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# SUSTAINABLE AGRICULTURAL DEVELOPMENT: THE ROLE OF INTERNATIONAL COOPERATION

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Edited by  
G.H. Peters, Agricultural Economics Unit, Queen Elizabeth House,  
University of Oxford, England  
and  
B.F. Stanton, Cornell University, USA  
Assisted by  
G.J. Tyler  
University of Oxford

INTERNATIONAL ASSOCIATION OF  
AGRICULTURAL ECONOMISTS  
QUEEN ELIZABETH HOUSE  
UNIVERSITY OF OXFORD

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## INTRODUCTION

Potential global climate change arising from increases in atmospheric CO<sub>2</sub> and other trace gas concentrations is an environmental issue of growing concern. While there is controversy about the timing and magnitude of climate change, forecasts from general circulation models (GCMs) of the earth's atmosphere suggest that the earth's climate will warm substantially (1.0° to 4.5°C) over the next century (Hansen, 1986; Houghton, Jenkins and Epraums, 1990). These increases in global mean temperature are expected to be accompanied by substantial changes in regional and seasonal temperature and precipitation (National Research Council, 1982; Manabe and Weatherald, 1987).

Climate change can affect virtually all ecosystems and ecosystem service flows (Wigley, Ingram and Farmer, 1981; Lough, Wigley and Palutikof, 1983). One ecosystem that is sensitive to climatic variability and of particular importance to human welfare is agriculture. The human consequences of crop failure arising from short-term climatic variation are apparent, as exemplified by recurring famine in the Sahel region of Africa caused by prolonged drought. The flora and fauna of natural or unmanaged ecosystems, including forests, estuaries, lakes and streams, are also likely to be affected by climate changes of the magnitude forecast by some of the GCMs. Changes in forest productivity, a rise in sea levels (due to partial melting of the polar ice caps) and alterations in hydrological balances induced by climate change could affect human welfare.

Implications for human welfare of alterations in ecosystem flows have been drawn largely by natural/physical scientists and engineers. Thus the role of human adaptations, either to slow the rate of CO<sub>2</sub> build-up or mitigate any resultant effects, has not been a central feature of most estimates of the social consequences of climate change. As the 'limits to growth' controversy of the early 1970s demonstrates, failure to account for the role of price mechanisms and other social incentives in altering human behaviour can often result in misleading predictions about paths of resource use (Meadows *et al.*, 1972).

Policy makers are focusing on strategies both to abate the build-up of greenhouse gases and to plan for climatic change (Lashof and Tirpak, 1989). Strategies for abatement include long-term reductions in fossil fuel consumption, reduced use of inputs and production practices that contribute to other

\*Oregon State University, USA.

trace gases, and establishment of forest plantations as 'carbon sinks'. Each strategy implies some costs. Several questions then seem relevant. For example, among the problems faced by mankind, does climate change warrant this current attention (and research expenditure)? Are the costs of slowing a CO<sub>2</sub> build-up justified by the benefits (of avoided damage)? What is the role for economic analysis in view of the long time horizons and the associated uncertainties in critical natural and physical science data?

The objective of this paper is to provide an economic perspective on these questions, including (1) an overview of contemporary economic thinking and research on potential benefits and costs of climate change abatement, (2) a discussion of problems and challenges in performing economic analysis of climate change, and (3) an assessment of research directions. The discussion draws heavily upon a sizable and growing economic literature on global climate change, including several recent articles by the author.

## BENEFITS VERSUS COSTS OF CLIMATE CHANGE ABATEMENT

As agencies and political bodies consider major investments in research or regulations pertaining to climate change, it is instructive to examine existing conceptual and empirical analyses of similar problems. While most economists would question the ability of the standard benefit – cost analysis (BCA) framework to assess a problem of this temporal complexity, economic input is critical to the design and structure of research of the topic (Sonka and Lamb, 1987; Adams, 1989). For example, despite their limitations, comparative static economic analyses can help to identify the important from the unimportant consequences of climate change and hence guide research and regulatory priorities. Some preliminary economic analyses of climate change effects and abatement strategies, dealing primarily with agricultural resource issues, are reviewed briefly in this section.

Climate change can affect crop yields through a number of mechanisms, including elevated atmospheric CO<sub>2</sub> concentrations and temperatures, as well as changes in precipitation (Decker, Jones and Achutuni, 1986; Rosenzweig, 1988). These changes can lead to increased pest and pathogen populations and reduced irrigation water supplies. Secondary effects of the greenhouse phenomenon, such as increased tropospheric ozone and surface incidence of UV-B radiation may also affect yields. While forecasting the magnitude and geographical distribution of these yield changes is difficult, some preliminary yield effects are available for the USA, Canada and selected areas of the remainder of the world in some recent US EPA-funded studies (Rosenzweig, 1988; Peart *et al.*, 1988). Several recent exploratory economics studies translate such yield forecasts to economic consequences (Adams *et al.*, 1991; Kane *et al.*, 1991; Fischer *et al.*, 1991; Kaiser *et al.*, 1991).

Most of the existing economic studies focus on consequences for US agriculture. For example, Adams *et al.* (1990) consider climate effects on US agriculture, including some preliminary analysis of changes in crop water use and irrigation supply. A similar study by Kane *et al.* (1991) investigates the consequences of climate changes for US trade in agricultural commodities.

Economic analyses that focus on state or multistate regions of the US include studies by Dudek (1988), Kaiser *et al.* (1991) and Easterling, Parry and Crosson (1989). A common finding of the studies which measure aggregate welfare effects is that climate change does not appear to be a food security issue, at least for North America. While locational shifts may occur in land and water use, the net economic effect could actually be positive under some climate change forecasts, owing primarily to the yield-enhancing effect of increases in atmospheric CO<sub>2</sub>. Even under more pessimistic GCM forecasts, the annualized loss is relatively modest (for example, for the USA, Adams *et al.*, 1990, estimate an annual loss of approximately \$11 billion or less than 7 per cent of the farm-gate value of production). Preliminary results from sensitivity experiments on global food production suggest a similar pattern to that observed for the USA; that is, likely regional gainers and losers but with relatively modest total changes in food production and economic welfare (Fischer, *et al.*, 1991).

While these studies suggest only modest losses (or gains) to the agricultural sector from climate change, predicted shifts in crop production and expansion in irrigated acreage imply demands or pressure on environmental and natural resources, including water quantity and quality, wetlands, soil, fish and wildlife and other resources. For example, a northward shift in corn and soybean production in North America (into Southern Canada) forecast by Adams *et al.* (1990) would exacerbate the loss of prairie wetlands by making drainage and conversion to crop production more profitable. Similar northward shifts in European agriculture are noted in Easterling, Parry and Crosson (1989). Obtaining water to facilitate any increases in irrigated acreage also implies more and larger reservoirs, which in turn implies greater pressure for water development. Other water resource effects can be inferred from the regional GCM temperature and precipitation forecasts. Specifically, increased spatial and temporal variability in rainfall and snow packs will also increase pressure to build dams for flood control. Increased competition for remaining streamflows seems likely.

Other resource effects are anticipated under climate change. Forest ecosystems will change, with some coniferous forest species, such as Ponderosa pine and Douglas fir, being displaced. Climate change, in connection with acid rain and photochemical oxidant air pollution, could be particularly stressful to forests in Europe and the eastern USA, where the forests die back to cover a smaller area. Wildlife populations may be reduced following habitat losses and more extreme weather variability. The implication for global wildlife resources, including endangered species, must be recognized (Batie and Shugart, 1989). A rise in sea level has implications for the productivity of coastal estuaries as well as agricultural production in low-lying areas of Bangladesh and Indonesia.

Climate change will impose some indirect effects on agriculture, particularly in terms of input costs. Perhaps the most important of these will be energy costs of control measures imposed on fossil fuel combustion. Current technology for CO<sub>2</sub> emissions reductions on fossil fuel combustion is costly. Construction of nuclear power plants is also costly. As a result, real per unit costs of electricity will rise. The feasibility of expanded or even current

irrigation will then be dependent on increases in real commodity prices sufficient to offset energy cost increases.

Agriculture itself generates various greenhouse gases. Methane from flooded rice fields, livestock and deforestation, nitrous oxide from fertilizer use, carbon dioxide from fossil fuel use and deforestation, and CFCs used in food processing are all greenhouse gases. The global increase in livestock numbers, irrigated rice acreage and nitrogenous fertilizer use is occurring as the result of population increases. Much of the deforestation in tropical areas, which contributes about a third of the total annual CO<sub>2</sub> flux, is for agricultural purposes. Control measures for such greenhouse gases could generate additional financial stress for farms and rural communities and exaggerate spatial adjustments. Indeed, as shown recently by Adams *et al.* (1991), the cost to US agriculture (consumers and producers) of controlling some trace gas emissions is substantial, ranging from \$550 per ton of methane from rice production to \$4 000 per ton of nitrous oxide. Additionally, controls on inputs such as fertilizer in developing countries would occur exactly when productivity increasing inputs would be in high demand.

Finally, the agricultural land base in some countries may be under pressure as a means of mitigating CO<sub>2</sub> increases. An increasingly popular proposal is to expand forested regions (through tree plantations) to remove carbon dioxide from the atmosphere (Woodwell, 1987). The preliminary analysis by Adams *et al.* (1991) indicates that a forest plantation programme on agricultural lands in the USA sufficient to sequester 20 per cent of annual US CO<sub>2</sub> production would require 50 million acres of land and cost between \$21 and \$38 per ton of carbon. A programme to sequester half of US CO<sub>2</sub> production would require over 270 million acres, at costs in excess of \$100 per ton of carbon. It is not clear what would be done with the timber produced on these plantations. The increase in timber supply from 50 million acres of additional forest area is estimated to reduce timber prices by up to 50 per cent, discouraging private timber production. This suggests the need for major subsidies or other incentives to encourage such a forest plantation programme.

In summary, the limited economic analyses on benefits and costs of climate change in North America, while crude, suggest that, in the aggregate, the effects may not be serious for agriculture. Indeed, gains in social welfare may be possible if the CO<sub>2</sub> fertilizer effect holds at elevated levels. However, regional or country-level effects are likely, with both gainers and losers. Costs of reducing trace gas emissions for agriculture seem large, suggesting that agriculture is not a cost-effective means of achieving such reductions. The lack of scientific information on a range of other resource effects under climate change precludes meaningful economic analysis at the present time. Unfortunately, these unaccounted consequences may be among the most important long-term effects of climate change. Technological change, and indeed economic analysis itself, may have little to contribute to the resolution of ethical issues involving intergenerational transfers of a degraded natural environment.

## PROBLEMS IN PERFORMING ECONOMIC ASSESSMENTS

There are several dimensions of climate change assessments that pose special analytical challenges. One important feature is the dominant role played by intertemporal considerations. Climate change is likely to alter the stream of returns that assets produce, whether the assets are buildings, public infrastructure, forests or agricultural products. Unfortunately, the benefit–cost calculation process is likely to be severely stressed when dealing with the time horizons associated with climate change.

The intertemporal features of climate change introduce the effects of risk on producer and consumer behaviour. However, most climate change damage assessments are *ex post* in nature. Because an *ex post* representation establishes a number of contingent states and proceeds to treat each of them as if it were certain, it is incapable of accounting for the agent's attitude towards risk; that is, it disregards the expenditures that the agent makes in preparing for states that go unrealized. The alternative, *ex ante* representation of the economic agent, addresses the consequences when the magnitude of the climate change effects is not yet known. The implications of these two analytical challenges are discussed in detail in Adams and Crocker (1989).

There are at least two conceptual dimensions of climate change assessments that need special consideration. Because climate change is a global phenomenon, assessing the consequences for other regions may require a different assessment perspective than is found in the US studies reviewed earlier. The first challenge relates to the different orderings of economic processes, markets and institutions across countries. This diversity requires an assessment framework that exploits the common relationships between economic orderings while adequately representing the relevant individual characteristics of each country or region. The second challenge relates to a fundamental lack of biological data from which to predict crop and other ecosystem responses across matrices of pollutant, site and time combinations. Innovative procedures are required to determine the 'transferability' of response parameters within this matrix.

A crucial starting-point in economic analysis is the correct representation of the choice problem facing decision makers. In market-oriented economies the neo-classical paradigm of producer and consumer behaviour provides an appropriate basis for such a representation. However, in many settings, individual supply and demand behaviours are essentially subsumed into planned, aggregate supply and demand decisions based on perceived social objectives. In addition to such planned, socialistic economies, a sizable percentage of world food production and consumption occurs in developing countries, where the interaction of subsistence, village-oriented agriculture and aggregate food demand/production goals creates a third possible configuration of market structures.

The challenge in measuring the international consequences of climate change on the service flows provided by agriculture, forestry and other ecosystems is to fold these diverse economic structures into a framework which provides some common measure of social welfare. The market-oriented and planned economies have a somewhat common goal, namely, to produce efficiently a

socially optimal level of agricultural output. Market-oriented economies work towards this goal through the market signals created by the interaction of supply and demand forces. Planned economies rely on indirect approaches based on planning goals (that is, perceived consumption needs) and associated allocations of resources to meet those goals. Interactive, iterative decision processes are frequently used to measure the contribution of alternative resource allocations to the attainment of the specified goals. However, a fundamentally different decision problem confronts the subsistence grower, who is both a producer and consumer of his output. Numerous behavioural models have been advanced to capture this dual role, but in general it is believed that such growers are risk-averse and thus produce first for family or local consumption, using historically proven techniques. Production moves into domestic or international markets only after the primary goal of subsistence has been achieved. In this producer/consumer setting, climate change may affect the individual in ways distinct from the cases treated heretofore. Specifically, while the grower's quantity (yield) and quality of commodities may be affected by climate change, as in any other economic setting, the effects on the grower may be more severe in terms of individual welfare. First, any productivity loss reduces marketable surplus and possibly even the subsistence component of production. Second, changes in quantity and quality of production may effect labour productivity if the grower's health is influenced, given that the grower (and immediate family) provide the major input, labour, into the agricultural production process. Third, climate-induced yield reductions may intensify risk-averse behaviour, thereby reducing the likelihood of the grower adapting new, yield-increasing technologies.

These unique dimensions of subsistence agricultural economies suggest that measuring the economic effects of pollution on developing countries will require economists to incorporate some of these producer/consumer/labour supplier linkages into the assessment framework. Available literature on economic development may provide some guidance. In addition, the concept of the 'household production function' proposed by Tinbergen (1956) and expanded by Lancaster (1966) offers a possible framework within which to explore the effects of pollution on the decision problem facing the producer/consumer.

The second general challenge in assessing climate effects is the scarcity of natural and physical science data. If more exact natural science information is to be of substantial value, this will probably be because of its contribution to better understanding of the manner in which the consequences of climate change impacts are distributed across groups and regions. Evidence provided by Adams and Crocker (1989) indicates that production and consumption patterns, and thus distributional consequences, are often sensitive to rather small changes in ambient environmental quality. Currently, it is not known whether estimates of the human behavioural responses which are the root sources of this sensitivity would be greatly altered by more exact natural science information.

The policy relevance of improved information concerning the sensitivities of production and consumption patterns to climate change is demonstrated by the consistent finding in many air pollution studies that farmers substitute



other inputs, especially land, for poor environmental quality; that is, reduced environmental quality causes more land and inputs such as fertilizer and pesticides to be used. The magnitude of substitution and the conditions that cause this magnitude to vary are at present little understood, although the finding reported by Adams and Crocker that producer losses often increase exponentially implies that the worth of available substitution possibilities declines. To the economist, good natural science information is synonymous with a precise mapping of the substitution possibilities. The importance of such a mapping becomes apparent when one recognizes that land, fertilizer and pesticide substitutions could be responsible for a good deal of the pollution and trace gases that originate from agricultural practices. Policy makers might then confront the paradox that the environmental change from other sources (such as CO<sub>2</sub>-induced climate change) which affects agriculture encourages agricultural practices which themselves contribute to climate change; for example, more nitrogen fertilization, more deforestation. Conversely, a reduction in exogenous environmental change from other sources could reduce some trace gases and other forms of pollution that originate in agricultural practices. A thorough understanding of whether this quite plausible story is, in fact, true will require an as yet unavailable detailed natural science and economic understanding of influential substitution possibilities and behavioural responses.

## CONCLUSIONS

Most economic inquiries concerning agriculture and related resource use suggest that, for moderate climate change, agricultural production appears capable of meeting projected demands. While these analyses are based on uncertain data and assumptions, the findings do suggest that economic adjustments can mitigate some adverse climate effects, but with attendant regional gainers and losers. Planning may therefore be needed to soften the negative impacts on specific regions, countries and resources.

The evidence to date on the possible consequences of climate change is largely drawn from the North America and European experience. While tropical deforestation and rice production attract attention as major sources of trace gases, there is little research on the relationship between the behaviour of farmers, including input use patterns, and both the causes and effects of climate or other environmental change in developing areas of the world. If BCA is to be used in debating the role of agriculture in global decisions pertaining to the regulation of trace gases, then economists need to influence the scientific research agenda to eliminate current gaps in both the natural and social sciences, particularly in terms of our understanding of effects in the LDCs.

In summary, a couple of points seem important. First, economic processes have the potential to mitigate the direct effects of climate change on agricultural production and consumption. In fact, such potential adjustments are likely to be understated in the economic studies recorded here, given the long time horizons involved. While the adequacy of food and fibre production may

not be an issue, it seems probable that the conflict between those adjustments that fill the stomach and those which nurture the human psyche will intensify. Thus a more rapid loss of environmental and other non-market assets and consumption opportunities seems likely under the climate projections. This implies that future generations will be the real losers. Second, most of the implications drawn here do not open vast new areas for economic research. Rather, they suggest a continuation (and perhaps renewal) of much of the resources-oriented research performed by agricultural economists over the last several decades, but with greater attention to the processes underlying agricultural development.

## REFERENCES

- Adams, R. M., 1989, 'Global Climate Change and Agriculture: An Economic Perspective', *American Journal of Agricultural Economics*, 71, p.5.
- Adams, R. M. and Crocker, T.D., 1989, 'The Agricultural Economics of Environmental Change: Some Lessons from Air Pollution', *Journal of Economic Management*, 28, pp. 295–307.
- Adams, R. M. et al, 1990, 'Global Climate Change and U.S. Agriculture', *Nature*, 345, p.6272.
- Adams, R. M., McCarl, B.A. and Callaway, J.M., 1991, 'The Role of Agriculture in Climate Change: A Preliminary Evaluation of Emission Control Strategies', in J. Reilly and M. Anderson (eds), *The Economics of Global Climate Change: Implications for Agriculture, Forestry, and Natural Resources*, Western Press, Boulder, Co.
- Batie, S.S. and Shugart, H.H., 1989, 'The Biological Consequences of Climate Change: An Ecological and Economic Assessment', in N.J. Rosenberg, W.E. Easterling, P.R. Crosson and J. Darmstadter (eds), *Greenhouse Warming: Abatement and Adaptation*, Resources for the Future, Washington, DC.
- Decker, W.L., Jones, V.K. and Achutuni, R., 1986, 'The Impact of Climate Change from Increased Atmospheric Carbon Dioxide on American Agriculture', U.S. Department of Energy, DOE/NBB-0077, Washington, DC.
- Dudek, D.J., 1988, 'Climate Impacts Upon Agriculture and Resources: The Case of California', in J.B. Smith and D.A. Tirpak (eds), *The Potential Effects of Global Climate Change in the U.S.*, Environmental Protection Agency, Washington, DC.
- Easterling, W. III., Parry, M.L. and Crosson, P.R., 1989, 'Adapting Future Agriculture to Changes in Climate', in *Greenhouse Warming: Abatement and Adaptation*, Resources for the Future, Washington, DC.
- Fischer, G., Froberg, K., Kayzer, M. and Parikh, K., 1991, *Linked National Models: A Tool for International Food Policy Analysis*, International Institute for Applied Systems Analysis, Kluwer Academic Publishers, Amsterdam.
- Hansen, J., 1986, 'The Greenhouse Effect: Projections of Global Climate Change', statement presented to US Senate Subcommittee on Environmental Pollution of the Committee on Environment and Public Works, 10 June.
- Houghton J. T., Jenkins, G. J. and Epraums, J.J., 1990, *Climate Change: The IPCC Scientific Assessment*, Cambridge University Press, Cambridge.
- Kaiser, H. S. Riha, Rossiter, D. and Wilks, D.S., 1991, 'Agronomic and Economic Imports of Gradual Global Warming: A Preliminary Analysis of Midwestern Crop Farming', in J. Reilly, and M. Anderson, (eds), *The Economics of Global Climate Change: Implications for Agriculture, Forestry and Natural Resources*, Westview Press, Boulder, Co.
- Kane, S., Reilly, J. and Tobey, J., 1991, 'Effects of Climate Change and World Trade Flows of Agricultural Commodities', in J. Reilly and M. Anderson (eds), *The Economics of Global Climate Change: Implications for Agriculture, Forestry and Natural Resources*, Westview Press, Boulder, Co.
- Lancaster, K. J., 1966, 'A New Approach to Consumer Theory', *Journal of Political Economy*, 74, pp.132–57.

- Lashof, D.A. and Tirpak, D.A., 1989, *Policy Options for Stabilizing Global Climate Change*, draft report to Congress, US Environmental Protection Agency, Washington, DC.
- Lough, J.M., Wigley, T.M.L. and Palutikof, J.P., 1983, 'Climate and Climate Impact Scenarios for Europe in a Warmer World', *Journal of Climate and Applied Meteorology*, 22, pp. 1673–84.
- Manabe, S. and Wetherald, R.J., 1987, 'Large-Scale Changes in Soil Wetness Induced by an Increase in Carbon Dioxide', *Journal of Atmospheric Science*, 44, pp. 1211–35.
- McQuigg, J.D., 1981, 'Climate Variability and Crop Yield in High and Low Temperature Regions', in W. Bac, J. Pankrath and S.H. Schneider (eds), *Food-Climate Interactions*, R. Reidel Publishers, Dordrecht, The Netherlands.
- Meadows, D.H., Meadows, D.L., Randers, J. and Behren, W.W. III, 1972, *The Limits to Growth*, Universe Books, New York.
- National Research Council, 1982, *Carbon Dioxide and Climate: A Social Assessment*, National Academy Press, Washington, DC.
- Peart, R.M., Jones, J.W., Curry, R.B., Boote, K. and Allen, L.H., 1988, 'Import of Climate Change in Crop Yields in the Southeastern US.', *Report to Congress on the Effects of Global Climate Change*, US Environmental Protection Agency, Washington, DC.
- Rosenzweig, C., 1988, 'Potential Effects of Climate Change on Agricultural Production in the Great Plains: A Simulation Study', *Report to Congress on the Effects of Global Climate Change*, US Environmental Protection Agency, Washington, DC.
- Sonka, S.T. and Lamb, P.J., 1987, 'On Climate Change and Economic Analysis', *Climatic Change*, 11, pp. 291–311.
- Tinbergen, J., 1956, 'On the Theory of Income Distribution', *Weltwirtschaftliches Archiv*, 77, pp. 155–74.
- Wigley, T.M.L., Ingram, M.J., and Farmer G. (eds), 1981, *Climate and History: Studies in Past Climates and Their Impact on Man*, Cambridge University Press, Cambridge, Mass.
- Woodwell, G.M., 1987, 'Biotic Implications of Climatic Change: Look to Forests and Soils', in J.C. Topping, (ed.) *Proceedings of First North American Conference on Preparing for Climate Change: A Cooperative Approach*, Climate Institute, Washington, DC.

## DISCUSSION OPENING – J. ARNE HALLAM\*

The analysis of significant environmental events provides important challenges to economists in both theory and measurement. In order to understand their impact, physical as well as economic information is needed. Adams discusses recent attempts to measure the impact of climate change and introduces some of the many theoretical issues that must be confronted. The author has done an excellent job in surveying the recent literature, presenting us with a number of important points that should be considered in all future attempts to measure the impact of climate change. While specific criticisms might be levelled at each of the papers reviewed by the author, which some discussants might choose to dispute, these comments will attempt to provide a framework that might be used to model climate change. This will provide a basis on which to discuss the problems presented by the author. In evaluating the impact of exogenous factors on the economy, three systems must be considered. The interactions of the physical (including biological), economic and social systems jointly determine outcomes.

\*Iowa State University, USA.

### *Physical models of climate change*

One simple type of model used by scientists is based on time series, extrapolating past trends into the future. More complicated models attempt to predict the future by simulating the physical system and then using forecasts of inputs to the system to predict outputs. For example, a scientist might predict global temperature based on total carbon dioxide emissions, determine emissions using the physical properties of current production practices, and then extrapolate the use of such practices in the future to forecast future climate conditions. The accuracy of such forecasts depends on the ability of the model to simulate dynamically the physical process, and on the precision of the exogenous extrapolation.

Models of climate change depend on data collected and synthesized over long time-periods. Much of the data used is also subject to significant errors of measurement. Atmospheric models, in particular, often depend on the solution of partial differential equations which are very sensitive to starting values and to parameter variation. When possible, all point estimates of change should be supplemented with precision estimates, so that induced models can both report standard errors and perform reasonable sensitivity analyses.

Most physical models also assume that input–output relationships are constant, or at least change according to some fixed and known rule. Given that production processes are operated by economic agents, there is inherent potential for both exogenous and induced technical change to occur. To the extent that physical models do not properly account for changes in technology, they may miss the essence of changes in the system. For example, if crop breeders were able (unlikely though it may be) continuously to produce new varieties having a constant rate of yield growth across all possible environments, then global climate change would have no impact.

A simple way to forecast system inputs is to extrapolate past trends. While this may be useful for short-term analysis, the essence of economics is that agents will respond to price signals. To the extent that system outputs change the economic environment, decision makers are induced to change the production process, and thus change the results of the system model. This is the major hypothesis of the next section.

### *Integrating economic and physical process models*

The physical and economic environment influence the choices of individual agents. In an equilibrium and dynamic context, the decisions of agents can influence both technology and the economic environment. These interactions are important in measuring and predicting the effects of changes in the physical system.

Consider a model of the decision process for an individual. There are three components of this process. The first is technology. This is the production function or input–output relationship, which can be considered fixed in the short run. The second component is the physical and economic environment. Elements of this component include prices, government policy variables,

physical parameters such as sunlight and rainfall, and elements of the legal and social system. The third component is the objective function reflecting the preferences of the decision maker. This includes individual attitudes towards income, wealth and risk. Given these three components, the decision maker or the economist can determine the optimal decision, given information about technology and the environment. The solution of this decision problem leads to economic relationships such that decision variables are expressed in terms of exogenous variables. An example is a supply function which depends on price movements and fixed input levels. If environment variables remain explicit in the reduced form economic model, then their impact can be evaluated directly. Alternatively, the effects can be evaluated by changing the levels of the climate parameter and resolving the optimization problem directly.

While some economic parameters, such as prices, are fixed for the individual, they are endogenous in the economic system. Thus individual models must be aggregated and solved to obtain market equilibrium effects. An important decision in modelling is the level of aggregation that accurately reflects the economic system. The conditions for aggregating micro-level models are stringent and often not reasonable, while models formed in the aggregate often inadequately reflect technological and site-specific environmental factors. To the extent that increased yields in one region have a price impact, economic conditions in all regions will be affected. More critically, over time, the outcomes of the individual decision process, when integrated into the system, may affect the underlying technologies available, and thus the underlying decision problem.

### *Some other modelling issues*

As pointed out by the author, individual preferences as regards risk and return are difficult to measure. Global climate change is a long-run phenomenon, and so intertemporal preferences are important. The appropriate discount rate for the individual is not obvious. Whether intertemporal preferences are time-separable, and thus amenable to the consequent simplifications in modelling, is an unresolved issue.

The current literature in macro-economics makes clear the need to model appropriately the way in which generations are linked together. Models with an infinite time-horizon and a single decision maker may have very different solutions from those with overlapping generations and different ways to transfer or trade wealth. Thus classical extraction models may lead to different conclusions, depending on whose wealth is maximized. While altruism may be a rational economic action, selfishness and maximization of one's own wealth are also possibilities.

Few detailed models of the economic system solve for a full intertemporal rational expectations equilibrium. A key aspect of modelling is how complete a model to build and how to link periods over time. Does the modelled system reach full equilibrium in each period or does the system muddle through a series of temporary equilibria, always shooting for a more complete solution?

The appropriate measure of welfare in an intertemporal context depends on whose welfare is to be measured. Simple sums of consumer and producer surplus seldom accurately measure the implications of regime change. Since work to date has shown more distributional than aggregate consequences for climate change, the appropriate way to measure such effects seems critical.

At a more macro level, shocks to the economic system may induce changes in the very fabric of the underlying political and social system. The induced innovation hypothesis is but one example of the way in which changes in technology may lead to other changes, with perhaps significant impacts on the social system. Global climate change could have an impact in such a way as to reduce the viability of the current world economic and social system. For example, suppose that climate change leads to a gradual northward movement in crop production, with resultant further impoverishment of much of the Third World. The currently unequal distribution of wealth would become worse and past unheeded calls for a new international economic order might become more poignant and more powerful. Such movements, if successful, could lead to the overthrow of the current system, with significant impacts on future technology, trade flows and wealth accumulation. Alternatively, the beginnings of global climate change may sensitize individuals in developed countries so that they call for significant changes in the production system in order to protect the environment. In either case, the underlying economic predictions from a model based on the current system lose credence.

### *Conclusions*

These comments have been very cautionary about the use of physical and economic models to evaluate global climate change. Nevertheless, the author firmly believes that such forward-looking analysis is necessary. Only by attempting to understand the future can correct decisions about the present be made. Those who undertake such analysis are to be commended for bravery and concern for society, but they should make the assumptions of their work transparent and attempt to address in one way or another the issues raised by these comments. Sensitivity analysis, complete with standard errors, would be a most welcome addition to much current work. Finally, all results from forward-looking work should be viewed with caution, since all crystal ball gazing is only as good as the current technology in crystal balls.