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Agriculture and global climate stabilization: a public good analysis

by

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Abstract

The stabilization of global climate presents one of the most complex problems in public good provision the world has faced. Continuation of 'business as usual' policies, leading to warming of more than 2 degrees over the next year, will produce significant damage to agricultural systems and catastrophic damage to the natural ecosystems that ultimately support agriculture. The best solution to the public goods problem is a 'contract and converge' agreement in which the ultimate outcome is a common global entitlement to CO2 emissions per person.

Keywords: Climate change, public goods, agriculture, environmental Kuznets curve

Agriculture and global climate stabilization

The analysis undertaken by climate scientists and summarized in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (IPCC 2007a,b,c) places beyond reasonable doubt[1] the the proposition that human action is causing changes in the global climate, and that these changes will continue throughout the 21st century. Attention has therefore turned to assessment of the likely impacts of climate change, and to the options for mitigation and adaptation.

Most assessments of impacts has focused on 'business as usual' scenarios in which no policy action is taken to stabilize global climate. Although there is considerable disagreement about the best modeling approach and about a range of estimation issues, there is now fairly general agreement that the risks associated with 'business as usual' are unacceptable.

This point emerged in discussion of the Stern Review (Stern 2007) While a number of economists disagreed with Stern's treatment of issues such as discounting, they endorsed his conclusion on the need for action to stabilize climate (Weitzman 2007).

Similarly, at the policy level, there is now widespread agreement on the need to stabilize the global climate. Hence, the appropriate focus of policy analysis is the choice between alternative stabilization policies and, in particular, how the burden of stabilization should be shared internationally.

Most advocates of stabilization have argued for a target that may be expressed in terms of either a global atmospheric concentration of greenhouse gases, most importantly carbon dioxide (CO_2). Such targets are commonly expressed in terms of CO_2 equivalents in parts per million (ppm), or a target temperature change, commonly expressed relative to a 1900 baseline, before human-generated

[1] Though not, unfortunately, beyond unreasonable doubt. The near unanimity of scientific opinion is matched by an equal and opposite unanimity in some uninformed circles, particularly those associated with the political right in English-speaking countries. Mooney (2005) describes the process by which the US Republican party in particular has developed a wide-ranging hostility to science. The contributors to Holbo (2006) provide further analysis. For space reasons, this issue will not be discussed further in the present paper.

emissions had a large impact on climate.

In this paper, the implications of climate change, adaptation and mitigation for agriculture are considered. There is a particular focus on the notion of agriculture as a global public good.

The paper is organized as follows. Section 1, which draws on Quiggin (2008), Adamson, Mallawaarachchi and Quiggin (2009) and Quiggin et al (2010), provides background information on projections of climate change and its impacts on agriculture. Economic evaluation of the impact of climate change on the agricultural sector is discussed, comparing 'business as usual' projections with the case where action is taken to stabilize global CO2 concentrations by around 2050. deals with. Issues addressed in this section include the choice of baseline, the effects of uncertainty, and the appropriate way to model adaptation in estimates of the likely effect of climate change.

Section 2 deals with impacts on public health and natural ecosystems. Impacts on public health are likely to be manageable, at least for developed countries. However, the effects of climate change on natural ecosystems are likely to be severe, even if strong mitigation policies are adopted. The potential effects of unconstrained climate change on natural ecosystems are catastrophic, and the implications for human welfare are unpredictable.

In Section 3, the possible role of agriculture in mitigating climate change is discussed. Issues examined include biofuels, the role of the agricultural sector in absorbing CO_2 emissions, and mitigation of agricultural emissions of methane.

In Section 4, the concept of global public goods is considered with particular reference to climate.

Finally, some concluding comments are offered.

1. Projections of climate change and its impact on agriculture

The IPCC (2007a,b,c) summarizes a wide range of projections of climate change, based on alternative scenarios for growth in emissions of CO_2 and other greenhouse gases. Most attention is focused on projections of changes in global mean temperatures. However, analysis of the impact of climate change on agriculture requires consideration of regionally specific changes in a range of variables including temperature, rainfall and the effects of CO_2 concentrations on crop growth.

The natural starting point for analysis is a 'business as usual' scenario in which no policies aimed at mitigating global change are adopted. Estimated changes in global temperatures under 'business as usual' scenarios vary widely, because of differences in projections of emissions trajectories, modeling assumptions, and estimated parameter values.

The differences in modeling assumptions are commonly summed up in a single variable, 'climate sensitivity' conventionally measured as the long-run change in global mean temperature associated with a doubling of CO_2 concentrations from pre-industrial levels (that is, from 278 ppm to 556 ppm). Alternatively, climate projections may be summarized by the estimated change in mean global temperature, relative to pre-industrial levels at some salient future date, such as 2050 or 2100. The IPCC (2007a) presents a range of 'business as usual' projections, in which estimates of warming over the period to 2100 range from 2°C to 6.4°C, with a midpoint around 4°C.

For policy analysis, however, the pre-industrial climate is not an appropriate baseline. Even with aggressive strategies to stabilize atmospheric CO_2 concentrations at levels between 400 and 500 parts per million (ppm), it seems inevitable that global temperatures will rise to levels least 2°C higher than the pre-industrial average. An increase of nearly 1°C has already taken place, and additional warming of at least 1°seems inevitable.

For the purposes of policy analysis, the most appropriate comparison is between warming of 2°C over the 21st century and the more rapid warming that may be expected under 'business as usual' projections, in which there is no policy response to climate change.

Water

Water, derived from natural precipitation, from irrigation or from groundwater, is a crucial input to agricultural production. IPCC (2007b, Chapter 3, p. 175) concludes, with high confidence, that the negative effects of climate change on freshwater systems outweigh its benefits. In addition to raising average global temperatures, climate change will affect the global water cycle. Globally, mean precipitation (rainfall and snowfall) is projected to increase due to climate change. However, this change will not be uniform.

Climate change is projected to increase the variability of precipitation over both space and time. Average precipitation is projected to rise in high rainfall areas such as the wet tropics, and decreasing in most arid and semi-arid areas (Milly, Dunne and Vecchia 2005).

There are likely to be more frequent high rainfall events, such as monsoon rain resulting from tropical cyclones (IPCC 2007a). Severe droughts are also likely to increase by a factor of between two to ten, depending on the measure (Burke, Brown, and Nikolaos 2006)

The increase in drought frequency is likely to be particularly marked in the temperate zone between latitude 30° and 60°, where rainfall is commonly a limiting factor constraining agricultural output. Managing the associated pattern of 'droughts and flooding rains' in an increasingly sunburnt landscape[2] will present a formidable adaptation challenge to farmers.

Higher temperatures will lead to higher rates of evaporation and evapotranspiration, and therefore to increased demand for water for given levels of crop production (Döll 2002). Water stress (the ratio of irrigation withdrawals to renewable water resources) is likely to increase in many parts of the world (Arnell 2004).

[2] The allusion is to the classic Australian poem 'My Country' by Dorothy Mackellar, which begins 'I love a sunburnt country, a land of sweeping plains, of rugged mountain ranges, or droughts and flooding rains'. The task of adapting to this highly variable climate has taken Australian farmers more than two centuries since the introduction of European agricultural systems developed under more benign conditions.

The interaction of high temperatures and decreasing precipitation can have severe affects on the availability of water, and particularly on inflows of water to river systems. Australian studies estimate an elasticity of inflows with respect to precipitation in excess of 3.5, indicating that a 10 per cent reduction in precipitation will generate a reduction in inflows of at least 35 per cent. Similarly a 10 per cent increase in evaporation will reduce inflows by around 8 per cent. (Jones et al)

Severe droughts and record low inflows, attributed at least in part to climate change, have already occurred in the Murray–Darling Basin the location of most irrigated agriculture in Australia. Inflows are projected to decline by as much as 70 per cent under business as usual scenarios, resulting in severe output losses and the cessation of most irrigated agriculture.

Crop yields

Climate change is projected to have a range of effects on crop yields, and on the productivity of forest and pasture species (IPCC 1995, 1999, 2001, 2007b). Some effects, such as increased evapotranspiration, will generally be negative, while others, such as CO_2 fertilization will generally be positive. Changes in rainfall and temperature will be beneficial in some locations and for some crops, and harmful in other cases. In general, it appears that for modest increases in temperature and CO_2 concentrations (CO_2 concentrations up to 550 ppm and temperature changes of 1 to 2°C) beneficial effects will predominate. For higher levels of CO_2, the benefits of CO_2 fertilization will reach saturation and, for temperature increases above 3°C, negative effects will predominate.

A large number of studies of the impact of higher temperatures on crop yields are summarized in IPCC (2007b). For small changes in temperature, these effects are generally unfavorable at low (tropical) latitudes and favorable at high latitudes. The most important beneficial effects are on the growth of wheat in Canada, Northern Europe and Russia (Smit, Ludlow and Brklacich 1988; Parry, Rosenzweig, and Livermore 2005).

The aggregate effects of modest warming are likely to be small, but the losers are likely to be concentrated in poor countries, particularly in the tropics. Because losses are concentrated in developing countries, global warming implies a significant increase in the number of people at risk of hunger, although this risk may be mitigated by expansion of trade. (Fischer et al. (2005), Parry, Rosenzweig, and Livermore (2005).

For warming of more than 2°C, the marginal effects of additional warming are unambiguously negative in most regions, particularly for rice. For temperature increases of more than 3°C, average impacts are stressful to all crops assessed and to all regions.

Increases in atmospheric concentrations of CO_2 will, other things being equal, enhance plant growth through a range of effects including stomatal conductance and transpiration, improved water-use efficiency, higher rates of photosynthesis, and increased light-use efficiency (Drake, Gonzalez-Meler, and Long 1997). However, the estimated relationships are curvilinear, implying that only modest increases in yields can be expected from increases in CO_2 beyond 550 ppm.

Moreover, temperature and precipitation changes associated with climate change will modify, and often limit, direct CO_2 effects on plants. For example, increased temperatures may reduce CO_2 effects, by increasing water demand (Xiao et al. 2005).

Uncertainty

Projections of the likely impact of climate change are subject to considerable uncertainty. The most significant areas of uncertainty regarding global climate projections include: the future time path of greenhouse gas emissions; the proportion of emissions that remain in the atmosphere; and the sensitivity of climatic variables such as global mean temperatures.

Another set of problems arise in 'downscaling' global model projections to local scales. Flowerdew and Green (1992) and others have developed techniques for downscaling projections of spatially-linked variables, such as precipitation.

Despite significant progress (Charles, Bates and Viney 2003; Pitman and Perkins 2007), considerable uncertainty remains.

These issues are discussed in more detail by Adamson et al. (2009), who conclude, with specific reference to the Murray–Darling Basin in Australia (p. 349):

> Although many issues remain unresolved, there has been considerable progress in improving projections of the mean values of climatic variables. Rather less progress has been made in projecting changes in the probability distribution of climatic variables over time and within given regions. In particular, while it is generally expected that the frequency of droughts will increase, there are few estimates of associated changes in the temporal distribution of inflows.

Baseline for analysis

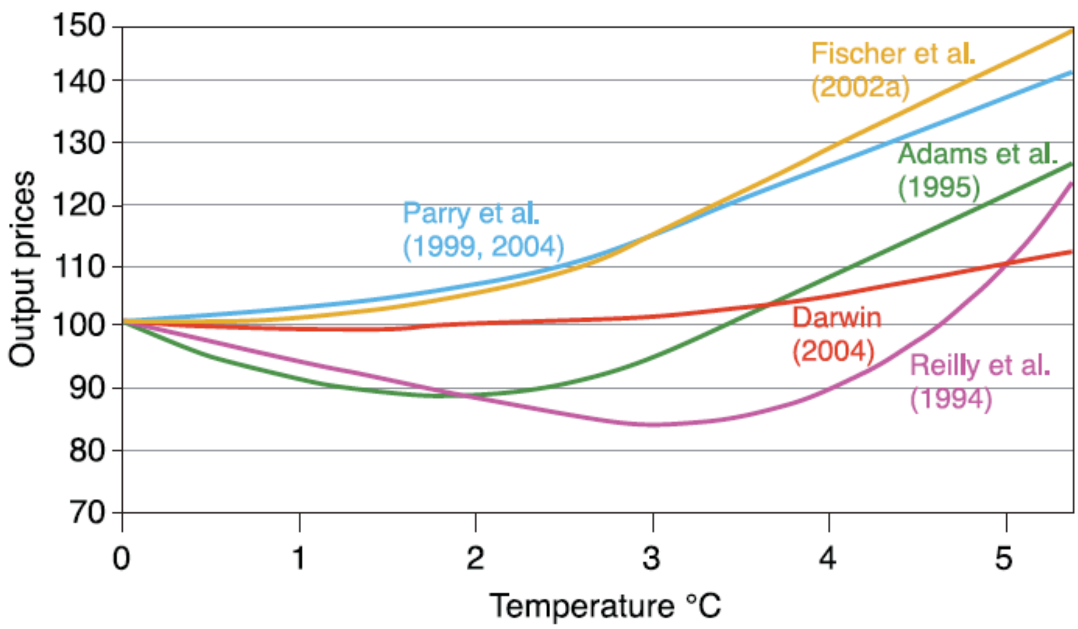
Before attempting an evaluation of the economic impact of climate change on agriculture, it is necessary to clarify the alternatives to be evaluated and the basis of evaluation.

In discussions of the impact of climate change, it is common to compare one or more 'business as usual' projections with a baseline counterfactual in which the current climate remains unchanged. Since some climate change would be inevitable even if emissions of greenhouse gases were halted immediately, such a comparison is of little value as a guide to policy.

A more appropriate basis for analysis is a comparison between 'business as usual' and a stabilization option, in which policy responses ensure that the atmospheric concentration of greenhouse gases is stabilized at a level consistent with moderate eventual climate change. Although the latter definition is somewhat vague, a target of 450 ppm has been canvassed widely. For typical estimates of climate sensitivity, this target implies temperature change of around 0.1°per decade over the next century, with stabilization thereafter at a mean global temperature 2°C above the pre-industrial level.

The IPCC (2007b) has summarized a number of studies (Adams et al 1995, Darwin 2004, Fischer et al 2002a, Parry et al 1999, 2004, Reilly et al 1994) that have estimated likely impacts on output prices of a range of possible temperature changes (see Figure 1). All except the oldest (that of Reilly et al. 1994) show cereal prices rising (hence, implicitly, cereal yields falling) once the temperature change exceeds 2°C. Moreover, the curves have fairly similar slope over this range, implying that the estimated relationship between temperature change and output prices is similar for temperature changes above 2°C.

Fig 1: Cereal prices (percent of baseline) and global mean temperature change (°C)



* Prices interpolated from point estimates of temperature effects.

Source: IPCC (2007b) Fig. 5.3

The treatment of adjustment

Quiggin and Horowitz (1999) show that the main costs of climate change will be costs of adjustment. Stocks of both natural capital and long-lived physical capital will be reduced in value as a result of climate change. Adjusting to a shift of 40 km per decade will involve substantial continuing costs. For example, Quiggin and Horowitz (1999) note that the optimal service radius for grain handling facilities in Australia is around 25 km. Hence a facility initially located near the margin of grain production might be outside the zone of production within a decade of construction.

Uncertainty and variability

The treatment of uncertainty and variability is crucial in evaluating the effects of climate change. Most obviously, the discussion above shows that damage to agriculture is a convex function of the rate of warming. At rates of warming below 0.2°per decade, aggregate damage over the period to 2100 is likely to be small, with gains offsetting losses. At higher rates of warming, damages increase and benefits decline so that aggregate damages grow rapidly.

Convexity implies, by Jensen's inequality, that the expected cost of warming is greater than the cost of warming at the expected rate. More importantly for policy purposes, the expected marginal cost of additional emissions is greater than the marginal cost of emissions in the case where the rate of warming is equal to its expected value. Most of the expected loss to agriculture from warming arises in the right-hand tail of the distribution. The importance of considering the tails of the distribution has been stressed by Weitzman (2007).

Uncertainty also affects estimates of the cost of adaptation. Most studies assume adaptation to a known change in climate. In reality, however, farmers must adjust to changing climate without being able to make a reliable distinction between permanent changes associated with global climate change and temporary local fluctuations. Thus the cost of adaptation may be underestimated and the benefits overestimated.

In general, then, uncertainty about climate change raises the likely cost of change. However, arguments based on option value may support delaying costly and irreversible mitigation actions. The argument, put forward by Nordhaus and

Boyer (2000) is that, if such actions are delayed, more information about the likely cost of warming will be obtained. If the rate turns out to be slow, and the mitigation actions are unnecessary, the option has yielded a positive return. This option value must be set against the likelihood that, the more rapid the rate at which mitigation must be undertaken, the greater the cost.

Aggregate economic impact

Farmers will not necessarily be worse off as a result of global reductions in agricultural productivity. In general, demand for agricultural products is inelastic. Conversely, the elasticity of equilibrium prices with respect to exogenous shifts in aggregate supply is typically greater than 1. That is, a reduction in global agricultural output caused by an exogenous shock such as climate change will increase the aggregate revenue of the agricultural sector.

However, global markets are not frictionless. If, as most projections suggest, moderate warming will increase output in temperate-zone developed countries while reducing output in (mainly tropical) developing countries, the net impact is ambiguous. Similarly, the costs of mitigation, and therefore the income effects on agricultural demand will also be unevenly distributed.

Various estimates have been made the impact of global warming on agricultural output and on aggregate returns to the agricultural sector. Fischer et al. (2002) estimate that, under a 'business as usual' projection, global output of cereals will decline by between 0.7 per cent and 2.0 per cent, relative to the case of no change in climate, while the estimated change in agricultural GDP ranges from -1.5 per cent to +2.6 per cent.

As noted above, comparisons in which the baseline simulation involves no climate change are not particularly useful. It is more appropriate to compare feasible outcomes under stabilization with those under 'business as usual'. Darwin (1999) estimates that world welfare may increase if the average surface land temperature does not increase by more than 1.0 or 2.0 C, as is likely under stabilization. If the average surface land temperature increases by 3.0 C or more, however, world welfare may decline. Similarly, Parry, Rosenzweig, and Livermore (2005) find that stabilization at 550 ppm avoids most of the risk of increased global hunger associated with a 'business as usual' projection.

2. Ecosystem effects

An analysis focused on adjustment costs is particularly appropriate in relation to the effects of climate change on natural ecosystems. As temperatures increase, climate in any given location becomes more like that previously observed at a point closer to the equator. Conversely, biozones suitable for particular ecological or agricultural systems tend to migrate away from the equator and towards the pole. Hansen et al. (2006) estimate that the average isotherm migration rate of 40 km per decade in the Northern Hemisphere for 1975–2005, exceeding known paleoclimate rates of change.

If this rate of increase accelerates over the next century, as is likely under 'business as usual', the consequences are likely to be catastrophic. Stern (..) lists the following likely consequences for possible rates of warming over the next century

The projections presented in the Stern Review and IPCC (2007b), illustrated in Figure 2, are alarming. Stern gives the following estimates:

> **1°C warming.** At least 10% of land species could be facing extinction, according to one study.79 Coral reef bleaching will become much more frequent, with slow recovery, particularly in the southern Indian Ocean, Great Barrier Reef and the Caribbean.80 Tropical mountain habitats are very species rich and are likely to lose many species as suitable habitat disappears.
>
> **2°C warming.** Around 15 – 40% of land species could be facing extinction, with most major species groups affected, including 25 – 60% of mammals in South Africa and 15 – 25% of butterflies in Australia. Coral reefs are expected to bleach annually in many areas, with most never recovering, affecting tens of millions of people that rely on coral reefs for their livelihood or food supply.81 This level of warming is expected to lead to the loss of vast areas of tundra and forest – almost half the low tundra and about

> one-quarter of the cool conifer forest according to one study.82
>
> **3°C warming.** Around 20 – 50% of land species could be facing extinction. Thousands of species may be lost in biodiversity hotspots around the world, e.g. over 40% of endemic species in some biodiversity hotspots such as African national parks and Queensland rain forest.83 Large areas of coastal wetlands will be permanently lost because of sea level rise (up to one-quarter according to some estimates), with acute risks in the Mediterranean, the USA and South East Asia. Mangroves and coral reefs are at particular risk from rapid sea level rise (more than 5 mm per year) and their loss would remove natural coastal defences in many regions. Strong drying over the Amazon, according to some climate models, would result in dieback of forest with the highest biodiversity on the planet.

The consequences of more rapid rates of warming, or of rapid warming continued beyond 2100 have not been evaluated in detail, but would obviously be catastrophic, involving species loss and ecosystem destruction on a scale comparable with the great mass extinctions of the past.

Such a mass destruction of our natural environment would be terrible in itself. Preventing such a disaster is more than enough justification for the relatively modest expenditure of resources required to limit further warming to 1 to 2 degrees beyond pre-industrial, a target that would still entail substantial environmental damage.

However, to obtain widespread support for action to mitigate climate change, it is desirable to consider impacts on humans. Stern (…) and IPCC (…) consider a range of ecosystem-mediated impacts on human health, most notably a likely expansion of the zone in which mosquito-borne diseases are endemic.

There has been little analysis of the effects of large-scale ecosystem destruction on human welfare and on agriculture in particular. Given the complexity of ecosystem interactions, discussion of such effects is necessarily speculative. On the other hand, repeated experience of the collapse of agricultural systems as a result of failure to take account of environmental constraints suggest that there is no room for complacency.

Agriculture necessarily involves radical transformation of the natural ecosystem into one dominated by a small number of plant or animal species useful to humans. In the short run, managers of agricultural systems seek, in large measure, to insulate them from natural ecosystems which represent a potential population of insect, plant and animal 'pests' attracted to a large and easily accessible food source.

In the long run, agriculture depends on natural ecosystems for a wide range of services, including biological control of pest species and new genetic material for plant breeding. Moreover, radically modified and simplified ecosystems are likely to give rise to unstable and therefore difficult to control variations in the prevalence of the remaining species, many of which are likely to become pests in this context. It seems unlikely that sustainable agricultural production can be maintained if the supporting ecosystems are destroyed.

3. Agriculture and mitigation

Agriculture is likely to play an important role in mitigating emissions of greenhouse gases. Possible avenues include reduced emissions of the main greenhouse gases (CO_2, methane and nitrous oxide), carbon capture through forestry, and the production of biofuels. Conversely, efforts to mitigate global warming, by reducing emissions of CO_2 and other greenhouse gases, or through the expansion of offsetting sinks, may have a significant effect on agricultural production.

Biofuels

A variety of policy initiatives, included policies proposed to reduce CO_2 emissions, have encouraged increased use of fuels derived from agricultural sources, collectively referred to as biofuels. . Considerable policy attention, both favorable and unfavorable, has been focused on biofuels derived primarily from food crops or from tropical products such as palm oil. Most notable in this context has been the use of ethanol, mainly derived from cane sugar or corn, as a substitute for gasoline.

In the past decade, expanded use of biofuels has been driven through direct policy mandates such as that embodied in the US *Energy Policy Act* 2005. Although these mandates have been adopted primarily in response to concerns about dependence on imported oil, and to pressure from farm lobby groups, experience with these measures has generated concerns which are relevant in considering the possible role of biofuels as a response to climate change.

In 2004, around 4 billion gallons of ethanol (16 billion litres), mainly derived from corn and sorghum, was produced in the United States, accounting for around 11.3 per cent of US corn output and 11.7 per cent of sorghum output and replacing around 3 per cent of US gasoline consumption.

Eidman (2006) claims that, even in the absence of continued subsidies or carbon taxes, bio-ethanol production will be a viable competitor at plausible prices for natural gas and corn (the inputs) and gasoline (the competing option).

Assuming that biofuels are economically competitive with fuels derived from fossil sources, the expansion projected by Eidman (2006) and others would imply the creation of a substantial new source of demand for agricultural output, in addition to existing demands for food. If existing processes were used to replace 20 per cent of fuel consumption, the input required would be equal to more than 50 per cent of the current US output of corn and sorghum.

Such an increased demand would have to be met either by an expansion of supply or by reductions in food consumption. In either case, the increase in demand implies an increase in prices, which will be beneficial to agricultural producers but harmful to food consumers.

The substantial increase in food prices observed in 2008, prior to the emergence of the global financial crisis focused critical attention on the negative effects of conversion of food crops to biofuels. The European Union, which had given strong support to biofuels, reoriented its policy to exclude food crops and palm oil.

It now seems clear that if biofuels are to become a viable long-term option, they must be derived primarily from energy crops such as switchgrass, grown on land that is marginal for agricultural production. However, even this option requires the allocation of substantial areas of land, which may provide important ecosystem services, to the production of biofuels.

More exotic possibilities include salicornia (also called glasswort or marsh samphire), a salt tolerant plant that grows in salt marshes and among mangroves. Salicornia seeds contain high levels of oil and protein and it has been argued that their growth could be accelerated using effluent from aquaculture operations. Christiansen (2008) discusses some pilot projects.

Other possible biofuel sources include bagasse and other crop residues used as fuel in electricity generation and methane derived from manure (Gallagher 2006). While more benign than the use of food crops to produce energy, these options are also likely to be more limited.

Land clearing and tree planting

The clearing of forested land for agriculture, mainly in the tropics, has been a significant contributor to net emissions of CO_2, partly offset by regrowth in boreal forests in Europe and North America. Conversely, expansion of the area of forested land is currently one of the most cost-effective methods of offsetting CO_2 emissions (IPCC 2007c), and is likely to play an important role in the future.

The treatment of land use in international agreements on climate change has been controversial. Under the Kyoto Protocol, Australia, which had adopted policies restricting land clearance on environmental grounds, was permitted to count the estimated reductions in emissions, relative to the 1990 level, towards its emissions target.

Forestry competes with agriculture for land, so a substantial increase in the area allocated to forestry will, other things being equal, increase the price of agricultural land. These effects must be considered in combination with the possible effects of increasing agricultural production of biofuels.

Soil carbon

Poor cultivation practices generate large, and potentially avoidable, losses of carbon from the soil. Between 30 billion and 55 billion tonnes of organic carbon have been lost from soil as a result of cultivation, compared to a current stock of 167 billion tonnes. Management practices to increase soil carbon stocks include reduced tillage, crop residue return, perennial crops (including agroforestry), and reduced bare fallow frequency. Cole et al. (1997) estimate that total potential carbon sequestration of 40 billion tonnes over a fifty year period is equivalent to 7 per cent of projected fossil fuel carbon emissions over the same period.

Agricultural emissions of methane

In addition to its role in the carbon cycle, agriculture is a major source of emissions of methane. Although the residence time of methane in the atmosphere is relatively short (an atmospheric lifetime of 10 to 15 years, compared to an effectively infinite lifetime for CO_2), it is a potent greenhouse gas. The largest agricultural sources of methane are ruminant animals and rice production. Emissions of methane from rice production arise primarily from the use of flood irrigation (Yan, Ohara and Akimoto 2003).

As Cole et al (1997) observe, methane lost from anaerobic digestion of livestock manure constitutes a wasted energy source, which implies that reductions in emissions can, potentially at least, yield net benefits. Emissions can be reduced either by changes in livestock diet, so that nutrients promote additional growth instead of being excreted, or by using manure as an energy source. There are also a range of options for reducing methane emissions from rice production.

4. Climate as a global public good

A public good is standardly defined one that is nonrival and nonexcludable in consumption. A global public good, therefore is a good that has these characteristics for the entire population of the world. The earth's atmosphere displays the characteristics of nonrivalry and nonexcludability, and is clearly a global good of fundamental importance to life. It is natural to consider on the one hand, how the concept of global public goods can help us to understand the policy issues surrounding atmospheric pollution and climate change and, on the other hand, how consideration of these issues may help us to understand the concept of global public goods.

Some, but not all global, public goods, or, more often, public bads, fit the simple textbook model. Pandemic diseases such as influenza are unambiguously negative in their impact. Hence, there is a common global interest in measures to mitigate the impact of pandemics. To pursue this common interest, it is necessary to achieve a generally acceptable distribution of the appropriate costs. This has proved easier in cases where impacts are widely distributed among rich and poor countries, as in the case of HIV/AIDS than where those affected are mainly in poor countries, as in the case of tropical diseases such as malaria.

The atmosphere as a complex public good

Unlike the simple public goods found in textbook samples, the atmosphere provides humans with a wide range of services which may be valued either positively or negatively. The rain that allows one farmer's crop to grow may flood the land of another. More generally, as we have already seen, changes in the climate will generate both benefits and costs, although, for rapid change, the costs may be expected to outweigh the benefits.

Initially, the atmospheric public goods (or bads) of policy interest were local. By the 19th century (and perhaps earlier), pollution and household fires had changed the climate of London, producing the 'pea-souper' fogs that later became known as smog. Problems of this kind were addressed through regulations which either reduced particulate emissions or used tall chimneys to disperse them.

Chimneys did not reduce emissions, but simply shifted and diffused them, ultimately generating more pervasive, though less acute problems such as acid rain. This is part of a more general pattern, where local environmental problems, have been resolved, particularly in developed countries, while global problems have been exacerbated by policies that seek to shift pollution elsewhere.

Thus the world is faced with the need to develop a policy response to the management of the atmosphere as a global public good. The atmospheric public good most closely related to that of climate change, is that of the depletion of the ozone layer by chloro-fluorocarbons and hydro-chlorofluorocarbons used for refrigeration and other purposes.[3] The Montreal Protocol, negotiated in 1987, led to the banning of the most damaging of these gases and a gradual phaseout of others. The protocol has been described by Kofi Annan, then Secretary General of the United Nations as "perhaps the single most successful international agreement to date" (Annan 2000, p. 56).

The Montreal Protocol is seen as a model for other international agreements and influenced the design of the Kyoto Protocol to the UN Framework Convention on Climate Change. In particular, the Montreal Protocol provided mechanisms by which developed countries compensated developing countries for forgoing the use of chloro-fluorocarbons and hydro-chlorofluorocarbons. These mechanisms served as a model for the Clean Development Mechanism associated with Kyoto.

However, the ozone layer is a much simpler example of a global public good than the global climate as a whole. Ozone depletion is an unambiguous bad and the actions required to reverse it are relatively simple to specify and cost little to implement. Environment Canada (1997) estimated the total costs of action under the Montreal Protocol at $235 billion, or about 0.5 per cent of aggregate global

[3] These gases are also potent greenhouse gases. Unfortunately, the same is true of the non-ozone-depleting hydrofluorocarbons (HFCs) that are replacing them in many uses.

income for one year. Benefits to agricultural and fisheries were estimated to be more than twice this amount, without considering benefits to human health.

By contrast, action to stabilize the global climate is likely to cost 1 to 3 per cent of aggregate global income annually. Given annual income of $50 trillion, the implied cost is between $500 billion per year and $1.5 trillion per year. The cost of stabilization is likely to increase over coming decades, but will ultimately decline as the development of alternative energy reaches the point where (unsubsidized) costs fall below those of carbon-based fuels.

Depending on the discount rate that is chosen the implied present value ranges from 20 per cent of global income (1 per cent annual cost, 5 per cent discount rate) to 150 per cent of global income (3 per cent annual cost, 2 per cent discount rate). That is, the cost is between 40 and 300 times that of implementing the Montreal Protocol.

The environmental Kuznets curve

This discussion may be understood in terms of the 'environmental Kuznets curve', a term apparently coined by Grossman and Kreuger (1993). The standard version of the environmental Kuznets curve shows an inverse-U relationship between output per person and the levels of various pollutants or, more generally, public bads generated by industrialization.

The usual explanation for the environmental Kuznets curve (Dasgupta et al 2002) is that the initial increase arises from the fact that (using least cost technology) pollution is likely to increase proportionately with output. In the absence of countervailing factors, this increase will continue linearly.

However, if the costs of pollution are convex, and the demand for environmental quality increases with income, expenditure on pollution reduction (including the cost increases associated with less polluting technologies) will increase more rapidly than output. Hence, if preferences for environmental quality are reflected in policy outcomes, pollution will increase more slowly than output, and, given a sufficiently high income elasticity of demand for environmental quality, will ultimately decline.

The environmental Kuznets curve is sometimes viewed as an inherent technological property of the process of economic growth. This view may be refuted by the observation that, in Communist countries where the costs of pollution damage were ignored, pollution continued to rise in line with output.

The standard explanation of the environmental Kuznets curve requires the assumption that social preferences for environmental quality are reflected in policy outcomes. This assumption is obviously problematic in the context of global public goods, such as the global properties of the atmosphere.

Critics of the environmental Kuznets curve such as Stern (2004) focus on cases of this kind to make the argument that, at least as a general proposition, environmental Kuznets curve cannot be sustained. It is important, therefore to distinguish between the idea that technological improvements automatically reduce pollution and the more plausible claim that, in the presence of appropriate governance arrangements, rising incomes create a higher effective demand for environmental services, which is met in part by restricting pollution.

In the case of global public goods, an international agreement is needed to make global social preferences effective. We must therefore consider the basis of such an agreement and the factors that have, so far, prevented one from emerging.

Contract and converge

The only feasible basis for a long-run solution to climate change is which each country is assigned an equal allocation of emission quotas per person, with the option of trade. If convergence in emissions quotas is accompanied by convergence in income and living standards, such a proposal (with side deals to compensate losers within any given country) should produce something close to Pareto-improvement. The net gains from increasing the global public good of a stable climate should, in most cases, outweigh differences in costs and benefits at the national level.

The situation is less clear, however, in the more likely case of large, and continuing, differences in incomes. The Environmental Kuznets Curve implies that both the poorest and the richest countries would prefer low levels of emissions.

This intuition can be supported by economic analysis. Any country poor enough that emissions per person in the absence of a quota would be lower than the quota allocation must gain from the opportunity to sell excess rights. Under plausible conditions, this result can be extended to show that any country that is a seller of emissions at all price-allocation pairs must benefit.

Considering rich countries, it is similarly straightforward to show that, if the income elasticity of demand for the public good is greater than one, all sufficiently wealthy countries must benefit from an equal allocation system that sets total emissions equal to the global socially efficient optimum.

However, no such guarantee applies to countries in the middle of the curve. These countries have high demand for emissions relative to their demand for the public good.

Concluding comments

The complex interactions between climate change and agriculture render impossible the task of producing a comprehensive assessment of the net impacts of climate change, including adaptation and mitigation. However, based on the discussion above, some general conclusions are possible.

The climate change estimated to arise under 'business as usual' projections will substantially reduce agricultural productivity relative to the outcome in which climate is stabilized after 1-2° C of warming. The costs of this reduction in productivity will be borne primarily by food consumers.

The atmosphere must be regarded as a global public good. The impact of climate change on agriculture, including adaptation and mitigation, will also be mediated through global markets, and reflected in global policy responses. Hence, a co-operative global solution is crucial.

Assuming a contract-and-converge solution to climate change is agreed, it is likely that poor countries, where agriculture makes up a large share of the national economy, will be net gainers. Wealthy countries will also gain because they place a high weight on the natural environment. Based on the environmental Kuznets curve, the countries most likely to be net losers are those in the rapid industrialization phase of development. However, given substantial net gains from a global agreement, it should be possible to generate something close to a Pareto-improvement.

References

Adams, R., Fleming, R., Chang, C., McCarl, B., Rosenzweig, C., 1995. A reassessment of the economic effects of global climate change in on US Agriculture. *Clim. Change*, **30**, 47–167.

Adamson, D., Mallawaarachchi, T., Quiggin, J., 2009. Declining inflows and more frequent droughts in the murray darling basin: Climate change, impact and adaption. *Aust J. Ag. and Res. Econ.*, **53(3)**, 345–66.

Annan, K., 2000. We the Peoples: The Role of the United Nations in the 21st Century (Millennium Report). *United Nations*, New York.

Arnell, N., 2004. Climate change and global water resources: SRES emissions and socio-economic scenarios. *Glob. Env. Change*, **14(1)**, 31–52.

Burke, E., Brown, S., Nikolaos, C., 2006. Modeling the recent evolution of global drought and projections for the twenty-first century with the Hadley centre climate model. *J. Hydromet.*, **7(5)**, 1113–25.

Charles, S., Bates, B., Viney, N., 2003. Linking atmospheric circulation to daily rainfall patterns across the Murrumbidgee river basin. *Water Sci. & Tech.*, **48(7)**, 233–40.

Christiansen, R., 2008. Sea asparagus can be oilseed feedstock for biodiesel. *Biomass Magazine*, http://www.biomassmagazine.com/article.jsp?article_id=1864.

Cole, C. et al., 1997. Global estimates of potential mitigation of greenhouse gas emissions by agriculture. *Nutrient Cycling in Agroecosystems*, **49**, 221–28.

Darwin, R., 1999. A farmer's view of the Ricardian approach to measuring agricultural effects of climatic change. *Clim. Change*, **41(3)**, 371–411.

Darwin, R., 2004. Effects of greenhouse gas emissions on world agriculture, food consumption, and economic welfare. *Clim. Change*, **66(1)**, 191–238.

Dasgupta, S., Laplante, B., Wang, H., Wheeler, D., 2002. Confronting the environmental kuznets curve. *The Journal of Economic Perspectives*, **16(1)**, 147–68.

Döll, P., 2002. Impact of climate change and variability on irrigation requirements: A global perspective. *Clim. Change*, **54(3)**, 269–93.

Drake, B.G., Gonzalez-Meler, M.A., Long, S.P., 1997. More efficient plants: A consequence of rising atmospheric co2? *Ann. Rev. Plant Phys. & Plant Mol. Biol.*, **48**, 609–39.

Eidman, V., 2006. Renewable liquid fuels: Current situation and prospects. *Choices*, **21(1)**, 15–19.

Environment Canada, 1997. The Right Choice at the Right Time, Highlights of the Global Benefits and Costs of the Montreal Protocol on Substances that Deplete the Ozone Layer. Canadian Government,

Fischer, G., Shah, M., van Velthuizen, H., 2002. Climate Change and Agricultural Vulnerability. International Institute for Applied Systems Analysis, Laxenberg, Austria.

Flowerdew, R., Green, M., 1992. Developments in areal interpolation methods and GIS. *Ann. Regional Sci.*, **26**, 67–78.

Gallagher, P., 2006. Energy production with biomass: What are the prospects? *Choices*, **21(1)**, 21–25.

Grossman, G., Krueger, A., 1993. Environmental impacts of the North American Free Trade Agreement. pp. 13-56 in *The US-Mexico Free Trade Agreement*, (Ed, Garber, T.) MIT Press, Cambridge, Mass.

Hansen, J. et al., 2006. Global temperature change. *Proceedings of the National Academy of Sciences PNAS*, **103(39)**, 14288–93.

Holbo, J. (ed), 2006. *Looking for a Fight* Glassbead Books, Parlor Press, Indiana, USA.

Intergovernmental Panel on Climate Change, 1995. IPCC Second Assessment Report: Climate Change. IPCC, Geneva.

Intergovernmental Panel on Climate Change, 1996. Second Assessment R II, Chapter 23, Agricultural Options for Mitigation of Greenhouse Gas Emissions (Lead Authors: V. Cole, C. Cerri, K. Minami, A. Mosier, N. Rosenberg, D. Sauerbeck, J. Dumanski, J. Duxbury, J. Freney, R. Gupta, O. Heinemeyer, T. Kolchugina, J. Lee, K. Paustian, D. Powlson, N. Sampson, H. Tiessen, M. van Noordwijk, and Q. Zhao).

Intergovernmental Panel on Climate Change, 1999. IPCC Third Assessment Report: Climate Change. IPCC, Geneva.

Intergovernmental Panel on Climate Change, 2001. Climate Change 2001: Working Group I: The Scientific Basis. IPCC, Geneva.

Intergovernmental Panel on Climate Change, 2007. IPCC Fourth Assessment Report: Climate Change 2007. IPCC, Geneva.

Intergovernmental Panel on Climate Change, 2007. Working Group I Report (WGI): Climate Change 2007: Summary for Policymakers. IPCC, Geneva.

Intergovernmental Panel on Climate Change, 2007. Working Group I Report (WGI): Climate Change 2007: The Physical Science Basis. IPCC, Geneva.

Intergovernmental Panel on Climate Change, 2007. Working Group II Report (WGII): Climate Change 2007: Impacts, Adaptation and Vulnerability. IPCC, Geneva.

Jones, R. et al., 2007. Climate change and Australian water resources: first risk assessment and gap analysis. Australian Greenhouse Office and the National Water Commission, Canberra.

Milly, P.C., Dunne, K.A., Vecchia, A.V., 2005. Global pattern of trends in streamflow and water availability in a changing climate. *Nature*, **438(7066)**, 347–50.

Mooney, C., 2005. *The Republican War on Science*. Basic Books, New York.

National Academy of Sciences Panel on Greenhouse Warming, 1992. Policy Implications of Greenhouse Warming: Mitigation, Adaptation, and the Science Base. *National Academy Press*, Washington, DC.

Nordhaus, W., Boyer, J., 2000. Warming the World: Economic Models of Global Warming. *MIT Press*, Cambridge Mass.

Parry, M., Rosenzweig, C., Iglesias, A., Livermore, M., Fischer, G., 2004. Effects of climate change on global food production under sres emissions and socio-economic scenarios. *Glob. Env. Change*, **14(1)**, 53–67.

Parry, M., Rosenzweig, C., Livermore, M., 2005. Climate change, global food supply and risk of hunger. *Philosophical Transactions of the Royal Society London B Biological Sciences*, **360(1463)**, 2125–38.

Parry, M., Rosenzweig, C., Iglesias, A., Fischer, G., Livermore, M., 1999. Climate change and world food security: A new assessment. *Glob. Env. Change*, **9(Supplement 1)**, S51–S67.

Pitman, A., Perkins, S., 2007. Climate change science: Status, and next steps in the projection of future changes. *Environmental Health*, **7(3)**, 22–42.

Quiggin, J., 2008. Counting the cost of climate change at an agricultural level. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources*, **2(092)**, 1–9.

Quiggin, J., Adamson, D., Chambers, S., Schrobback, P., 2010. Climate change, uncertainty and adaptation: the case of irrigated agriculture in the Murray–Darling Basin in Australia. Risk and Sustainable Management Group, University of Queensland

Quiggin, J., Horowitz, J., 2003. Costs of adjustment to climate change. *Aust J. Ag. and Res. Econ.*, **47(4)**, 429–46.

Reilly, J. et al., 2003. U.S. Agriculture and climate change: New results. *Clim. Change*, **57(1)**, 43–67.

Reilly, J., Hohmann, N., Kane, S., 1994. Climate change and agricultural trade : Who benefits, who loses? *Glob. Env. Change*, **4(1)**, 24–36.

Smit, B., Ludlow, L., Brklacich, M., 1988. Implications of a global climatic warming for agriculture: A review and appraisal. *Journal of Environmental Quality*, **17 (4)**, 519–27.

Stern, D.I., 2004. The rise and fall of the environmental Kuznets curve. *World Development*,

Stern, N., 2007. The Economics of Climate Change – the Stern Review. *Cambridge University Press*, Cambridge.

Weitzman, M., 2007. A review of *The Stern Review of the Economics of Climate Change*. *Journal of Economic Literature*, **45(3)**, 703–24.

Xiao, G., Weixiang, L., Qiang, X., Zhaojun, S., Jing, W., 2005. Effects of temperature increase and elevated co2 concentration, with supplemental irrigation, on the yield of rain-fed spring wheat in a semiarid region of china. *Agricultural Water Management*, **74(3)**, 243–55.

Yan, X., Ohara, T., Akimoto, H., 2003. Development of region-specific emission factors and estimation of methane emission from rice fields in the east, southeast and south asian countries. *Global Change Biology*, **9(2)**, 237–54.

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