

# Climate change and the re-evaluation of cost-benefit analysis

Francis Dennig<sup>1</sup> 

Received: 5 August 2015 / Accepted: 24 July 2017 / Published online: 30 August 2017  
© The Author(s) 2017. This article is an open access publication

**Abstract** The evaluation of climate policy has emerged as an important application of cost-benefit analysis (CBA). But the tool, as it had been most widely used previously, was not suited for this problem. Spatially, the effects of climate change transcend national boundaries and, temporally, they transcend generational time scales. CBA, in its standard form, relies on assumptions that are not fully appropriate in this context. In this essay, I discuss the shortcomings of CBA framed by its historical development and argue that its relatively recent application to climate change has contributed to growth in the literature re-evaluating its normative foundations. In relation to discounting, recent innovations emphasise aspects such as the aggregation of a multiplicity of time preferences and the distinction between inter- and intra-generational time preferences, which lead to discounting approaches that differ from the standard approach with the Ramsey equation. In relation to spatial equity, much of the recent literature argues for the use of equity weights to account for impacts on different income groups. These are significant changes relative to the orthodoxy in the field before the emergence of climate change.

## 1 Introduction

At the turn of the century, the eminent economist Tony Atkinson lamented the “strange disappearance of welfare economics”—Atkinson (2001). He was referring to the fact that the study of normative foundations of economics was no longer regarded as an essential part of the economics curriculum and that, consequently, there was little ongoing critical analysis of the normative aspects of economic analysis. He documents this through a sweeping case

---

This article is part of a Special Issue on “Historicizing Climate Change”  
edited by Melissa Lane, John R. McNeill, Robert H. Socolow, Sverker Sörlin

---

✉ Francis Dennig  
fdennig@yale-nus.edu.sg

<sup>1</sup> Yale-NUS College, Singapore, Singapore

study of macroeconomics from the 1970s through to the 1990s, but would have observed the same phenomenon had he considered the subject of cost-benefit analysis. In this essay, I will argue that climate change may be causing a “reappearance” of normative analysis, as the application of cost-benefit analysis to climate policy has led to renewed interest in normative foundations. This process is generating interesting new alternatives to the standard approach of cost-benefit analysis (CBA). In due time, the economics curriculum might also catch up and the process of disappearance identified by Professor Atkinson may be reversed.

As with all questions involving consequential value judgements, the standard approach to cost-benefit analysis up to the beginning of the 1990s was a compromise between different views. There were interpretational differences amongst practitioners, and some cracks in the foundations, but there was a broad consensus that this particular approach to cost-benefit analysis was appropriate for a range of policy questions. This compromise resulted in CBA becoming a very successful tool for policy evaluation. In the USA, for example, Executive order 12291 mandates its use in the federal regulatory process. Especially for environmental regulation, it is used ubiquitously and entrenched in the evaluation process of international organisations such as the UNO, the World Bank Group, and the OECD.<sup>1</sup>

But since the first applications of CBA to climate change in the 1990s the long held consensus has begun to fade.<sup>2</sup> Two aspects in particular have been the target of the emerging critical analysis in relation to climate change. The practice of valuing (contemporary) dollar impacts equally, regardless of the economic status of the affected, and the discounting of future impacts at observed market interest rates. Climate policy was a natural breaking point for those two practices in particular. Its spatial and temporal scopes are greater than those of any previous policy question, and it was the limited scope along these dimensions that provided much of the rationale for the compromise underpinning the previously existing consensus. The application of CBA to climate change laid these issues bare, prompting new as well as recycled critical analysis. This process is resulting in better understanding of the normative foundations of policy evaluation and even some revision of the existing orthodoxy.

I illustrate this process by tracing the historical development of cost-benefit analysis.<sup>3</sup> In doing so, I will highlight the previous debates on normative issues, describe their (tentative) resolutions, and explain why those didn’t survive intact the contact with climate change.

## 2 New welfare economics and interpersonal comparisons

The basic normative question in economics is how to weigh costs and benefits against each other when alternative policies impose these on different individuals. There is widespread agreement in the profession that any contending method must take individual preferences as the basic source of value.<sup>4</sup> As different individuals (or groups) value things differently,

<sup>1</sup>These organisations contributed to the development and establishment of cost-benefit analysis as sponsors of the early manuals, Little and Mirrlees (1974) and Marglin et al. (1972).

<sup>2</sup>William Nordhaus’ earliest contributions to climate change economics date from 1990–Nordhaus (1990a, b).

<sup>3</sup>A more complete account of the historical development is given in Gowdy (2004).

<sup>4</sup>This view is known as *consumer sovereignty*—see Lerner (1972) for a defence and Scitovsky (1962) for a critique of this approach. This anthropocentric view leaves no room for valuation of the welfare of non-human animals over and above the value humans put on them. As we shall see later, the standard approach to cost-benefit analysis treats currently unborn humans similarly, in that the only way their welfare enters the valuation is through the value this generation places on its own future consumption.

there is a source of conflict in the establishment of what is valuable. The resolution of this conflict is the main task of normative analysis.

Classical (nineteenth century) economists were in broad agreement that it was legitimate to resolve this conflict by comparing utility across individuals—Mill (1901). If it were possible to agree on the utility scale to be used, it could be said that policies which generate a greater sum of utilities are preferred to policies that generate a smaller sum. With the development of positive economics in the early twentieth century came the realisation that such judgements were based on quantities that are not measurable according to an agreed-upon scale. It could therefore not properly be the subject of economic science, as the field began to define itself. This led to the development of what came to be known as “new welfare economics”.

Lionel Robbins is associated with the claim that it is not possible for an economist *qua* economist to make interpersonal comparisons of utility. In particular, he considered the joint presumptions of equal capacity for satisfaction and diminishing marginal utility, which were common amongst classical utilitarian economists, to be based “on assumptions which, whether true or false, can never be verified by observation or introspection.”<sup>5</sup> Critics replied that without some basic commensurability between outcomes across individuals, it would be impossible for economists to determine the desirability of most policies. Only those policies satisfying the Pareto criterion (some persons gain, while no person loses) could be endorsed by the economist, and not many alternatives can be unambiguously ranked in such a way.

In a reply to Robbins, Roy Harrod cited the expansion of free trade from the repeal of the English Corn Laws as an example of an *evidently* desirable policy, which could not be established as such by the Pareto criterion.<sup>6</sup> The Corn Laws imposed tariffs on cereal imports to the UK to protect landlords (on whose land the cereals were produced) against foreign competition. The understanding at the time, based on Ricardo’s analysis of comparative advantage, was that the loss to the landlords from increased competition, would be outweighed by the gains to the consumers of cereal from having lower prices.<sup>7</sup> The gain outweighed the loss in pure monetary terms, as well as due to the fact that the beneficiaries of the repeal were a disadvantaged group relative to the landlords. But notably, it was not necessary to appeal to, and measure, this disadvantage to find the repeal desirable.

Still, the laws endured for 34 years through the support of vested interests. By then, the intellectual establishment had long concluded them to be misguided. Robbins and Harrod debating a century later certainly held that view. And yet, according to Harrod, welfare economics without the possibility of interpersonal comparisons would not be able to conclude even that much. If the gains to the consumers could not be weighed against—and found greater than—the losses to the landlords, the economist could not provide guidance.

Robbins himself held that there is no observable basis whereby one could establish how much gain to one individual is necessary to offset the loss to another. This is a normative question outside the scope of *economic science* and “if these (economic) findings were to be applied to the human improvement, that they should be supplemented by political philosophy”.<sup>8</sup> Notably, Robbins was willing to supplement positive economics with the necessary additional normative value judgements in order to make policy recommendations.

---

<sup>5</sup>This is done in the context of an effort to establish the boundaries of economics as a positive science, Robbins (1932), pg. 137.

<sup>6</sup>Harrod (1938).

<sup>7</sup>Ricardo (1817).

<sup>8</sup>Robbins (1938), pg. 639.

Others tried to claim more for positive economics. In an attempt to establish a principle that was both “objective” and a sufficient expansion on the Pareto criterion, Nicholas Kaldor and John Hicks proposed their eponymous compensation criterion in 1939.<sup>9</sup> The criterion states that a policy is judged desirable if the beneficiaries are being made so much better off that they could compensate the losers for their loss, and still have something left over. Since the gain from the repeal of the Corn Laws were greater than the losses in pure monetary terms, the landlords could presumably have been compensated for their loss by taxing some of the gains away from consumers, as pointed out in Kaldor (1939). Kaldor’s conclusion was that in such situations, “the economists case for the policy is quite unaffected by the question of the comparability of individual satisfactions: since in all such cases it is *possible* to make everybody better off than before...”.<sup>10</sup> Hick’s conclusion was similar. The *willingness-to-pay* by the winners of policy is measured in money units and required no interpersonal comparisons of utility.

Unfortunately for this enterprise, it was not as simple as the new welfare economists had hoped. The criterion turned out to be theoretically inconsistent. In 1941, de Scitovszky showed that the criterion yields prescriptions of the sort *B* is better than *A* and *A* is better than *B*. The problem is that the gainer from *B* can compensate the loser, and still be better off than in *A*, but, once *B* has been implemented, the (original) loser could compensate the (original) winner to go back to *A* – see de Scitovszky (1941). In fact, 10 years later, Kenneth Arrow proved his famous impossibility result (Arrow 1951), which shows that no criterion that eschews interpersonal comparisons will at the same time satisfy the most basic principles required of such a social decision criterion.

But the new welfare economists were able to salvage something. In 1941, Hicks showed that Marshall’s older concept of consumers’ surplus could, under certain restrictions, be seen as an approximation to the willingness-to-pay from the compensation criterion (Hicks 1941)<sup>11</sup> and promoted its use as a welfare criterion. In 1964, Harberger published the first prominent and widely cited applications of the cost-benefit analysis using consumers’ surplus (Harberger 1964a, b). Subsequently, this type of policy evaluation gained widespread recognition. It was, strictly speaking, not an application of the compensation criterion, but it was met with approval by the new welfare economists.

Boadway later showed that a positive sum of consumer’s surplus (or positive consumers’ surplus) did not amount to passing of the aggregate compensation criterion (Boadway 1974). So even if the problem highlighted by de Scitovszky was ignored and one accepted the flawed compensation criterion, maximising consumers’ surplus was not even guaranteed to yield results corresponding to the compensation criterion. Somehow still, the compensation criterion (approximated by Marshall’s measure of surplus) survived all these criticisms. That it did has to be understood in the context of extreme reluctance to revert back to the interpersonal comparisons of the past. Hammond notes that

“so great was the reluctance to make other interpersonal comparisons that it took almost twenty years after the publication of the first edition of Arrow’s *Social choice and individual values* before (Sen 1970a, b) and others started a systematic study of the implications of relaxing Arrow’s most restrictive assumption – namely, the

<sup>9</sup>These are in fact two similar but distinct criteria, proposed in Kaldor (1939) and Hicks (1939) respectively.

<sup>10</sup>Kaldor (1939) pg. 550.

<sup>11</sup>When there are no income effects – an unrealistic assumption – the two concepts are equivalent.

total avoidance of all interpersonal comparisons of utility in his definition of a ‘social welfare function’.”<sup>12</sup>

### 3 More solid foundations and distributional weights

The critics of the compensation criterion were also drawn to cost-benefit analysis, but they had a different way of rationalising it (see Blackorby and Donaldson (1990) for a critique of the use of consumers’ surplus and Boadway and et al. (2006) for a more complete explanation of the role of the social welfare function in the foundations of cost-benefit analysis).

In 1938, Bergson (1938) formalised the notion of a social welfare function. This is simply a function of measurable quantities, such as consumption, in which the value judgement relating to interpersonal trade-offs are made explicit. It does not necessarily rely on personal utility and interpersonal comparability. It is simply an explicit objective to be maximised for policy decisions. The sum of consumption, for example, is a possible social welfare function. It is in fact the social welfare function that disregards distributional issues and rationalises the use of consumers’ surplus. Alternatively, social welfare functions in which the distribution of consumption plays a role are also possible. A concave function in consumption leads to the evaluation of putting greater weight on impacts to the poor. In fact, the weight associated with a given impact is simply the derivative of the social welfare function with respect to the overall consumption of the individual subject to the impact. If the welfare function is concave, individuals with greater overall consumption are assigned lower weights.

In this way a social welfare function makes the value judgements in the evaluation explicit. Of course, this simply pushes the political decision back to the choice of the social welfare function and the implied weights. But that distributional issues matter and that some non-trivial weights might be chosen were certainly the views of the authors of one of the foundational handbooks:

[...] we shall distinguish two categories of national parameters, “weights” and “shadow prices”. We shall reserve the term weights for those national parameters that directly reflect political value judgments. In this category are the weights reflecting judgments about the distribution of income, and weights on “merit wants”, [...] In addition this category includes the social rate of discount, which reflects the relative weight placed on aggregate consumption at different times and is properly a subject of political choice.<sup>13</sup>

Despite this, in practice so-called *distributional weights* for different income groups (or types of goods) were rarely used in CBA.<sup>14</sup> This won it the endorsement of the new welfare economists so opposed to interpersonal comparisons, as it provided a way to maintain that some approximation to the compensation principle was at work in the analysis and that no interpersonal comparisons were actually being made. Hicks, the early proponent of this principle, justifies it as follows:

<sup>12</sup>Hammond (1991), pg. 202.

<sup>13</sup>Marglin et al. (1972), pg. 139. Shadow prices are the generalisation of market prices used to compute the money value of the changes induced by the policy.

<sup>14</sup>An exception to this rule is the social discount rate, which is the weight put on the consumption in future time periods, as we describe below.

“If the economic activities of a community were organised on the principle of making no alterations in the organisation of production which were not improvements in this sense, and making all alterations which were improvements that it could possibly find, then, although we could not say that all the inhabitants of that community would be necessarily better off than they would have been if the community had been organised on some different principle, nevertheless there would be a strong probability that almost all of them would be better off after the lapse of a sufficient length of time.”<sup>15</sup>

But even those, like Little and Mirrlees, who believed that a concave (inequality averse) Bergson social welfare function provided the correct normative foundation for CBA had good arguments against using distributional weights in practice:

It (*the explicit modelling of distributional issues with weights*) would be unnecessary if it were true that other instruments of policy [...] could achieve as much equality as was desirable [...] more efficiently.<sup>16</sup>

The idea here is that in a country in which the politically desired distribution of resources can be achieved by other means such as redistributive taxation, the evaluation of other policies need not further consider distributional impacts. If such other means of redistribution are actually implemented, this is indeed more efficient. The logic is as follows. First maximise the total monetary surplus, without consideration of where it falls, as this gives you the largest economy that is feasible. Then use the most efficient mode of redistribution to achieve the level of equality deemed desirable in the society. It is easy to see that this will yield a better outcome than accounting for distributive goals within each individual policy, unless all policies are equally efficient at redistributing.

This provision, and the use of progressive income taxation in most developed countries, has meant that distributional weights have not played a big role in applied CBA, even amongst practitioners who are inclined to think that distributional issues warrant being considered. It also has the big advantage of being informationally less demanding. Aggregate variables can be used to estimate the dollar values of the impacts without the need to attribute these to individuals in different socio-economic strata. The resulting low informational requirement was an important factor in the successful spread of the use of CBA.

It would seem that by the time, CBA was applied to climate policy, the “disappearance” of welfare economics lamented by Atkinson had already set in, and the normative foundations were no longer an essential part of the economics curriculum. Else, it would have been obvious that cost-benefit analysis in such a form could not be applied to climate policy. At the relevant global scale, there is neither the redistribution by other means required by Little and Mirrlees nor the possibility of repeated application of global cost-benefit analysis that would wash out the distributional effects, as suggested by Hicks.

One issue in particular highlights the problem in evaluating climate change *without* distributional weights. The monetary value attached to increases in mortality become vastly different for regions at different stages of development. This runs against a widely shared intuition that lives should be equally valuable, at least from the point of view of public policy.

<sup>15</sup>Hicks (1941) pg. 111.

<sup>16</sup>Little and Mirrlees (1974). This argument is originally due to Musgrave (1959).

In the first round of applications of cost-benefit analysis to climate change, some practitioners were so set in the rationale of the standard approach that they failed to appreciate how strongly counter intuitive this would be to appear to outsiders. The following quote is from a prominent paper defending the old approach regarding the value of life:

“In particular, when human life is at risk, as it is with climate change, then the benefit-cost test may produce the result that less should be spent to ‘save a life’ in developing countries than in developed countries. ‘Lives’, it seems, are valued unequally, and it is this *apparent* implication that offends the critics.”<sup>17</sup>

Predictably, this caused a re-evaluation of the valuation of lives. More generally, distributional considerations have made a comeback in cost-benefit models of climate change, as evidenced by Azar and Sterner (1996), Fankhauser et al. (1997), Azar (1999), Tol (2001), Tol et al. (2004), Tol (2005), Hope (2008), Anthoff et al. (2009), Anthoff and Tol (2010), and Dennig et al. (2015). More importantly, their previous omission was not a trivial matter. Several of these studies show that optimal climate policy is strongly affected by the use of such weights.

Equally predictable, this re-evaluation has not been without criticism. Lomborg (2003) and Mendelsohn (2006) are just two of many examples of authors that are critical of the use of distributional weights. The debate is alive and well, and the normative foundations of distributional weights are being evaluated still.

## 4 Discounting, prices, and weights

Climate change has also breathed new life into the century old debate on discounting. The debate concerns the extent to which future impacts of policy should be discounted relative to current ones. Unlike for impacts across contemporaries, where the standard approach has customarily applied equal weights, when it came to impacts across time, the standard approach has been to discount future impacts by applying lower weights to them. This literature speaks of a *discount rate*, rather than weights,<sup>18</sup> which is often separated into two components:

$$d = \eta * g_c + \rho \quad (1)$$

Here,  $\eta$  is a parameter of the social welfare function that measures the extent to which inequality (across generations) is socially disliked.<sup>19</sup> It is multiplied by the growth rate of consumption  $g_c$ , resulting in greater discounting of future impacts when growth is faster. This term is analogous to the requirement that impacts on poorer people be given more weight. When applied to weighing impacts across time, this has never been particularly controversial as the discounting literature has always worked under the assumption that

<sup>17</sup>Fankhauser et al. (1997), pg. 250. Emphasis added.

<sup>18</sup>In comparing costs and benefits in adjacent periods, the discount rate (1) amounts to putting an additional weight of

$$\omega = (1 + \rho) \left( \frac{C_{t+1}}{C_t} \right)^\eta$$

onto costs and benefits in period  $t$  relative to period  $t + 1$ . Here, we use the fact that the growth rate of consumption is defined as  $g_c = \frac{C_{t+1}}{C_t} - 1$ .

<sup>19</sup>Depending on context and interpretation, the parameter  $\eta$  is known as the (absolute value) of the elasticity of marginal utility, or the coefficient of relative risk aversion, or the coefficient of relative inequality aversion.

there is some form of underlying (concave) social welfare function.<sup>20</sup> Notice also that if growth is projected to eventually stop or even turn negative, this term does not discount at all, but rather puts greater weight on future impacts.

The *pure rate of time preference*  $\rho$  is an additional term that has raised more heated debate, as it amounts to prejudice against future people simply for being in the future. The evaluation puts less weight on them because they are born at a later date. Frank Ramsey, who was the first economist to analyse such a problem formally, included the parameter in his seminal analysis of optimal savings (Ramsey 1928), but held strong views against using non-zero values for it:

“it is assumed that we do not discount later enjoyments in comparison with earlier ones, a practice which is ethically indefensible and arises merely from the weakness of the imagination; we shall, however, in Section II include such a rate of discount in some of our investigations.”<sup>21</sup>

The main result of his analysis is summarised in what is known today as the Ramsey equation:

$$r = \eta * g_c + \rho \quad (2)$$

It states that on the optimal path the discount rate defined in Eq. 1 must be equal to the interest rate on savings,  $r$ . Ramsey thought of this result as a normative statement. Given a political and ethical choice for the parameters of the social welfare function,  $\eta$  and  $\rho$ , it prescribes the optimal savings rate (and the implied interest rate,  $r$ ). Many proponents (but not all) of this view furthermore agree with Ramsey that the only ethically acceptable choice is to set  $\rho = 0$ .<sup>22</sup>

Ramsey himself understood that the implications for the savings rate of such an approach might be quite contrary to commonly held views, recognising that

“the rate of saving which the rule requires is greatly in excess of that which anyone would normally suggest...”<sup>23</sup>

One of the most forceful critiques of this view came from exploiting this fact. Tjalling Koopmans argued against using prior ethical considerations on the social objective to make decisions on discounting, proposing instead to consider thought experiments on the implications of different assumptions in order to guide our intuitions on this issue. In his words

“The underlying idea of this exploratory approach is that the problem of optimal growth is too complicated, or at least too unfamiliar, for one to feel comfortable in

<sup>20</sup>That some discounting on account of growth ought to happen has been uncontroversial, but there is still debate as to the extent, encapsulated by the value taken by  $\eta$ . Depending on which interpretation (see footnote 19) is used, different values are deemed appropriate, with a range of [1,2] capturing almost all the values used in climate change models.

<sup>21</sup>Ramsey (1928), pg. 543.

<sup>22</sup>See Allais (1947), Harrod (1960), and Marglin (1963) for prominent proponents of this view, and Broome and Economic and Social Research Council (Great Britain) (1992) and Cline (1992) and famously Stern (2007) for more recent proponents in relation to climate change.

<sup>23</sup>Ramsey (1928), pg. 548. He goes on to say that the relaxation of some of the simplifying assumptions might lead to rates that are more in line with practice.

making an *entirely* a priori choice of an optimality criterion before one knows the implications of alternative choices.”<sup>24</sup>

In Koopmans (1965), he rejects a zero pure rate of time preference on account of the striking and prima facie undesirable implications it can be shown to have in simple growth models with sufficiently long time horizons. By exploiting a possibly infinite horizon, he was even able to show that zero discounting can lead to a contradiction (Koopmans 1960). Of course, his approach drew its own criticism, with most critics focusing on the high specificity of the model needed to reach his more absurd conclusions.

A related and ultimately more enduring critique of zero discounting pertained to the way in which people actually seem to provide for the future. It is known as the descriptive, or positive, approach, in contrast to the prescriptive, or normative, approach of Ramsey and his followers. The extreme version of this view, espoused by Bauer (1957), states that the trade-off between current in future generations implied in the savings rate of the current generation is necessarily the correct one. There is, therefore, no need for further inquiry into the discount rate. Underlying this is a very strong form of consumer sovereignty. A milder version is based on the observation that for policies with impacts contained within the lifetime of a single generation, the revealed preferences for savings tell us how the people impacted by the policy choose to allocate their consumption between the different periods in their life, and that this rate should also be used in the evaluation of a public policy affecting only them.

These approaches take the interest rate,  $r$ , on left hand side of Ramsey Eq. 2 as the principal source of information to settle the dispute and choose  $\rho$  and  $\eta$  in order to make the Ramsey equation hold at current consumption growth rates,  $g_c$ , rather than the other way around, as Ramsey did. Once these are determined, they can be used to compute future discount rates for any assumption of future growth rates. In practice, with an interest rate of say 3% and a growth rate of 1%, a combination of  $\rho = 1.5\%$  and  $\eta = 1.5$  would make the Ramsey equation hold. This was the dominant approach to discounting up until the 1990s and the approach used in most of the early climate change models (see Nordhaus (1994), Manne et al. (1995), and Peck and Teisberg (1992)).

To understand the importance of these values, notice that at a pure rate of time preference of 1% per annum, impacts in 100 years are only worth one third of impacts today. At 2%, the same impacts are worth one seventh of impacts today. The relative weights go down to one eighth and one fiftieth respectively at a 200-year time horizon. Climate change is unprecedented as a policy question with such an extraordinary time horizon, making the correct choice of discount rate a more sensitive issue than for previous policy questions. This, and the fact that there is no agreement in the literature on discounting, was recognised early on in the climate change debate and a magisterial review of the alternative positions was prepared for the second assessment report of the IPCC (Arrow et al. 1996). But the review simply explained the different points of view, acknowledging that there is no consensus.

Since then, a large literature has produced several critical reviews (Lind 1995; Dietz et al. 2007; Beckerman and Hepburn 2007) and various attempts at new approaches to achieve some consensus. Portney and Weyant (1999) brings together a number of contributions—along with replies to them—by leading economists exploring the role of risk, time consistency, the role of market prices, and hyperbolic discounting in pinning down

---

<sup>24</sup>Koopmans (1965) pg. 226.

the discount rate. More recently, Zuber and Asheim (2012) propose a criterion that avoids the implication of prejudice against the future implicit in a positive pure rate of time preference. Heal and Millner (2013) take a political economy approach to establish an aggregate discount rate that is representative of a population in which a range of discount rates are represented. von Below et al. (2015) back out discount rates from an overlapping generation model in which generations bargain over the surplus generated by climate policy. These are just a few examples, with no definitive approach having yet achieved consensus. In the meantime, the literature on the topic continues to grow.

## 5 Conclusion

Climate change is an unprecedented economic and political challenge. Due to its scale, its encounter with economics and cost-benefit analysis has exposed some limitations in the normative foundations of the latter, which had undergone very little critical analysis for some time. This has provided the impetus for a re-evaluation of these normative foundations in order to produce a cost-benefit analysis that does justice to the scale of the problem. I have illustrated this by describing the historical development of these normative foundations and referencing new research that has emerged as a consequence of the economic study of climate change. I am certain to have omitted many contributions, but these here should suffice to show that climate change has reopened a debate on the normative foundations of economics that had laid dormant for some time. One can only hope that by this process, one of the legacies of climate change will be a better understanding, not just of the earth's climate system but of the economics needed to tackle problems of such scale in the future.

**Acknowledgments** I would like to thank the organisers of the workshop for inviting me to contribute and Robert Socolow in particular for his encouragement. The audience at the workshop and at the University Center for Human Values in Princeton provided useful comments, and three anonymous reviewers as well as Kian Mintz provided advice above and beyond their obligation. All errors remain my own.

**Open Access** This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made.

## References

- Allais M (1947) *Economie et interet: exposition nouvelle des problemes fondamentaux relatifs au role economique du taux de l'interet et de leur solutions*. Imprimerie nationale et librairie des publication officielles
- Anthoff D, Tol RSJ (2010) On international equity weights and national decision making on climate change. *J Environ Econ Manag* 60(1):14–20
- Anthoff D, Cameron JH, Tol RSJ (2009) Equity weighting and the marginal damage costs of climate change. *Ecol Econ* 68(3):836–849
- Arrow KJ (1951) *Social choice and individual values*, Cowles Commission Monographs. Wiley, New York
- Arrow KJ, Cline WR, Maler K-G, Munasinghe M, Squitieri R, Stiglitz JE (1996) *Intertemporal equity, discounting, and economic efficiency*. Cambridge University Press, Cambridge
- Atkinson AB (2001) The strange disappearance of welfare economics. *Kyklos* 54(2-3):193–206
- Azar C (1999) Weight factors in cost-benefit analysis of climate change. *Environ Resour Econ* 13(3):249–268

- Azar C, Sterner T (1996) Discounting and distributional considerations in the context of global warming. *Ecol Econ* 19(2):169–184
- Bauer PT (1957) Economic analysis and policy in underdeveloped countries. <https://books.google.com.sg/books?id=IQ7AAAAAAAJ>
- Beckerman W, Hepburn CJ (2007) Ethics of the discount rate in the Stern review on the economics of climate change. *World Economics-Henley on Thames*- 8(1):187
- Bergson A (1938) A reformulation of certain aspects of welfare economics. *Q J Econ* 52(2):310–334
- Blackorby C, Donaldson D (1990) A review article: the case against the use of the sum of compensating variations in cost-benefit analysis, *Canadian Journal of Economics*. pp 471–494
- Boadway R et al (2006) Principles of cost-benefit analysis. *Public Policy Review* 2(1):1–44
- Boadway RW (1974) The welfare foundations of cost-benefit analysis. *Econ J* 84(336):926–939
- Broome J, Economic and Social Research Council (Great Britain) (1992) Counting the cost of global warming: a report to the economic and social research council on research by John Broome and David Ulph, White Horse Press. <https://books.google.com.sg/books?id=aSvsAAAAAAAJ>
- Cline WR (1992) The economics of global warming. Institute for International Economics. <https://books.google.com.sg/books?id=9UOSAAAAIAAJ>
- de Scitovszky T (1941) A note on welfare propositions in economics. *Rev Econ Stud* 9(1):77–88
- Dennig F, Budolfson MB, Fleurbaey M, Siebert A, Socolow RH (2015) Inequality, climate impacts on the future poor, and carbon prices. *Proc Natl Acad Sci* 112(52):15827–15832
- Dietz S, Hepburn CJ, Stern N (2007) Economics, ethics and climate change. *Ethics and Climate Change*. pp 2007
- Fankhauser S, Tol RSJ, Pearce DW (1997) The aggregation of climate change damages: a welfare theoretic approach. *Environ Resour Econ* 10(3):249–266
- Gowdy JM (2004) The revolution in welfare economics and its implications for environmental valuation and policy. *Land Econ* 80(2):239–257
- Hammond PJ (1991). In: Elster J, Roemer JE (eds) *Interpersonal comparisons of well-being interpersonal comparisons of utility: why and how they are and should be made*. Cambridge University Press, London, pp 200–254
- Harberger A (1964) Taxation, resource allocation, and welfare. In: *The role of direct and indirect taxes in the Federal Reserve System*. Princeton University Press, pp 25–80
- Harberger AC (1964) The measurement of waste. *Am Econ Rev* 54(3):58–76
- Harrod RF (1938) Scope and method of economics. *Econ J* 48(191):383–412
- Harrod R (1960) Towards a dynamic economics: some recent developments of economic theory and their application to policy. <https://books.google.com.sg/books?id=C0cNAQAIAAJ>
- Heal G, Millner A (2013) Discounting under disagreement. *National Bureau of Economic Research*. <http://www.nber.org/papers/w18999>
- Hicks JR (1939) The foundations of welfare economics. *The Economic Journal*. pp 696–712
- Hicks JR (1941) The rehabilitation of consumers' surplus. *Rev Econ Stud* 8(2):108–116
- Hope C (2008) Discount rates, equity weights and the social cost of carbon. *Energy Econ* 30(3):1011–1019
- Kaldor N (1939) Welfare propositions of economics and interpersonal comparisons of utility. *Econ J* 49(195):549–552
- Koopmans TC (1960) Stationary ordinal utility and impatience. *Econometrica: Journal of the Econometric Society* 28(2):287–309
- Koopmans TC (1965) On the concept of optimal economic growth. In: *Pontificiae academiae scientiarum scripta varia 28, 1: semaine d'étude sur le rôle de l'analyse econometrique dans la formulation de plans de développement*. Pontifical Academy of Sciences
- Lerner AP (1972) The economics and politics of consumer sovereignty. *Am Econ Rev* 62(1/2):258–266
- Lind RC (1995) Intergenerational equity, discounting, and the role of cost-benefit analysis in evaluating global climate policy. *Energy Policy* 23(4):379–389
- Little IMD, Mirrlees JA (1974) Project appraisal and planning for developing countries. <https://books.google.com.sg/books?id=UZ63AAAAIAAJ>
- Lomborg B (2003) *The skeptical environmentalist: measuring the real state of the world*, Vol. 1. Cambridge University Press, Cambridge
- Manne A, Mendelsohn R, Richels R (1995) MERGE: A model for evaluating regional and global effects of GHG reduction policies. *Energy policy* 23(1):17–34
- Marglin S (1963) The social rate of discount and the optimal rate of investment. *Q J Econ* 77(1):95–111
- Marglin S, Sen AK, Dasgupta P (1972) Guidelines for project evaluation. UNIDO, Vienna
- Mendelsohn RO (2006) Critique of the Stern Report. *A, Regulation* 29:42
- Mill JS (1901) *Utilitarianism*. Green and Company, Longmans
- Musgrave RA (1959) *The theory of public finance*, McGraw-Hill Book Company, Inc

- Nordhaus W (1990) A general equilibrium model of policies to slow global warming. In: Economic models of energy and environment, Proceedings of a Workshop, Washington, DC
- Nordhaus WD (1990) Slowing the greenhouse express: the economics of greenhouse warming, Setting National Priorities. Washington: The Brookings Institution. pp 185–211
- Nordhaus WD (1994) Managing the global commons: the economics of climate change, vol 31. MIT press Cambridge, MA
- Peck SC, Teisberg TJ (1992) CETA: a model for carbon emissions trajectory assessment, *The Energy Journal*. pp 55–77
- Portney PR, Weyant JP (1999) Discounting and intergenerational equity, *Resources for the future*
- Ramsey FP (1928) A mathematical theory of saving. *Econ J* 38(152):543–559
- Ricardo D (1817) *On the principles of political economy and taxation*. John Murray, London
- Robbins L (1932) *An essay on the nature and significance of economic science*. Macmillan, London
- Robbins L (1938) Interpersonal comparisons of utility: a comment. *Econ J* 48(192):635–641
- Scitovsky T (1962) On the principle of consumers' sovereignty. *Am Econ Rev* 52(2):262–268
- Sen AK (1970) *Collective choice and social welfare*. San Francisco, Holden-Day
- Sen AK (1970) Interpersonal aggregation and partial comparability. *Econometrica: Journal of the Econometric Society*. pp 393–409
- Stern N (2007) Ethics, equity and the economics of climate change paper 2: economics and politics. *Econ Philos* 30(3):445–501
- Tol RSJ (2001) Equitable cost-benefit analysis of climate change policies. *Ecol Econ* 36(1):71–85
- Tol RSJ (2005) The marginal damage costs of carbon dioxide emissions: an assessment of the uncertainties. *Energy policy* 33(16):2064–2074
- Tol RSJ, Downing TE, Kuik OJ, Smith JB (2004) Distributional aspects of climate change impacts. *Glob Environ Chang* 14(3):259–272
- von Below D, Dennig F, Jaakkola N (2015) *The climate debt deal: intergenerationally efficient climate policy*, Technical Report, mimeo
- Zuber S, Asheim GB (2012) Justifying social discounting: the rank-discounted utilitarian approach. *J Econ Theory* 147(4):1572–1601