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Prerequisites and limits for economic modelling of climate change impacts and adaptation

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Abstract

There is demand for qualitative and quantitative economic analysis on the optimum degree of climate change mitigation and adaptation, the optimal timing of such actions, and their optimum distribution between countries and sectors. This paper discusses what is possible for economic modelling in this field and what is not, with specific reference the paper by Bosello, Carraro and de Cian (2009) as well as Tol (2009). Integrated assessment modelling can provide powerful qualitative insights, for example about the need for both mitigation and adaptation and the interactions between the two, or the need for both individual and policy-driven adaptation. However, the more detailed quantitative results from such studies are subject to such strong limitations, and in many cases are virtually irrelevant as a guide to policy. Three important features are needed in economic models of climate change in order for these models to be useful representations of reality: representation of uncertainty about impacts, in particular the risk of abrupt climate change; fuller representation of economic impacts from climate change and inclusion of non-market impacts; and modelling of equity dimensions. These features are absent in many model currently used, and as a result quantitative results tend to be biased against mitigation as an option to address climate change, and in favour of other adaptation.

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1. Introduction

It is likely that climate change will have substantial impacts on natural and human systems in decades and centuries to come, and that there is the risk of severe disruptions to economic activities. It could force the relocation of large numbers of people between and within countries, and change the location, extent and nature of economic activities including agriculture. In some cases, adaptation to changed climatic conditions could be feasible simply through changed practices, not necessarily incurring significant economic costs. In others, it will require expansion and remodelling of service systems such as public health; and necessitate the early retirement of existing and construction of new infrastructure including in housing, transport, water supply, energy and so forth (Richardson et al 2009).

These facts drive a demand for qualitative and quantitative economic analysis on optimum degree of climate change mitigation (that is, reducing greenhouse gas emissions) and adaptation to the effects of climate change, the optimal timing of such actions, and their optimum distribution between countries and sectors. This paper discusses what is possible for economic modelling in this field and what is not, with specific reference the paper by Bosello, Carraro and de Cian (2009).

Adaptation to climate change impacts will be necessary, will occur both through individual and policy-driven actions, and may require substantial economic resources; but that the quantitative economic analysis of climate change impacts and adaptation is a long way from being directly useful for the formulation of policy decisions. I argue that to make such analysis relevant for policy decisions, the analysis must incorporate three factors that define the economics of climate change. The first is uncertainty, in particular the risk of abrupt climate change, which is a major reason for urgency in addressing climate change. The second is improved calibration of economic climate change impacts, and the inclusion of non-market impacts. The third is equity and differential climate impacts at the fine scale, which will define adaptation actions in practice. Analyses that leave out these factors tend to yield results biased against mitigation, and their more detailed quantitative results are of very limited use as a guide to policy.

2. Basics of the economics of adaptation: what is clear and what is not

Climate change is already being observed, further change already loaded into the system, and persistence of greenhouse gas emitting system even if the world were to set on a path of strong climate change mitigation soon. It appears almost certain that adverse climate change impacts will occur, and will continue occurring for a long period of time. Hence, the role of mitigation is to reduce the extent of future damages and to limit the risk of dangerous climate change. Adaptation to the impacts that are already unavoidable will be necessary alongside mitigation.

Adaptation is going to occur. This is in contrast to mitigation, which suffers severe problems of coordination and free-riding, so that the extent of global mitigation might therefore forever remain below the social optimum. Adaptation will typically consist of a localised or regional actions, changing economic systems (and more broadly human systems) to deal with observed or anticipated environmental changes. Taking adaptive action is in the direct self-interest of those individuals and communities affected by the changes. While externalities will exist within communities or nations for some adaptation actions, a much greater share of benefits will be captured by those groups taking action than for mitigation, and the lag between investment and return will generally be much shorter than with mitigation.

A number of factors will inhibit efficient adaptive action, among them credit constraints, imperfect information or wrong perceptions about climate change impacts and risks, the use of socially non-optimal discount rates, and shortcomings in public policymaking. As a consequence, optimal abatement responses may not be achieved, but a large extent of useful adaptation will nevertheless take place.

Both market-driven and policy-driven adaptation are needed, as pointed out by Bosello, Carraro and de Cian (2009), and it is a fair expectation that both will occur. Individuals will react to climate change impacts as they do to any other changes in their physical, social and economic environment. And policy action to facilitate adaptation will for the most part be of a similar type as government reactions to other societal needs.

It is also clear that benefit-cost ratios will in aggregate be positive for adaptation, at least in expectation terms (that is the anticipated benefits and costs when adaptation is decided on). As a principle, this follows directly from the nature of adaptation as specific actions in response to specific changes and risks at a local level. Adaptation options whose costs exceed their anticipated benefits will, on the whole, not be implemented, but options with positive ratios will. Hence benefit-cost ratios somewhere above one, as posited by Bosello, Carraro and de Cian (2009), are unsurprising.

Much harder and less tractable questions revolve around the optimal mix between adaptation and mitigation. While it is clear that some degree of mitigation action is economically beneficial, debate is lively (and unlikely to ever be resolved) over what the optimal amount of mitigation is – see for example the conflicting conclusions reached by Stern (2006) or Garnaut (2008) on the one hand, and Nordhaus (2007) or Tol (2009) on the other (for more on these see below). And it is clear that adaptation will be economically beneficial in many circumstances, and not in others. But the theoretically optimal amounts of mitigation and adaptation are also interlinked. If more effort goes into limiting the extent of climate change, then this will change the options and needs for, and payoffs from, adaptation. But as I will argue below, the data and tools available to economic analysis at this point in time are insufficient for a reliable empirical analysis.

Moreover, adaptation and mitigation are not substitutes in important respects. They are treated as substitutes in economic analyses and models that revolve around single aggregate welfare measures. But in reality, mitigation and adaptation will in important respects serve different objectives. A key objective of mitigation is precaution, reducing the risk of irreversible impacts. For many climate change damages, there is no adaptation. This is particularly true for the natural environment.

Finally, the question of how, when, and where to adapt cannot be answered with confidence, because of pervasive and persistent uncertainty about future climate change and its impacts. Aggregate analyses are at a particular disadvantage as they do not have fine grained information about whether particular adaptation actions are possible and beneficial in a particular setting. Hence, predictions about the extent, type and timing of adaptation based on aggregate economic models cannot be more than illustrative scenarios.

3. The uses and limits of quantitative climate change modelling

The likely costs of climate change adaptation are beginning to be estimated in detailed sector-by-sector studies (as an example see Ciscar et al 2009; and for an overview, Parry et al 2009). Only some of the cost studies include an explicit assessment of the benefits from adaptive action, and thus make it possible to assess benefit-cost ratio of adaptation. Where they do, the result is typically that the costs of adapting are far smaller than the economic losses that would be incurred without adaptation. The focus in such studies is typically on options for adaptive action that will pay large dividends (think of expanded water storage and improved fire prevention in areas that become drier with climate change). One could also think of adaptive investments that are economically wasteful (an example might be sea walls to shield existing infrastructure from sea level rise when it would be cheaper to re-build at a higher elevation), but for obvious reasons these are typically not included in studies of adaptation options.

At the other end of the spectrum of quantitative economic analysis, aggregated models of the economy overall, in particular Computable General Equilibrium (CGE) models, are beginning to be used for the analysis of climate change impacts as well as the analysis of adaptive responses. Where both mitigation and impacts/adaptation are modelled together, these models are referred to as 'integrated assessment models' (IAMs). The specific example of an application of such a model, discussed here, is the study by Bosello, Carraro and de Cian (2009).

Such modelling, in principle, has decisive advantages over micro-level, partial-equilibrium modelling: it gives an integrated representation of benefits and costs adaptation over many different sectors and countries; a representation of economic flow-through effects such as changes in relative prices, trade, production and consumption patterns that may result from climate change impacts, mitigation and adaptation actions; and it can be used in simultaneous analysis of mitigation and adaptation. But IAM modelling also brings great abstractions, generalisations and reliance on assumptions about parameters that drive the aggregate results but are difficult or impossible to estimate or determine.

Some results in Bosello et al (2009)

Bosello et al (2009) show that the optimal policy mix for the world entails both mitigation and adaptation, that an increase in mitigation action reduces the optimal level of adaptation action, that both market and policy driven adaptation is needed, and that the degree of climate change damages as well as time preferences affect both the extent of optimal adaptation and mitigation, as well as the optimal mix.

Regarding the time dimensions of mitigation and adaptation, Bosello et al conclude that mitigation action needs to come first, and little adaptation action is needed until the middle of the century, when climate impacts are assumed to begin. However, it stands to reason that many adaptation actions would need to take place ahead of time, to manage the risk of future climate change. This relates in particular to long-lived infrastructure, including for transport. A current real-world example are desalination plants, which in Australia and elsewhere are now being planned and in some cases built, to come on line if and when drought and water shortages become worse.

The findings by Bosello et al on benefit-cost-ratios of different scenarios of adaptation and mitigation show, firstly, the overwhelming role played by the discount rate. Under the 'low discount rate' scenario, both benefits and costs of adaptation, and in particular joint mitigation and adaptation, are greatly higher than for high discount rates. This is of course a familiar result, especially in the wake of the Stern Review, and is a core difficulty with benefit-cost analysis in climate change (Quiggin 2008). Along with the overall magnitude of benefits and costs, the absolute difference between them increases greatly under a lower discount rate. The benefit-cost *ratio* however is lower with low discount rates. Hence, considering only the BC ratio could lead to the fundamentally wrong impression that greater concern for the future *reduces* the desirability of climate change adaptation and mitigation compared to other investments.

Using higher damage functions greatly increases both the absolute size of benefits and costs, and the BC ratios. This is intuitive, if climate change is more of a problem, then the payoff from addressing it is greater. However, the stark differences in BC ratios between the 'low' and 'high' damage scenarios show that to a great extent, these ratios are driven by the assumptions about climate change damages. As discussed below, leaving out the risk of extreme or catastrophic climate outcomes biases the damage estimates downward, perhaps severely. Leaving out non-market values and equity impacts will bias the results generally in the same direction.

A fundamental point to note in assessing the benefit-cost ratios and other quantitative results is the damage cost estimates and functions, which go back to Nordhaus and Boyer (2000), and which assume only relatively small impacts from climate change on economic activity and welfare from climate change, with any economic damages swamped by increases in economic growth over time. In Bosello et al, only modest GDP impacts are shown even at temperature increases around four degrees, which is now commonly regarded as carrying a significant risk of large-scale, highly disruptive and possibly catastrophic climate change (Schellnhuber 2009).

Remarkably, when market driven adaptation is considered in Bosello et al's model, OECD countries as a group *benefit* from climate change (and presumably net benefits are even greater when taking into account government driven adaptation). This result could be seen to imply that OECD countries' interest, as a group, is in increasing global emissions, not reducing them, and that only the developing world has an interest in mitigation – which is in obvious conflict with actual climate policy.

Limits of economic modelling of climate change

These results derive from the climate change damage functions used in the model, and the fact that the risk of abrupt or catastrophic climate change is not considered in the modelling. Much of the relevant economic modelling literature incorporates similar assumption that climate change damages are small relative to economic growth over time, and ignores the risk of catastrophic change. The conclusion that follows from such assumptions is that the globally optimal amount of mitigation is rather small – a conclusion that is at odds with the dominant view in the natural sciences, and with the precautionary considerations that are clearly an important motivator for climate policy in the real world.

Tol (2009) is an example of a modelling analysis that finds small amounts of mitigation to be optimal, as a direct consequence of assumptions about climate change damages. Tol assumes that the social cost of carbon is only \$2/ton of carbon (equivalent to \$0.5/tCO_2), far less than mainstream views of the social cost of carbon, and an extreme outlier in the literature.[1] By comparison, the marginal cost of emissions already in place under the EU emissions trading system has been in the range of \$15–30/tCO_2. From such an assumption inevitably follows the conclusion that the costs of mitigation exceed the benefits for anything more than very small efforts.

Any modelling analysis is defined and limited by the choice of features of reality that are represented and ignored, and the calibration of parameters, for which empirical evidence is often scarce. I argue that the aggregated modelling tools at the disposal to the economics community, and including those applied by Bosello et al, are not nearly sophisticated enough to yield quantitative answers that are useful to policymakers. They may be able to give important qualitative indications, such as about the complementarity of mitigation and adaptation, but the quantitative results are under a heavy cloud of

[1] For example Tol's (2005) own survey showed the mean of 28 studies assumed a social cost of carbon \$97/tC, and the sub-sample of studies published in peer-reviewed journals \$43/tC, denoted in 1995US\$ (and thus higher in current value terms). A social cost of carbon of \$2/tC or below is found only at the extreme end of the range of assumptions in some of the studies.

doubt even for broad aggregate results, and are generally not of use as a guide to policy at a disaggregated level.

Below I discuss three aspects that would need to be included in quantitative economic modelling of climate change, in order for the quantitative results to usefully speak to policy. The first is uncertainty, in particular the risk of abrupt climate change, which is a major reason for urgency in addressing climate change, but difficult to capture in economic models. The second is improved calibration of economic climate change impacts, and the inclusion of non-market impacts, which motivate much of public concern about climate change and for which adaptation options are typically much narrower than for market impacts. The third is equity and differential climate impacts at the fine scale, which will define adaptation actions in practice, but cannot be represented in aggregate models.

4. Uncertainty

Most modelling of whole economies, in particular that using CGE models, takes places in a deterministic framework. CGE models consist of a set of parameters that describe observed economic data and relationships (such as inputs to production processes, and trade flows), and fixed assumptions for behavioural responses (such as responses to changes in prices). In typical applications, including Bosello et al, the model is then subjected to ‘shocks’ in the form of sets of changes in exogenous variables. In modelling of climate change, a set of assumptions about the impacts of climate change is imposed, for example through changes in the productivity of certain sectors of the economy; and a price (tax) on emissions is imposed which results in shifts in production and consumption away from emissions intensive processes, goods and services. The myriad effects and interactions in the model can then be presented in an aggregate measure such as GDP or consumption. It is generally thought that responses in an economy to changes in relative prices, for example through changes in taxation or tariffs, can be modelled in this way with at least some degree of confidence.

The extension to the modelling of climate change impacts however brings hugely more complex issues into play. The nature and extent of future physical climate change impacts is unknown. Climate change science increasingly indicates that there may be strong feedback mechanisms in the system, making the correlation between greenhouse gas emissions, temperature increase and physical impacts highly non-linear (Richardson et al 2009). In other words, there is a wide probability distribution for the possible climate impacts (and their economic effects or damages) of any given level of emissions or global temperature increase. Consequently, modelling that deterministically maps emissions to climate change damages lacks the crucial dimension of uncertainty about what the actual effect might be, and in particular risk of very strong damages.

The risk of extreme climate change is in fact the main reason why the mainstream of climate change scientists urge fast and strong action to reign in emissions, and the key reason why a range of governments pursue urgent global mitigation action. A central objective of climate change mitigation, already evident in the 1992 UN Framework Convention on Climate Change, is to reduce the risk of extreme climate change in an expression of societal risk aversion.

It has been shown that under assumptions about the probability distribution of climate change damages that appear plausible given current knowledge, the (low) probability of catastrophic climate change alone could be the single overwhelming factor in an economic analysis of climate change, and for considerations relevant to economic decision-making about mitigation. In the words of Weitzman (2009), the problem is characterised by “deep structural uncertainty in the science coupled with an economic inability to evaluate meaningfully the catastrophic losses from disastrous temperature changes". Thus avoiding the risk of very large scale economic damage dominates the effect even of the choice of discount rate, traditionally seen as the main variable driving the optimal level of mitigation.

Similar arguments, though likely to a lesser extent, also apply to the modelling of adaptation. Abrupt climate change could necessitate very different adaptation responses, and at a different timescale, including requiring a greater extent of anticipatory adaptation to achieve greater readiness for possible climate change impacts.

Furthermore, it must be questioned whether current assumptions about behavioural parameters built into economic models are an accurate guide to what may happen in the future, particularly under scenarios of significant change in the structure of economies.

The upshot for economic modelling of climate change, its economic effects and policy responses is that at a minimum, stochastic modelling of climate impacts is needed, rather than only using the median of the presumed probability distribution as is so often done. In the first instance, this would involve the modelling of a large number of different scenarios of climate change impacts, ranging from very small to catastrophic changes according to an assumed probability distribution. Such stochastic modelling was undertaken for example by the Stern (2006) Review, then conflated into an aggregate measure of expected economic impacts from climate change. Such a stochastic approach does not overcome structural uncertainty and the inability to economically evaluate catastrophe, but at least it can give a sense of the range of possible outcomes.

5. Economic impacts and valuation of climate change impacts

A second set of fundamental issues for economic modelling of climate change and adaptation options relates to the likely economic effect of environmental change, especially if and where such change is large in scale; and the inclusion and valuation of non-market impacts. Most current modelling exercises, Bosello et al included, rely on highly aggregate climate change damage functions that may underestimate feedback effects within economies, and do not represent non-market impacts such as the loss of species or natural icons.

CGE models typically assume a strong degree of substitutability in both production and consumption structures, and aggregate welfare measures such as GDP and consumption are driven much more by assumed underlying growth in productivity, than by changes in productivity because of a shift in structure away from the optimum. Physical factors, such as the need to produce and consume a certain amount of food per person, are oftentimes not or inadequately represented. Similarly, and using a related example, possible feedback effects such as escalating food prices during times of shortage are generally not well represented. Hence, even large scale physical impacts from climate change tend to be translated into only small changes in welfare, especially when compared to the assumed increase over time.

A striking result from Bosello et al is that adverse impacts on tourism are the approximately equal largest category of economic damages, alongside agriculture. By contrast, the impacts from sea level rise and health are almost insignificant. Total net climate change damages are less than half a percentage point of GDP at 2050, compared to GDP typically expected to more than treble over that time span. This is in a scenario of a 3 degrees increase in mean temperatures, which now generally regarded to herald unacceptable risks from climate change for humanity.

These damage estimates originate in the damage functions taken from other studies, in interaction with the data and assumptions in the models. While it is impossible to confirm or refute any particular pattern of climate change damages, this particular result provokes doubts over the damages functions used. Alternative specifications need to be explored that accord with notions that impacts on coastal infrastructure, health and agriculture and so forth would be serious to an extent that they would likely far outweigh economic impacts on the tourism industry.

A well-understood, yet extremely difficult to address shortcoming of standard economic modelling of climate change is the omission of non-market impacts of climate change, including amenity value to people and existence value of natural and cultural icons. These aspects are difficult to quantify, and leaving them out is in the mainstream modelling tradition. Nevertheless, an analysis that speaks to actual policy decisions on climate change cannot afford to set aside non-market impacts. In an illustration from Australia, it appears that the possible or indeed likely loss of the Great Barrier Reef, the world's largest coral reef, is a major factor in public concern about climate change. While it will be impossible to reliably quantify the amenity and existence value of such natural icons, they must figure in the overall evaluation of mitigation and adaptation strategies.

Adaptation options will typically be more restricted for issues revolving around non-market values, than for market impacts. The coral reef example is obvious in that there are no apparent adaptation options. The situation may be similar if somewhat different for issues such as the survival of species, where assisted relocation may be an option in some instances. The inclusion of non-market values in the analysis thus shows greater importance of mitigation, rather than adaptation.

6. Equity and scale

A third set of issues critical for the modelling relates to the distribution of impacts of climate change, and the costs and benefits of mitigation and adaptation.

Mainstream economic modelling exercises aggregate welfare measures across countries, and implicitly within countries, and derive optima over the globally aggregated result. The implicit assumption is that an extra dollar of income provides the same utility to each person in the world. Given stark differences in income and living standards between and within countries, this is self-evidently untrue. The point is generally recognised in the climate policy debate, where there is heavy emphasis – at least in the rhetoric of international negotiations and domestic politics – on shielding the poorest countries and people from climate change damages.

One way to deal with this in a modelling context is to give equity weighting to welfare results. In a multi-country model, this would result in a different global optimum, namely one that gives greater emphasis to the best outcome in poor countries. On the basis of the numbers reported by Bosello et al, this would probably mean a greater optimum amount of both mitigation and adaptation, and a changed mix between the two.

A final issue to note here relates to the scale of the modelling. The sectoral and regional detail in economic models used for climate change analysis is much coarser than the likely pattern of damages and benefits from climate change and adaptation. For example, a net loss within agriculture in one country could in fact consist of gains in some regions and for some types of agriculture, offset by larger losses in other areas. Similarly, there would be pertinent and highly cost-effective adaptation options in some activities and regions, whereas none may exist elsewhere. The design and implementation of policy must and will take the fine scale into account. Data from much coarser aggregate economic modelling will be of limited value in guiding such policy.

7. Conclusion

Integrated assessment modelling, such as that by Bosello et al (2009) can provide powerful qualitative insights, for example about the need for both mitigation and adaptation and the interactions between the two, or the need for both individual and policy-driven adaptation. However, the more detailed quantitative results from such studies are subject to such strong limitations as to be virtually irrelevant as a guide to policy.

The Copenhagen Consensus exercise places heavy emphasis on benefit-cost-ratios. These ratios come about as a result of highly contestable assumptions about climate change impacts, economic damage functions, societal valuations and preferences, with interactions between them shaped by assumptions about behavioural relationships in economies decades in the future. Consequently, the estimated benefit-cost-ratios are highly unreliable as a guide for policy.

This paper has argued that three important features are needed in economic models of climate change in order for these models to be useful representations of reality: representation of uncertainty about impacts, in particular the risk of abrupt climate change; fuller representation of economic impacts from climate change and inclusion of non-market impacts; and modelling of equity dimensions. Where these features are absent, it tends to result in quantitative results that are biased against mitigation as an option to address climate change, and in favour of other alternatives including adaptation. A stark example is the analysis by Tol (2009), which assumes an extremely low social cost of carbon, and by virtue of the assumption concludes that only very small mitigation efforts would be cost-effective. Insofar as the recommendations from the convenors of the Copenhagen Consensus – in particular the low ranking for mitigation – are based on such modelling, there must be strong doubts over the validity of those conclusions.

For adaptation, the type of quantitative analysis that will be most useful for policymakers is not aggregate estimates of economic benefits and costs. Rather, it will be detailed and localised benefit-cost estimates that take into account actual preferences of the communities concerned, including for equity, non-market valuations and aversion to risk. This is because decisions about adaptation will not be taken in aggregate for whole economies (as might often be the case for mitigation), but sector by sector and locality by locality.

Arguably the most pressing need for understanding in the policy community relates to the effect of policy settings on adaptation. Existing policies can support adaptation, or be counterproductive and hinder adaptive responses. This implies that many aspects of the existing policy framework in any country will need to be examined for their likely effect on climate change adaptation. New policies will be needed in some areas, to support types of adaptive behaviour that would otherwise not come about, and some existing ones will need to be scrapped. Much work will need to be done to understand where these needs are and how they would best be met. This will include quantitative work about benefits and costs, but rarely at a highly aggregated level.

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