when approaching a fully decarbonized economy. The stronger the reduction targets, the higher the optimal carbon prices and the earlier the backstop, technology is in place. In the unconstrained optimal run (NH), the backstop technology would substitute 100% of fossil fuels after the middle of next the century (at cost of substitution of approximately \$170 per ton CO_2). Maintaining warming within the 2 °C limit (NH2) would demand a full replacement of carbon emissions by the year 2065 but at higher prices (approximately \$260 per ton CO_2). Initial carbon prices in the IE2 approach are much higher but follow a flatter trajectory. The immediate and strong mitigation efforts yield lower future damages, which gives more time for full substitution of CO_2 emissions. Thus, full replacement will not be realized before the year 2145 at cost of approximately \$175 per ton CO_2.

In general, a lower warming limit demands stronger reductions in the early stage of the mitigation path. That is illustrated in the difference between NH and NH2. Our interest is piqued, however, because Figs. 1 and 2 also indicate that satisfying IE2 requires immediate reductions in greenhouse gas emissions that are much greater and more expensive than those demanded by NH2. This suggests that the two constrained approaches assign costs differently over the course of the twenty-first century, and that raises the question of fairness in the assignment.

Figure 3 represents the ratio of projected costs to projected GDP of limiting warming to 2 °C across generations for the next two centuries for each of the two approaches.

[12] As a consequence, climate-related costs (and subsequently ratios of costs to GDP) will be zero from some point on and the accumulated differences of the ratios (Eq. 1) cannot rise infinitely. For a more detailed analysis of transversality conditions in models of climate change, see Michel (1982) and Greiner et al. (2009).

[13] Following Eq. 5, reduced emissions include decarbonization due to normal market effects.

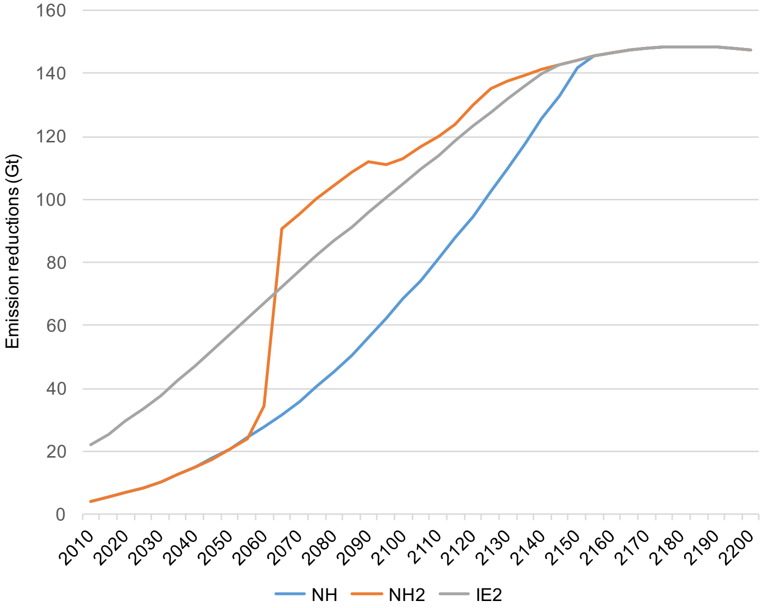

Fig. 1 Required emission reductions according to the NH, NH2, and IE2 approaches

NH2 lays proportionally the heaviest costs on those living in about 2050. One might think that seems fine in relation to earlier time periods in which people are poorer. But it is noteworthy that NH2 also lays proportionally lighter costs on people later. This is the case despite the assumption that later the GDP will be larger. In other words, the burden on people living later is less, even though they will be wealthier. Now, even though NH2 has a discount factor—the elasticity of the

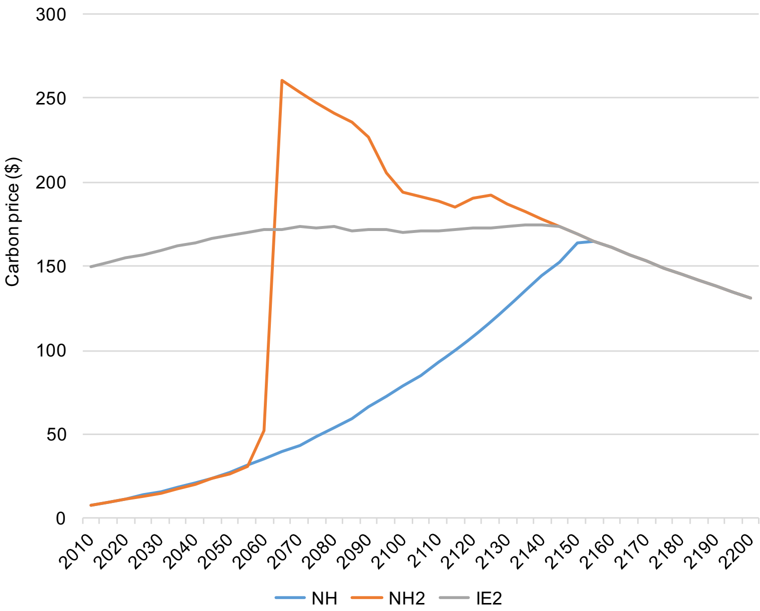

Fig. 2 Optimal carbon price according to the NH, NH2, and IE2

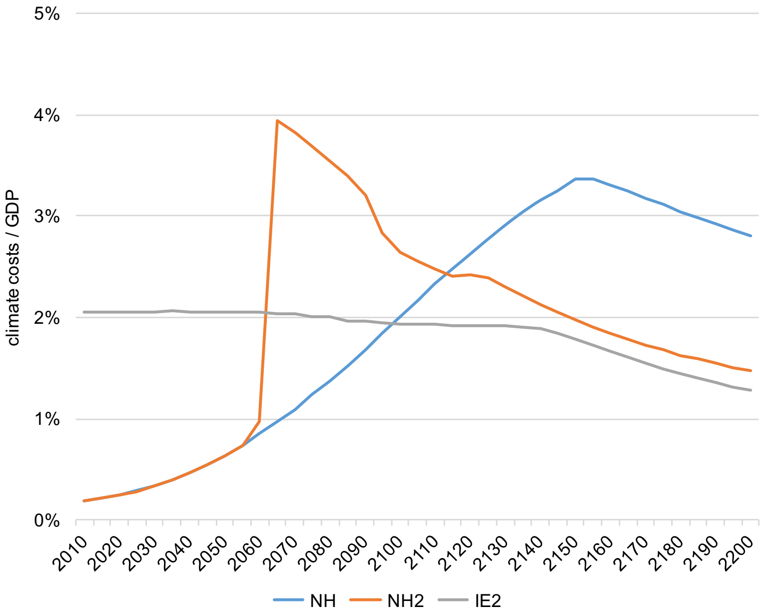

Fig. 3 Costs/GDP NH2 and IE2 scenario

utility of marginal consumption—that decreases the value of the consumption of those who consumes more, it is still possible that wealthier people might be burdened less, as Fig. 3 makes plain. This depends wholly on whether it is optimal to do so. NH2 then seems permissive of distributional unfairness. To the representative of the generation at 2050, who might complain that her generation bears a heavier burden than subsequent wealthier ones, the response that the defender of NH2 gives is that it is optimific that it should be so.

In contrast, the burden differentials are less extreme with IE2. It does not equalize the burdens, but the path represented in Fig. 3 is the path of minimal accumulated differences in ratios. Through the twenty-first century, the burden is about equal and it begins to fall off after that in the twenty-second century. The reason for this is not, however, that it is optimific but rather that strict equality is not possible. The transition to renewable energy is like a one-time cost. Once made, there will be no additional cost from mitigation. Once infrastructure, agriculture, and human communities have made the investments that allow them to adapt to climate change, the only remaining costs are the residual damages.

In the previous section, we argued that a priori there seem to be reason to doubt the fairness of an approach to the distribution of intergenerational costs and benefits that aggregates and seeks to optimize the benefits. It is consistent with such an approach that a generation might carry a heavy burden because it is offset by a sufficient number of other generations. One of the important insights that can be gained from modeling NH2 and IE2 is an understanding of how, given various assumptions, the assignment of costs should be made to accord with different moral principles. According to NH2, people around the mid-twenty-first century will carry an especially heavy burden. Perhaps, this could be justified in comparison to the poorer persons in the decades before, but in comparison to the wealthier subsequent generations, it seems unfair. The need to optimize consumption cannot justify laying a heavier burden on poorer people. Hence, the results of the modeling exercise cohere with the a priori argument about fairness made in Section 2.

4

The IE2 path requires laying comparatively greater costs on current and near-future generations than does the NH2 path. If the arguments of the previous two sections are plausible, it seems appropriate to think of the costs paid by current people under IE2 that are greater than the costs paid by current people under NH2 as the price of fairness. Suppose we assume, as discounted utilitarianism seems to do, that utility is simply a function of consumption. We can represent this price of fairness as the comparative disutility of the present generation under IE2 in comparison to NH2. Figure 4 illustrates the price of fairness by showing the projected losses of utility of the present generation and the gains of future generations against the baseline of the NH2.

Achieving a fairer distribution of the intergenerational costs of limiting warming to 2 °C requires that the current generation accept losses in utility by about 2.5% less than NH2 would require. Compared to NH 2, IE 2 assigns a price that present generations must pay.

It is arbitrary, however, to consider the matter of price only from the perspective of gains and losses in comparison to just one of the two paths. A richer understanding is gleaned by also considering the matter from the perspective of gains and losses in comparison to IE2. NH2 lays greater costs on future generations in comparison to IE2. This might be thought of as the price of optimization. Figure 5 represents the price of optimization.

In our view, it is inadequate to claim that the cost assignment that one should opt for should be determined simply by whether one prefers present or future costs. Since the costs are to different generations, the policymaker's preferences are irrelevant. The only way to determine

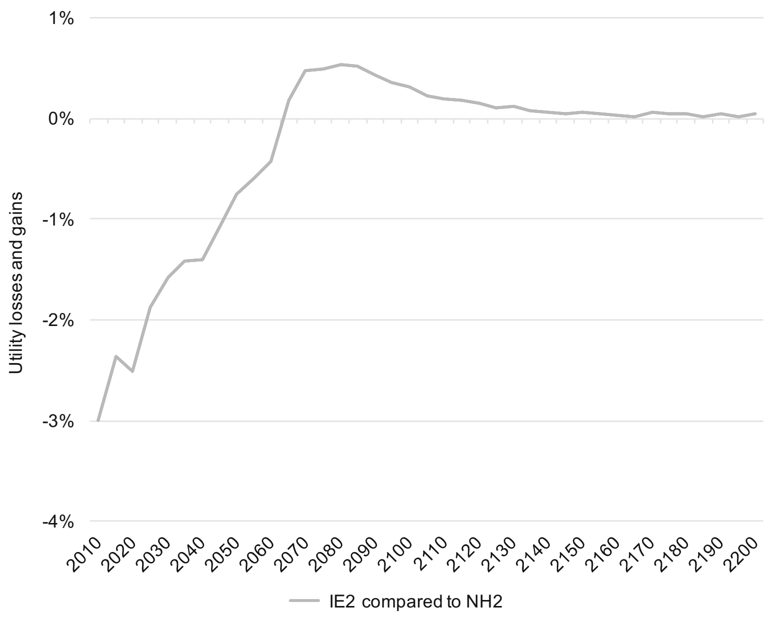

Fig. 4 Price of fairness (losses (−) and gains (+) of IE2 compared to NH2; utility, based on the elasticity of the utility of marginal consumption used by Nordhaus (≈1.5))

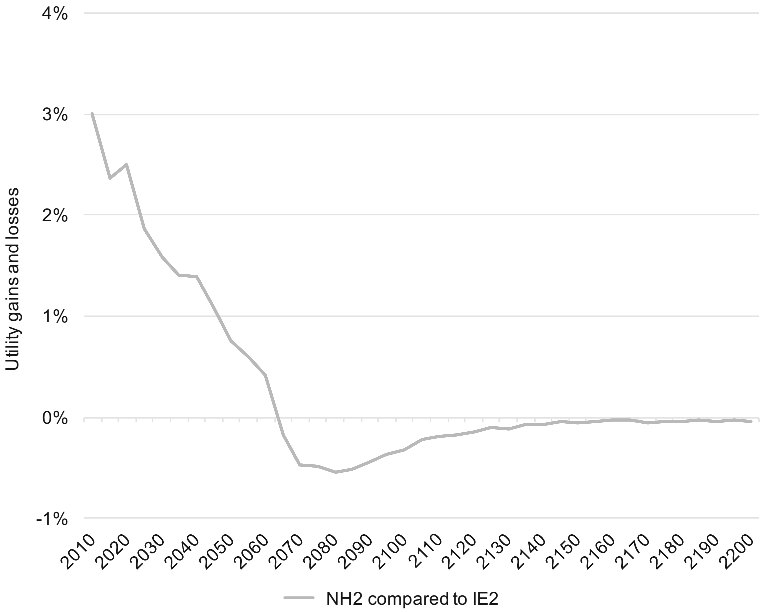

Fig. 5 Price of optimization (gains (+) and losses (−) of NH2 compared to IE2; utility, based on the elasticity of the utility of marginal consumption used by Nordhaus (≈1.5))

which cost assignment is best is in light of considerations of justice. We have made two arguments, one based on a priori considerations, and one based on the results of a modeling exercise, to the effect that IE2 is superior to NH2.

5

Let us backtrack to Fig. 3 for a moment. Notice that NH2 assigns a lower burden in 2010 than in 2200, but with IE2, it is the opposite, even though by assumption people in 2200 are wealthier than those in 2010. That could form the basis of the following criticism from the partisans of NH2: NH2 is fairer because it lays a heavier burden on those more able to carry a greater burden. It is better that NH2 assigns burdens unequally, with a heavier burden going to the generations more able to bear them. Since IE2 claims to have egalitarian credentials, this criticism might seem to hit it where it is particularly vulnerable. In response, we highlight four points.

First, the challenge is not really a defense of the principle of discounted utilitarianism that produces the path NH2. The challenge claims that the path of NH2 is better. But that the path sometimes lays a heavier burden on the more able has little to do with the principle that seeks optimization. A principle that ensured along the entire path that the wealthier paid a heavier burden might have superior egalitarian credentials than IE2. But NH2 is certainly not that principle; if it was, it would not allow persons in 2050 to bear the highest burden of all. NH2 cannot really claim any principled egalitarian advantage over IE2.

Second, any principle that would demand that people later bear heavier burdens, on grounds that they would be wealthier, would be too risky to employ. It would tend to reduce current mitigation burdens significantly on the grounds that the present generations is least well-off—

assuming aggregate global economic growth. Maximizing benefit to least advantage would pile damage costs on future generations very considerably. The limit of the assumption of costs by later generations would seem to be reached only when a marginal increase in the costs to them would diminish their well-being so much that they would be rendered less well-off than a preceding generation. That would allow warming well beyond 2 °C, and it would mightily increase the risks of catastrophe. Some of this could, of course, be factored into the calculation as risks. But for those events that are scientifically uncertain, that would not work.

Third, what Fig. 3 does not show is that the present costs of climate change and those at the end of the twenty-first century differ importantly in kind. The present costs are a combination of adaptation and mitigation costs with the latter dominating. Towards the end of the twenty-first century, the costs will be almost entirely damage costs. So, in assigning fewer costs now and greater costs later, NH2 is substituting damage costs for mitigation costs. That is a doubtful substitution to make for several reasons. One reason is that it is generally more efficient to mitigate than to repair damages because mitigation is a one-time cost that yields ongoing savings. A second reason is that in assigning mitigation costs, the present generation has the policy levers to protect the poor from burdens. But there is a danger that residual damage costs are likely to fall on the poor who lacked the means to adapt to a changing climate. A third reason is that forecasting damage costs is far less precise than forecasting mitigation costs since the exact damages and how best to respond to them are not certain. So, there could be considerable error built into the later estimates. Finally, postponing mitigation in favor of repairing damages is terribly risky. The immense costs that it might allow future generations to incur in the form of climate catastrophes cannot be justified on grounds of fairness.

Fourth, neither NH2 nor any other principle can as a matter of principle require continually progressive burdens and satisfy the 2 °C. Figure 3 makes clear that both NH2 and IE2 involve declining shares of costs over the long term. This must be the case if the 2 °C is to be satisfied. Assuming there are no unpredictable catastrophes, once the energy transition required by maintaining the 2 °C warming limit is made, absolute costs fall since they are comprised only of damages. Assuming continued economic growth, then costs in proportion to GDP will fall even more.[14] Progressive burdens are then impossible within the 2 °C warming limit.

In sum, whatever resemblance NH2 might have to a principle that would lay heavier burdens on those more able to bear them is merely accidental. Moreover, in the case of climate change, the nature of the difference in the kinds of costs and the uncertainty of catastrophe are reasons to think that fairness inclines towards IE2 rather than NH2.

6

We have argued that important questions of the intergenerational distribution of the costs of climate change remain even if a temperature target is assumed since the target can be pursued in ways that assign intergenerational costs differently. Additionally, the approach that is standard in the economics literature of assigning costs that optimizes discounted consumption is suspect in light of an a priori argument about fairness. And, when models of constrained discounted utilitarianism and constrained intergenerational equality are compared, the a priori worry seems largely born out. The former assigns poorer generations a heavier burden because

[14] Stern (2009) argues that mitigating to limit warming to 2 °C is like a one-time cost to the economy, delaying only by 6 months the time at which the size of the world economy in 2050.

it is optimific to do so. If these arguments are plausible, the tremendous credibility that discounted utilitarianism enjoys in climate policy is cast in doubt, and mitigation policy for reaching 2 °C degrees should take note. The most important policy upshot of our approach is represented in Fig. 2. In order to pursue a fair path towards limiting warming to 2 °C, policy should be directed to increasing the price of carbon over the short term significantly more than what is called for by NH2. That is the price of fairness.

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