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Economic valuation of climate change adaptation in developing countries

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This paper reviews the literature on the economics of climate change adaptation in developing countries, and identifies three key points for consideration in future studies. One key point is that all development policy should be formulated using forecasts from climate science as a baseline. When this is not done, there is risk that a false status quo without climate change is seen as an implicit baseline. Another key point is that authors must be clearer about their behavioral assumptions: Many studies either (problematically) assume profit maximization on the side of farm households, or do not specify behavioral assumptions at all. A third important point is that the allocation of rights is crucial for the results; if households have a right to maintain their current livelihoods, the costs of climate change in developing countries are considerably greater than traditional willingness-to-pay studies would indicate. Thus, costs and benefits of climate change adaptation cannot be analyzed using economic aspects only; climate science, behavioral science, and legal and moral aspects have crucial implications for the outcome of the analysis.

Keywords: climate change; climate change adaptation; developing countries; Ricardian analysis; WTP/WTA

Introduction

This paper is intended to provide an overview of the literature on valuing the costs and benefits of climate change adaptation in developing countries. The paper is not intended to be exhaustive, but merely to indicate some issues that it may be useful to consider when valuing impacts of climate change in practice in developing countries. The paper begins by discussing the conceptual issues involved in cost–benefit analysis of climate change adaptation. Following this, some specific issues involved in analyzing adaptation in developing countries, notably the importance of subsistence and near-subsistence production, are discussed. This is followed by an overview of the current state of the literature. The paper ends by discussing some potential conclusions from this overview.

Needless to say, countries need to consider climate change in their development strategies, as climate change will be an important constraint on the choices that are likely to be available to many countries. However, there is nothing unique about climate change in this regard; developing countries are subject to many internal and external constraints and stresses that affect their choice of development strategies, positively or negatively. Changes in terms of trade, natural disasters, wars, and other external factors, as well as internal factors, such as weak institutions, corruption, and domestic strifec, all affect the portfolio of choices available, and all need to be considered when a country determines its development strategy. It may seem unnecessary to value the costs and benefits of a country's adaptation policy separately from the costs and benefits of other development policies that the country is pursuing, since in practice the adaptation policy will be part of an overall policy in any case.

Similarly, it is reasonable to assume that even though firms and households will consider the need to adapt to climate change in their overall strategies, they will not do this in isolation from other decisions. Firms will presumably seek to maximize their profits regardless of the weather, and climate change will only be one of the many factors affecting their production and investment decisions. The

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same will presumably be true of households' consumption and savings decisions.

However, there are at least two reasons to consider climate change adaptation separately from other issues affecting development, both related to the way in which the international debate on climate change is framed. In international climate policy discussions, the estimated future costs of climate change impacts on individual countries are an important component in the debate on allocation of emission rights and compensation criteria. Similarly, costs and benefits of climate change adaptation have become an important part of the discussion in development aid. A developing country's capacity for providing credible estimates of the future costs of climate change, including the costs of adaptation to climate change, is therefore likely to affect its flows of development assistance, emission rights allocations, and compensation for climate change impacts. It is, therefore, in a developing country's interest to consider climate change-related costs and benefits of its development strategy separately from the costs and benefits of other components of its development strategy, at least when discussing its development strategy with other countries.

Cost–benefit analysis of adaptation

The discussion above suggests, however, that valuation of climate change adaptation may be difficult in practice. Many decisions that incorporate climate change as part of the background will, nonetheless, not necessarily be seen as explicit climate change adaptation.

In this context, it is useful to consider two components of climate change adaptation that are frequently discussed separately in the literature; autonomous adaptation, and planned (or policy-driven) adaptation.[1] Autonomous adaptation refers to adaptation decisions that are not made by government agencies; decisions that are made by private firms and households in order to adjust to the realities of climate change. Planned adaptation refers to decisions that are made by government bodies.

Looking at these two adaptation categories, it is clear that neither will consist exclusively of explicit adaptation decisions. Firms will presumably seek to maximize their profits and households their utility, no matter what the climate situation and no matter what planned adaptation policies are being carried out. The climate and the planned adaptation will affect what choices firms and households can make, and hence also affect their behavior, but will not affect their overall objectives; they will only affect how successful firms and households are in reaching those objectives. Similarly, governments will presumably seek to maximize the welfare of their citizens regardless of the climate, and will (mainly or exclusively) carry out planned adaptation policies when the expected welfare effects of these policies are positive, even if this means that not all possible climate change adaptation is carried out.

In practice, this means that cost–benefit analysis, in a broad sense, is likely to be the only framework within which it is meaningful to assess climate-change policies.[2–4] Most other frameworks, such as cost-effectiveness analysis, will only work well when the adaptation policy is the main or single government policy objective; in practice, this is rarely the case. Moreover, in practice there is considerable risk that cost-effectiveness analysis and other partial methods will lead to the adaptation measures, and their costs, implicitly being compared to the current status quo rather than to the climate change–affected "no adaptation" outcome that will prevail if nothing is done. For cost–benefit analysis, where the correct procedure is to compare the alternatives actually available, the appropriate approach is to compare adaptation measures to the outcome that will prevail in the absence of adaptation.[3] Thus, comparing adaptation measures to the current status quo is explicitly incorrect, which is not the case with other methods where there is no explicit alternative option being considered. When adaptation is only one goal among many, the best way of comparing different outcomes or policies will be to compare their overall welfare effects. This can ensure that climate adaptation is seen as an integral part of development policy, rather than as a costly and unnecessary extra.

This is complicated in practice, unfortunately. In many cases the economic effects of climate change are highly uncertain[5–7]; in many cases the exact benefits of adaptation measures are also uncertain.[8] Thus, any evaluation of adaptation measures will have to be made using an uncertain baseline scenario where no adaptation measures are carried out. However, the alternative is to evaluate adaptation measures against the status quo, which will tend to bias evaluations toward less costly measures and

toward measures that would increase welfare in the absence of climate change but will not necessarily do so in its presence.

Even if there are no government adaptation measures, many firms and households will change their behavior as a result of climate change, and as a result of this autonomous adaptation they will be better off than if they had ignored climate change in their decision making. However, in many countries the net effect of climate change will nonetheless be that aggregate social welfare is lower than it would have been without climate change. This remaining difference may be seen as the net cost of climate change to this society, after adjusting for autonomous adaptation.

If government also changes its behavior, in order to adapt to climate change, we will have both planned and autonomous adaptation. The decisions made by the government will affect the portfolio of choices available to private agents and will also affect which of these choices that the private agents choose to make.[8] Hence, the government's planned adaptation measures will have indirect effects on private agents' autonomous adaptation measures. A government policy may lead to less autonomous adaptation, by making autonomous adaptation less necessary or by reducing the number of available options, or to more autonomous adaptation, by making a wider range of autonomous adaptation decisions profitable to firms or households. This means that when evaluating a potential planned adaptation policy, one also needs to predict the response of private agents to this policy. The net impact, again, can be seen as the overall net cost of climate change, given this planned adaptation policy. A government choosing between different potential planned adaptation policies can thus do so by looking at which policy leads to the highest social welfare and hence, the least loss compared to a counterfactual scenario where climate change does not occur.

Let us consider a concrete example. Suppose that in the absence of any adaptation measures, agricultural production in a region is expected to decrease as a result of increased incidence of flooding caused by climate change. Suppose that it is known that the loss of production would be greatly reduced if farmers were to dig ditches to reduce the risk of flooding. Further suppose that frequent land reallocations mean that farmers can reasonably expect that the land will soon be redistributed so that, if they dig ditches, most of the future benefits of this will accrue to someone else. In this situation it is likely that, if there is no planned adaptation, autonomous adaptation (in the form of digging ditches) will be limited and that the welfare losses associated with climate change will therefore be large, because the only autonomous adaptation actually taking place will be in the form of minor changes in farming practices.

One potential policy measure in order to reduce the overall welfare loss might be government construction projects aimed at digging ditches. This would make better crop choices possible for the farmers and hence lead to more autonomous adaptation, so that the welfare gain compared to the situation without planned adaptation might be substantial even with the cost of paying workers to dig the ditches. Compared to the case where no planned adaptation takes place, adaptation costs would be greater (since carrying out the government construction program is more expensive than not carrying it out), but the benefits of adaptation would also be greater, and the net result would be a welfare gain compared to the scenario where no adaptation takes place.

Another potential policy measure might be to increase farmers' security of tenure, through land certification or titling schemes. This would make the farmers more likely to dig ditches of their own volition, and would thus also increase overall welfare compared to the scenario in which no planned adaptation takes place. In addition, a land titling or certification scheme might affect farmers' overall investment and soil management strategies and have additional positive impacts on production, further reducing the net effect of climate change. Which of these two planned adaptation measures would have the best overall impact on social welfare would depend on the relative costs of construction workers in the first scenario and of government surveyors in the second, but would thus also depend on the estimated magnitudes of the impacts on farmers' autonomous adaptation behavior.

We may note that in this example, many would not consider a land-titling scheme as a climate-change adaptation measure but, rather, as a component of overall agricultural policy. However, if the expected net effect of land titling were positive without climate change, the government would presumably already have carried it out. It is only

the additional effect of climate change that makes the expected net present value of the titling scheme positive, by increasing the importance of enhanced adaptive capacity on the side of the farmers. More broadly, given the uncertainty associated with climate change projections in general, and many country and regional projections in particular, many measures that improve firms' and households' adaptive capacity are likely to become attractive as a means of insurance against the worse-case outcomes.

A separate but related issue is that of proactive versus reactive adaptation, i.e., whether countries should undertake measures aimed at handling anticipated but uncertain future problems of climate change, or whether they should wait until the problems have appeared and their extent is known with greater certainty.[8] Obvious arguments for waiting would be that the present value of adaptation costs will be lower, the later those costs are undertaken, and that waiting will provide more information on the actual magnitude of the problems. An obvious argument against waiting would be that delaying adaptation may lead to far greater adaptation costs at the point when the costs are realized. A less obvious argument[3,9,10] is that introducing new technology tends to have spillover effects on human capital formation that can enhance growth; thus, given that the adaptive technology will need to be introduced at some point in any case, it may be better to introduce the technology earlier and hence get the spillover benefits sooner.

Issues related to valuing the impacts of climate change

It is expected that climate change will have impacts on most parts of society in most of the countries of the world, and there are already many studies aimed at assessing the costs and benefits of climate change and of various adaptation strategies. Many of the studies carried out so far, however, have focused on impacts on gross domestic product (GDP) and on components of GDP, to the exclusion of impacts on other components of social well-being.[11] While these measures can be useful as indicators of countries' overall capacity to adapt to climate change, they provide only an incomplete picture, especially for developing countries.

In many developing countries, a large part of agricultural production, and frequently also other primary production, such as fishing, is a subsistence or near-subsistence activity, carried out by households and buffeted by numerous stresses and constraints that are not part of the formal economy. This means that this production, while crucial for the livelihoods of many people in developing countries, is frequently ignored completely in economic statistics. Even when it is included in economic statistics, the monetary value of this production is frequently low. This means that, if climate change affects the subsistence component of the primary sectors in developing countries, the impacts on many people's livelihoods may be devastating without having much impact on GDP. Thus, a recent study of possible climate change impacts on Namibia[12] concluded that, even in the worst-case scenario studied, overall GDP might only fall by 5% or so—but half of the population would have their livelihoods destroyed and would have to find new means of survival, leading to almost unthinkable strains on social cohesion. Focusing on GDP alone can give a completely misleading picture even in a middle income country like Namibia, not to mention lower income countries. For countries where subsistence production is important, the impacts of climate change on this production will have to be modeled explicitly in order to give some idea of what the overall impacts on livelihoods will be.

In this section we therefore focus on impacts on marginalized groups living at subsistence or near-subsistence levels. We begin the section, however, by discussing some other issues that have been raised in the debate, and that have bearing on the valuation of climate change in developing countries. Some of these are common to any economic analysis of climate change; others are likely to be especially important in developing countries. This overview is not intended to be exhaustive, but merely to mention some of the issues.

Baseline development scenario

Any attempt to estimate the economic impacts of climate change needs to take into account the fact that many of the physical impacts of climate change are expected to appear only with considerable time lags. This means that comparing the counterfactual "no climate change" scenario with the counterfactual "climate change but no adaptation" scenario and the actual "climate change and adaptation"

scenario, and doing this for several different possible outcomes of climate change, is a very tall order. Effectively, predicting the economic impacts of climate change along the lines outlined above entails predicting the future trajectory of an entire economy a century or more into the future, and doing so for a series of different scenarios and policies. Moreover, since the economic impacts of climate change on a specific country will depend crucially on the impacts and policies in other countries, this needs to be done for the entire world economy and, ideally, for the most important individual countries as well. One need only consider the state of the world economy a century ago and imagine what types of projections would have been made then, in order to realize how difficult this endeavor is.

This does not mean that such an undertaking is pointless; the policies that we undertake today will have impacts on the future course of climate change, and the fact that it is extremely difficult for us to predict that future course is not an argument for not doing our best to consider these impacts when designing our policies. In addition to this, there is the moral problem that many of the impacts of climate change will be felt by people who have not contributed much to the problem. The fact that it is difficult to predict exactly how large future problems the rich countries are causing for people in the poor countries is not an argument for ignoring those problems, either in policy design or in discussions of compensation.

Income elasticities

In the absence of climate change, many of the countries that are currently poor would have experienced considerable increases in average income over the coming century. Hopefully this income growth will happen even with moderate climate change, although if the more extreme climate change scenarios come to happen, any future increases in income will be in question.

Increased income means, among other things, that the demand for most goods and services will increase. This will affect production of many goods and services and hence have general equilibrium effects; this, in turn, means that the economic impacts in different scenarios become even more complex to estimate. In addition to this, demand will also increase for "goods" where production cannot easily increase, such as environmental goods.[13] This means that if climate change is expected to, for example, lead to losses of pristine nature, this nature should not be valued at the value currently attached to it by a country's inhabitants but, rather, at the value which it is expected that future inhabitants would have attached to it given the expected income increases under the counterfactual "no climate change" scenario. In practice, this means that if environmental valuation approaches are used (which is likely to be necessary), it is necessary to estimate income elasticities so that future welfare losses can be estimated.

This also means that to the extent that climate change is expected to lead to losses of life, either through catastrophic weather events, through reduced overall carrying capacity, or for other reasons, the appropriate value of statistical life measure for losses of life at a specific time is the one that would have prevailed at that time at the income levels in the "no climate change" scenario; this will normally be a higher value than the one currently used in the country.[14]

Relative prices

An issue that is linked to that of income elasticities but still deserves separate mention is that of relative price changes. The income increases in the different scenarios studied will all have general equilibrium effects and hence lead to different relative prices for many goods. In addition to this, there is the issue of losses of productive land (and perhaps land area in general) due to climate change, which will lead to additional relative price changes. If land becomes scarcer as a result of climate change, this will in itself lead to relative price changes with attendant general equilibrium effects.[15]

Willingness to pay versus willingness to accept

In cost–benefit analysis, practitioners normally measure the willingness to pay (WTP) to avoid an environmental degradation rather than the compensation that will make people willing to accept the degradation, even in situations where willingness to accept (WTA) would be preferable on theoretical grounds. The WTP concept is usually easier to get across to survey respondents, and there is less risk that the results will be muddled by issues of loss aversion. The pragmatic argument is that, even in situations where WTA is the conceptually

correct measure, the two measures tend to differ only slightly. Therefore, a correctly measured WTP is likely to be closer to the mark than an incorrectly measured WTA.[16–18]

However, when valuing impacts of climate change in developing countries, the difference between WTP and WTA becomes crucial both in practical and moral terms. Most inhabitants in developing countries have no share of the blame for the problem; it has almost exclusively been caused by inhabitants in the rich countries. The issue is therefore not how much the inhabitants of poor countries are willing to pay to prevent climate change, the issue is how much it is reasonable that the rich countries should pay in compensation for the damage that they are causing for inhabitants of the poor countries. It is important that developing countries make this argument in negotiations over climate change, and hence it is important that valuation exercises actually carried out in these countries should be made with this argument in mind.

In addition to this moral argument, it is well known on theoretical grounds that the difference between WTP and WTA (correctly measured) is far larger for goods or services that play a major role in the lives of the respondents, and where there are no close substitutes, than it is for goods and services that play only minor roles. Hanemann,[19] in his seminal paper showing this, explicitly noted that "in the limit, WTP could equal the individual's entire (finite) income, while WTA could be infinite" (pp. 635–636). For many people in developing countries the WTP to prevent climate change is likely to be very limited, simply because their incomes are very limited. Per capita production losses caused by climate change are likely to be small in absolute terms, since per capita production is low, and hence those affected by climate change can pay very little even if they pay almost all that they have. This does not mean that the welfare impacts for these victims are likely to be small. Climate change can be expected to destroy the current livelihoods of huge parts of the populations in many developing countries; the correct measure of welfare loss is not those populations' low WTP for preventing the destruction of their livelihoods—the correct measure is the level of compensation that will make those populations accept having their livelihoods destroyed. This WTA is likely to be considerably higher than the WTP, even if correctly measured; this means that the compensation which developing countries should demand in climate change negotiations should be correspondingly higher than the value of the production losses caused by climate change.

Valuation of impacts on subsistence and near-subsistence production

In situations where all important markets function well, estimating the economic impacts of climate change is straightforward in principle, once one has estimates of the physical impacts and once the issues raised earlier in this section have been resolved. All one needs to do is to estimate supply and demand functions of all goods and services as functions of various underlying parameters, predict the changes in these underlying parameters, and predict the impacts of these changes in underlying parameters on production and consumption of various goods, including indirect general equilibrium effects.

Needless to say, this is a tall order in practice. However, when dealing with subsistence and near-subsistence production the situation is even more complex, as there are additional issues making the estimation of supply and demand functions less straightforward than usual.

The standard neoclassical assumption of separability between production and consumption decisions is frequently problematic for subsistence and near-subsistence production, and more generally for production decisions in situations where important markets are missing.[20,21] Farm households in many developing countries will, in the absence of credit markets and markets for crop insurance, not necessarily grow the most profitable crops. Rather, they will choose to devote some (or all) of their land to low-risk, low-yield crops in order to ensure that they will survive even in worst-case scenarios where many of the crops fail. Similarly, if markets for, for example, farm labor or important intermediate inputs are shallow or nonexistent, farmers will be constrained in their decisions by the amounts of labor or inputs that they can provide themselves. They will optimize, not with respect to the observed market prices (if any), but with respect to unobserved shadow prices that may be higher or lower than the observed market prices and that will often be specific to the individual household.

There is an ongoing debate about how such market failures affect how much, and how rapidly,

farmers in developing countries adapt to climate change, and what the policy implications of this are. Adger[22,23] finds that social and institutional capital is crucial for farming communities' capacity to adapt. Eakin and Appendini[24] argue that traditional autonomous adaptation to climate variability is more flexible than planned adaptation activities are likely to be. Shewmake,[25] studying South African farmers, argues that many of them are highly vulnerable to climate fluctuations as it is, and hence risk being affected substantially by additional climate change. Eakin[26] studies climate vulnerability in Mexican farming and finds that market integration *per se* makes little difference for coping capacity; even farmers who sell most of their produce may, because of limited access to, for example, credit or insurance markets, remain highly vulnerable to climate fluctuations. Groom *et al.*[27] study the role of risk aversion for farming strategies of ostensibly profit maximizing commercial farmers in Cyprus, and find that perceived risk matters considerably even for these farmers. Candel,[28] Maddison,[29] and Nhemachena and Hassan[30] discuss the importance of access to insurance and access to credit for autonomous adaptation. Osgood *et al.*[31] study the scope for introducing crop insurance among Malawian farmers as a means of helping them cope with climate change. Musango and Peter[32] claim that neither policy makers nor farmers know how sensitive different agricultural activities actually are to climate fluctuations, and study the scope for adaptation strategies given these limitations. Nyong *et al.*[33] argue that African farmers already have a rich set of coping strategies that policy makers and others can draw upon; Barrios *et al.*,[34] on the other hand, argue that historical experience demonstrates that African farmers have little capacity to cope with climate fluctuations.

It is clear that for many farmers, the capacity to undertake autonomous adaptation will be constrained by a number of factors—institutional, social, economic, and others. This has several implications for the estimation of economic impacts of climate change. One implication is that simply estimating supply and demand functions, without taking such issues into account, will lead to severe flaws in the results if these issues are in fact important; instead, behavioral economics will need to be considered.[35] In some cases, shallow or nonexistent markets will cause price responsiveness in other markets to be highly limited. In other cases, price responses may have the "wrong" sign or the wrong magnitude, compared to what they would be if all markets functioned. In both sets of cases, welfare impacts can only be estimated correctly by using the shadow prices, rather than market prices, of important goods and services.

Another important implication is that even if one believes that general equilibrium effects of climate change will be important for a specific country (which they may well be), markets for various goods and services in that country may be so fragmented that one needs to consider them as a large number of separate, possibly interlinked, regional markets rather than as nationwide markets. This means that simulations using computable general equilibrium (CGE) models, or other attempts to simulate nationwide general equilibrium impacts, will need to model impacts in a number of regional markets rather than impacts in a single nationwide market. Thus, e.g., Rosenzweig and Parry,[36] who attempt to model global food price impacts of climate change, do so using a set of linked regional models rather than a single global pricing model.

A third implication is that there is a range of possible planned adaptation policies. One of the most important reasons why climate change is expected to have more adverse impacts in poor countries than in rich countries is that people in poor countries have less scope to adapt to changes in their living conditions. One reason for this is of course their low income, but another is precisely that so many markets are shallow or nonexistent, and that this leaves households and firms little room for maneuver. Policies that improve the functioning of shallow markets, or that create markets where these did not exist before, can improve the scope for households and firms to undertake autonomous adaptation. Hence, well-directed policies aimed at such market problems may be able to leverage limited planned adaptation interventions into huge improvements in autonomous adaptation.[8]

A fourth implication is that estimating economic impacts of climate change is likely to be orders of magnitude more complicated for many developing countries than for developed countries, even though the range of economic activities is smaller, precisely because autonomous responses are more difficult to predict in developing countries where many producers and consumers will be

responding to changes in shadow prices rather than in market prices. There is by now a considerable literature on modeling agricultural households.[20,37] One factor which all these studies have in common is that they are highly data-intensive. Modeling subsistence households well enough to estimate economic impacts of climate change, even for a single agricultural region, is going to be a huge undertaking. Doing so for an entire country will be difficult in the extreme.

In practice, this means that less comprehensive methods for estimating the economic impacts of climate change are necessary. The most practical method (discussed in more detail below) is probably the Ricardian method. However, any analysis using this method (or other methods) will need to take into account the fact that many parameters are likely to be misestimated and that, as a result, the estimated economic impacts will be highly sensitive to limitations in the data. This is not a reason not to attempt to estimate economic impacts, but it does call for a great deal of humility in how the results are presented. Sensitivity analysis is always important in cost–benefit analysis, but even more than usual in this situation.

The current literature

Research on the economics of climate change adaptation in developing countries has been highly limited until recently, but the last few years have seen an explosive increase in interest. There are therefore undoubtedly works in progress and recently published working papers that are not covered by this review.

A number of papers attempt to assess overall economic impacts of climate change on one or several developing countries. The Stern report[1] and the various DICE and RICE models[38,39] are of course seminal references, but there have been many prior and subsequent studies as well. Magadza[40] estimates impacts of climate change on a range of different economic activities in southern African countries but does not consider general equilibrium effects of the projected impacts. The assumption is that little autonomous adaptation will take place and that, due to poorly functioning political systems, planned adaptation will be limited and short-term in character. Winters *et al.*[41] use CGEs to model impacts of climate change on agriculture, and indirect general equilibrium effects of these agricultural impacts, on stylized African, Asian, and Latin American economies. The future sizes and structures of the three economies are projected using historic economic data and Intergovernmental Panel on Climate Change estimates. Planned adaptation is imposed exogenously. Neoclassical profit maximization is assumed in agricultural production responses although the price responsiveness is varied to account for the fact that subsistence producers in Africa are likely to be less responsive to price changes. Callaway *et al.*[42] use a programming model to study how water allocation between different economic activities in a South African river basin is likely to be affected by climate change. This study incorporates both planned and autonomous adaptation measures; however, since farming in this area is largely a commercial for-profit activity the autonomous adaptation is, arguably, easy to model than in many other developing countries. Dasgupta *et al.*[43] estimate economic impacts of sea-level rise for the world's economies but assume that there will be no adaptation at all—planned or autonomous—making the estimates more of baseline projections than forecasts of actual economic impacts. Seo[44] discusses how climate change might affect Latin American economies at the macroeconomic level, largely using geographical data as a basis for the discussion, but offers few firm conclusions. Bigano *et al.*[45] use multicountry CGE models to assess the impacts of sea-level rise and changes in tourism flows on the overall economy. Reid *et al.*[12] similarly use a CGE model to estimate the impacts of changed agricultural productivity and changed fish availability on the Namibian economy; the study assumes limited autonomous adaptation and almost no planned adaptation, and can most fruitfully be seen as a set of baseline projections for the outcome if no policy interventions are made. Calzadilla *et al.*[46] use general equilibrium modeling to study the impacts of potential planned adaptation measures for sub-Saharan African agriculture, and find that measures to improve crop productivity (and hence increase the scope for autonomous adaptation by individual farm households) are likely to have greater impact than measures to extend irrigation networks. Juana *et al.*,[47] finally, study climate effects on water availability in South Africa and use a CGE model to estimate how this will affect the economy under different planned adaptation

policies. These two studies are among the few to estimate welfare impacts of climate change; however, both estimate equivalent variation measures (WTP) rather than compensating variation measures (WTA) and thus underestimate the welfare losses caused by climate change.

Other papers discuss the principles of climate change adaptation. Tol[48] argues that increasing developing countries' adaptive capacity through development aid is more fruitful than climate change mitigation. Halsnæs and Verhagen[11] argue that focusing on market outcomes of climate change risks missing the larger picture of climate change impacts on human well-being. Collier *et al.*[49] discuss potential planned and autonomous adaptation in Africa but are pessimistic about the scope for planned adaptation measures at least by national governments.

Apart from agriculture, there appear to be few studies of sectoral impacts; however, Spalding-Fecher and Moodley[50] study health impacts in South Africa. Velarde *et al.*[51] study impacts on protected areas in Africa and is one of the few studies to incorporate the effect of increasing income on the WTP for protected nature; however, this effect is modeled by using a range of different discount rates, and thus reweighting the values of all protected areas equally, rather than by using estimated income elasticities to estimate future changes in relative values of the protected areas.

Many studies have, for obvious reasons, focused on agricultural impacts and impacts on production values. Mendelsohn and Dinar[52] provide a useful subdivision by methodology: agronomic/agronomic-economic studies, agroecological zone studies, and Ricardian studies. The *agronomic* and *agronomic-economic* studies focus on examining what the implications of anticipated climate change will be on the yields of the crops currently being grown in various parts of the world, and on potential other varieties of those crops. Examples of this literature include Rosenzweig and Parry,[36] who simulate global crop yields and feed these into a trade model in order to estimate price impacts; Matthews *et al.*,[53] who simulate impacts on rice yields in a number of Asian countries, though without any assessment of the economic implications; Parry *et al.*,[54] who use yield impact estimates for a range of crops to simulate price and livelihood impacts in a global-economy model; Njie *et al.*,[55] who study yield effects in the Gambia under a range of different scenarios for planned adaptation, and economic impacts in these scenarios; Lobell *et al.*,[56] who estimate crop yield impacts in a range of developing country regions, but without explicitly modeling the economic effects; and Reid *et al.*,[12] who use agricultural yield estimates as a starting point for simulating economy-wide effects in Namibia. We may note that the implicit assumption in these studies is that the only autonomous adaptation taking place will be that farmers currently growing some crop may switch to other varieties of the same crop, or may switch to different planting seasons. Other than this, any adaptation (autonomous or planned) has to be modeled explicitly in the analysis by incorporating additional ad hoc assumptions. Of the studies listed, only Njie *et al.*[55] explicitly discuss the potential for planned adaptation policies in any detail.

In the *agroecological zone* studies, it is assumed that when climate change leads to shifts in agroecological zones, this will lead farmers to adapt by switching from the crops that they currently grow to those crops that are currently grown in the zone into which they are shifting. This method appears not to have been widely applied in developing countries, although a recent set of World Bank studies of climate change impacts on African agriculture[57–59] can be seen as examples.

The *Ricardian* studies, finally, take their starting point in the Ricardian method.[60] The assumption is that all farms choose their production portfolio so as to maximize their profits, given their characteristics—including the local climate. If climate change leads to a switch from climate state A to climate state B for farms in a particular region (e.g., less rainfall and higher temperature), farms in the region will adapt by switching to the production portfolio chosen by farms elsewhere that are currently in climate state B. The economic impact of the switch from A to B can then be estimated either by studying the change in net revenue that the switch in production will entail, or (more rarely in developing country applications) by using the hedonic pricing method, studying the difference in land values between the farms in the area and the farms that are currently experiencing climate state B. Applications of this method in developing countries include Mendelsohn and Dinar,[52] who study Brazilian and Indian cop yields and use Ricardian functions to estimate impacts of a range of different

temperature increases; Deressa *et al.*[61] and Gbetibouo and Hassan,[62] who study South African agriculture; Timmins,[63] who studies a range of land uses in Brazil; and a recent series of World Bank studies of agriculture in African[64–73] and South American[74,75] countries. Of these, Timmins[63] and Maddison *et al.*[71] are the only ones to use land values to assess economic impacts; all the others use price data for crops and livestock.

As should be obvious from the above list, the Ricardian method has become the methodology of choice among economists studying impacts of climate change on agriculture in developing countries, with an explosive increase in recent years in the number of studies made. There is good reason for this. In the other two methods, any climate change adaptation has to be imposed exogenously, whereas the Ricardian method models autonomous adaptation by farmers endogenously. As noted earlier, there is considerable debate over how much farmers in developing countries can actually adapt to changed circumstances; Stern[76] criticizes Ricardian analysis and states that current temperature variation cannot be used to predict how—or if—we will cope with a shift in the entire spectrum of temperatures. However, over the span of several decades, it does seem likely that farmers will, at least to some extent, change their production patterns, and that part of this is that they may switch to entirely new crops or new farming activities, rather than merely to new crop varieties.[a]

This does not mean that there are no problems with the Ricardian method. As noted above, many farmers in developing countries are not profit maximizers now, and it is problematic to assume that they are. Some of the studies discussed above note that land values were problematic in their Ricardian analyses; some farmers would or could not provide information on the value of their land, due to poorly functioning land markets and insecure land tenure. Other studies note that a large share of farm production is for own consumption, but nonetheless proceed to use market (rather than shadow) prices to value the farm's entire production.

Farmers in developing countries choose their crops subject to a number of constraints, not merely climatic and agronomic but also institutional, social, and economic, and these constraints need to be included in the analysis. Moreover, it is likely that many of these constraints will change in the decades to come, due to ongoing changes in the economy, and this should in principle be modeled if one wishes to forecast how production will actually change. Only a few of the Ricardian studies incorporate constraints to adaptation. Thus, most of these studies exaggerate farmers' potential for autonomous adaptation and hence underestimate the impacts of climate change.

Finally, we should note that even if the Ricardian method may provide reasonable forecasts of production changes in areas where there are few constraints to autonomous adaptation, even in those areas the method does not provide accurate estimates of changes in welfare. The production losses caused by climate change can perhaps provide estimates of the WTP to avoid climate change effects, but not of the WTA.

However, despite these caveats, the Ricardian method can provide a useful starting point for policy interventions. A Ricardian study can help identify the production patterns that farmers are likely to switch to, given the anticipated changes in climate; policy makers and analysts can use these projections to identify policy measures that can make it easier for farmers to switch to these new production patterns. Using Ricardian analysis in this fashion as a guide to designing policies for planned adaptation, rather than as a prediction of autonomous adaptation activities, can help make the adaptation to a new climate substantially less painful for rural communities.

Summary and conclusions

Climate change adaptation in developing countries has probably suffered from the fact that it has been regarded as a single issue, pushed by foreign donors, rather than as part of the background against which development planning has to take place. It is

[a]A reviewer suggests that adaptation to drastic climate shifts in historic subsistence and near-subsistence societies, such as the Maya experience,[77] could be used as an indication of how well current subsistence producers are likely to adapt. However, it is debatable how useful these historical comparisons are. In today's world, even subsistence producers are part of societies that are far more integrated in the world economy than their historical predecessors were, providing potential access to a far greater range of planned and autonomous adaptation activities.

important to have realistic forecasts of expected climatic changes at the local and national level, and timeframes for these changes, to help mainstream adaptation into national policy. As long as such local and national forecasts are not available, climate change will probably continue to be seen as an unnecessary extra activity rather than as a crucial part of development planning.

Once such forecasts are available, adaptation should become an integrated part of development planning, and adaptation measures should be assessed in the same fashion as any other development project or policy. Policy makers should judge whether they believe that these measures will make the country better off in the longer term, and pursue the measures if they believe that this is indeed the case. There is, mostly, no need for new economic tools to make such judgments; traditional cost–benefit analysis, and the valuation methods already used in, for example, ecological economics, health economics, and water economics will largely suffice.

However, shifts in agricultural production, including subsistence production, are likely to be important. Here, owing to the complex nature of many agricultural markets in developing countries, there *is* a need to think about slightly newer tools. The Ricardian method, one such tool, has been developed in recent decades as a means of forecasting autonomous adaptation to climate change. Used wisely, this method can help inform policy makers about the future needs of agricultural policy; it can help forecast in what ways farmers will wish to adapt, and policy makers can use these forecasts to put policies in place that make this adaptation easier. Additional tools are likely to be needed in order to analyze the effects of the complicated interactions between weak institutions and poorly functioning markets on the impacts of climate change on agriculture in many developing countries.

On the whole, though, climate change should not be seen as a completely novel type of problem. A big problem in adaptation planning so far is precisely that climate change has been perceived as a separate issue, unrelated to other problems, rather than as one of many problems facing developing countries. Developing countries have always been buffeted by various shocks; climate change may be a new shock, but it is nonetheless only one (large) shock among many. Looking at it in this fashion, and evaluating adaptation measures with the same yardstick as any other development projects, is a better way of mainstreaming adaptation into regular development planning.

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Conflicts of interest

The author declares no conflicts of interest.

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