Agriculture and global climate stabilization

By

John Quiggin

Presented at the 27th International Association of Agricultural Economists Conference
Beijing, China

August 16-22, 2009

This version:3/07/09

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John Quiggin

Australian Research Council Federation Fellow

School of Economics and School of Political Science and International Studies

University of Queensland

EMAIL j.quiggin@uq.edu.au

PHONE + 61 7 3346 9646

FAX +61 7 3365 7299

http://www.uq.edu.au/economics/johnquiggin

I thank Nancy Wallace and an anonymous referee for helpful comments and criticism.

This research was supported by an Australian Research Council Federation Fellowship.

Abstract

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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) leaves little doubt that human action is causing changes in the global climate, and that these changes will continue through 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 modelling 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. While a number of economists disagreed with Stern's treatment of issues such as discounting, they nevertheless endorse his conclusion on the need for action to stabilize climate.

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.

Most advocates of stabilization have argued for a target that may be expressed in terms of either a global atmospheric concentration of greenhouse gases, expressed in terms of ppm CO2 equivalents, or a target temperature change, commonly expressed relative to a 1900 baseline, before human-generated emissions had a large impact on climate.

The paper is organized as follows. Section 1 is a discussion of projections of climate change and its impacts on agriculture, comparing 'business as usual' projections with the case where action is taken to stabilize global CO2 concentrations by around 2050.

Section 2 deals with economic evaluation of the impact of climate change on the agricultural sector. 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.

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

In its Fourth Assessment Report, the IPCC (2007a,b,c) summarizes a wide range of projections of climate change, encompassing different climatic variables, time and spatial scales, models and scenarios. 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 CO2 concentrations on crop growth.

Even with aggressive strategies to stabilize atmospheric CO2 concentrations at levels between 400 and 500 parts per million (ppm), it seems inevitable that warming over the next century will be at least 2 degrees C relative to the 20th century average.

Thus, for the purposes of policy analysis, the relevant comparison is between warming of 2 degrees 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. The IPCC (2007a) presents a range of 'business as usual' projections, in which estimates of warming over the period to 2100 range from 2 degrees C to 6.4 degrees C, with a midpoint around 4 degrees C.

As shown by Quiggin and Horowitz, the main costs of climate change for agricultural producers are adjustment costs. It follows that the rate of change of warming is more important as the change in temperature levels at equilibrium or over a century. Recent observed warming has been at a rate of around 0.2 degrees per decade (Hansen et al. 2006). Business as usual projections imply an increase in the rate of warming over coming decades.

Water

Water, derived from natural precipitation, from irrigation or from groundwater, is a crucial input to agricultural production. IPCC (2007b, Chapter 3, p175) 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. Areas that are already wet are likely to become wetter, while those that are already dry will in many cases become drier, with average precipitation increasing in high rainfall areas such as the wet tropics, and decreasing in most arid and semi-arid areas (Milly, Dunne and Vecchia 2005). Where precipitation increases there are likely to be more frequent events involving very high rainfall, such as monsoon rain associated with tropical cyclones (IPCC 2007a). Severe droughts are also likely to increase by multiples ranging from two to ten, depending on the measure (Burke, Brown, and Nikolaos 2006) particularly in the temperate zone between 30 and 60 degrees latitude.

In addition, 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).

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 may be expected 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 CO2 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 CO2 concentrations (CO2 concentrations up to 550 ppm and temperature changes of 1 to 2 degrees C) beneficial effects will predominate. For higher levels of CO2, the benefits of CO2 fertilization will reach saturation and, for temperature increases above 3 degrees C, negative effects will predominate.

IPCC (2007b) summarizes a large number of studies of the impact of higher temperatures on crop yields. Unsurprisingly, 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 et al. (2005).

For warming of more than 2 degrees C, the marginal effects of additional warming are unambigously negative in most regions, particularly for rice. For temperature increases of more than 3 degrees 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).

3. Economic evaluation of the impact of climate change on the agricultural sector

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

Baseline for analysis

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 550 ppm has been proposed on a number of occasions (Stern 2007). For typical estimates of climate sensitivity, this target implies temperature change of around 0.2 degrees per decade over the next century, with stabilization thereafter.

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.

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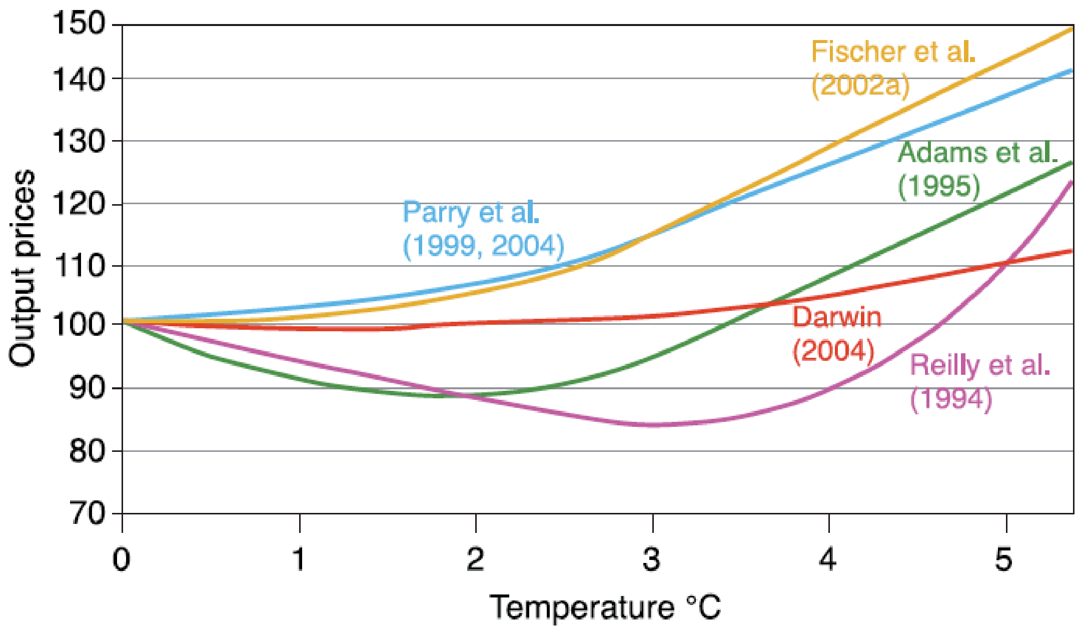

Fig 1: Cereal prices (percent of baseline) versus global mean temperature change for major modelling studies. Prices interpolated from point estimates of temperature effects.

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.

An analysis focused on adjustment costs is appropriate both in relation to human activity and 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.

Human activities are more adaptable than natural ecosystems. Nevertheless, 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 or 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 degrees 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

In assessing the aggregate impact of climate change on agriculture it is necessary to take account of the interaction between production systems and markets. 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.

This general result must be qualified, however, by the observation that 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.

A number of studies have attempted to estimate 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.

4. 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 (CO2, methane and nitrous oxide), carbon capture through forestry, and the production of biofuels. Conversely, efforts to mitigate global warming, by reducing emissions of CO2 and other greenhouse gases, or through the expansion of offsetting sinks, may have a significant effect on agricultural production

Biofuels

Policies aimed at reducing CO2 emissions are likely to encourage increased use of fuels derived from agricultural sources, collectively referred to as biofuels, either through direct policy mandates (such as that embodied in the US Energy Policy Act 2005) or through the market incentives associated with carbon taxes or cap-and-trade systems of emissions permits.

Considerable policy attention, both favorable and unfavorable has been focused on biofuels, currently derived primarily from food crops or from tropical products such as palm oil. Most notable in this context has been the use of ethanol as a substitute for gasoline.

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 ...

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. Other possible biofuels include bagasse and other crop residues used as fuel in electricity generation and methane derived from manure (Gallagher 2006).

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 CO2, 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 CO2 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. However, the Australian government subsequently decided not to ratify the Protocol.

Discussion of the potential role of forestry in mitigating emissions of CO2 is beyond the scope of the present paper. However, it is important to note that forestry competes with agriculture for land, and that 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 at 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 CO2), 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). Emissions from ruminant animals have been estimated to account for as much as … per cent of total warming ….

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.

Climate as a global public good

A public good is standardly defined one that is non-rival and non-excludable 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 it 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 the global distribution is widespread and unpredictable than where those affected are mainly in poor countries

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 typically 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 typically 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 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.[1] 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, Secretary General of the United Nations as "perhaps the single most successful international agreement to date" in "We the Peoples: The Role of the United Nations in the 21st Century" (Millennium Report), p. 56

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

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 income for one year. [The Right Choice at the Right Time, Sep. 1997 (Environ. Canada).] Benefits to agricultural and fisheries were estimated to be more than twice this amount, without even 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 stabilisation is likely to increase over coming decades, but will ultimately decline as the development of alternative energy reaches the point where (unsubsidised) 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 the Montreal Protocol.

The environmental Kuznets curve

This discussion may be understood in terms of the 'environmental Kuznets curve'. The standard version of the EKC shows an inverse-U relationship between output per person and the levels of various pollutants or, more generally, public bads generated by industrialisation.

The usual explanation for the EKC 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 EKC 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 EKC 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. In the case of global public goods, an international agreement is needed to make global social preferences effective.

Contract and converge

It seems clear that 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 if climate is stabilized with 1-2 degrees 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 industrialisation phase of development. However, given substantial net gains from a global agreement, it should be possible to generate something close to a Pareto-improvement.

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