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CLIMATE CHANGE, SUSTAINABLE ECONOMIC SYSTEMS AND WELFARE

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Abstract

Research on the effects of climate change on US agriculture and world grain markets suggests that adaptation will occur with relatively small effects on total production. Additional research shows that reducing emission of greenhouse gases from US agricultural production is relatively expensive compared to encouraging reforestation as an offset to emissions of carbon dioxide. Nevertheless, continued population growth and the increasing inequality of income across countries are likely to exacerbate the adverse effects of climate change. Concepts of sustainability should be expanded to cover industrial as well as agricultural production, and promote the efficient use of fossil fuels in general. Dealing with climate change effectively will require international cooperation and a willingness to address population growth and the divergence of incomes between rich and poor countries.

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1. INTRODUCTION

The primary objectives of this paper are 1) to summarize current economic research on the effects of climate change on agriculture, 2) to identify questions that remain unanswered, and 3) to suggest directions for future research. The overall conclusion is that climate change is one component of a more general set of problems that will affect the future well-being of people throughout the world. Growth in population and the increasing inequity of the distributions of wealth and income among and within countries underlie many environmental problems. The effects of climate change may exacerbate these problems, but solutions to climate change must involve social as well as technical components. Technical options are necessary for developing solutions but are not sufficient for success. Furthermore, solutions must deal with broad social issues, and can not be limited, for example, to simply reducing levels of greenhouse gases.

Probably the most important consequence of the publicity on climate change is the realization that the combined effects of many small unrelated activities can have substantial effects on the world's climate. These effects are not transitory, and they will last for many years into the future even if drastic measures are adopted now to reverse them. Such considerations have important implications for economic research. Analyses of climate change should put more emphasis on 1) the global scope of issues, 2) the physical relationships that govern economic activity, and 3) the long-range implications of results. Given the complexity of the scientific issues relating to climate change and the need to look ahead 50 or 100 years into the future, a fourth consideration for economic analysis is uncertainty [see Manne and Richels]. Policies should be designed to reflect this reality by 1) incorporating flexibility to adapt to new situations, 2) establishing procedures for improving scientific knowledge and monitoring progress, and 3) setting schedules for revising goals.

For some people, uncertainty about the true magnitudes of climate change and the effectiveness of different policy instruments is used as an excuse for inaction. However, the lack of clear policies for addressing global environmental problems undermines the effectiveness of efforts by individual countries and regions to improve environmental quality. The increase of greenhouse gases in the atmosphere and the associated effects on climate provide a classic example of an environmental externality. The people who cause the problem do not pay for the effects, and the people affected do not have any choice in the matter. A general solution to externalities is to internalize the costs of environmental damage. This can be done by putting taxes on emissions, establishing markets for emission permits or by limiting emissions through legislation. In all cases, some form of international agreement is needed to make any policy for solving a global environmental problem work. Since it will take time to establish international cooperation and agreement on policies, it is clear that the United Nations Conference on Environment and Development (UNCED) in Rio de Janerio, Brazil, next June will provide an important opportunity to establish common goals for environmental policies relating to climate change.

International agreements adopted now will help determine future levels of environmental quality and human welfare. It is argued below that current economic practices in industrialized as well as developing nations are not sustainable. Consequently, there is no justification for complacency at the present time. Most governments would agree that some form of sustainability is a sensible national objective, but in many cases, the status quo is not desired domestically or desirable from a global perspective. The importance of the economic factors causing climate change and the scale of the problem have forced environmental issues into the international arena. The environmental and social problems associated with climate change could provide the stimulus for developing viable ways to ensure that economic systems are sustainable in the future. Without new initiatives, it is likely that global environmental problems will remain unsolved and that income differences between rich and poor nations will continue to diverge, leading to larger numbers of economic refugees and greater political instability.

2. SOURCES OF UNCERTAINTY

The main scientific source of information about the effects of higher levels of greenhouse gases on global warming and climate change comes from General Circulation Models (GCM) of the atmosphere (e.g. Houghton, Jenkins and Epraums). There is a great deal of uncertainty about specific effects, but there is general agreement that average temperatures will rise given current increases in the levels of greenhouse gases (primarily carbon dioxide from burning fossil fuels). There is less agreement in how much this increase will be, and predicted increases range from 1.0°C to 4.5°C over the next century. However, the increase in temperature is not uniform across all regions, and the associated effects on rainfall are even more uncertain.

The changing spatial patterns of temperature and rainfall are the most important climatic variables affecting agriculture. Since the magnitudes and even the directions of these changes for different regions are uncertain, analyses of the associated effects on world agriculture are highly speculative. Predicted changes on agricultural production must be interpreted as conditional on the specified changes in the spatial patterns of temperature and rainfall as well as the specified changes over time.

Other sources of uncertainly about the effects of greenhouse gases include the complex interactions that exist among gases in the atmosphere. For example, methane is a more potent greenhouse gas than carbon dioxide, but it breaks down more quickly. Chlorofluorocarbons (CFC) are even more potent, but their effects may be offset by allowing more infrared radiation to escape from the atmosphere due to the associated effect of depleting ozone levels in the stratosphere. Nitrogen oxides emitted at high altitudes from airplanes may have a greater effect on climate than the same amount of emissions from automobiles. Hence, even if economic models could predict the emissions of greenhouse gases accurately their effects on radiative forcing are not yet understood completely.

Greenhouse gases have other effects on the environment. Some are good and some are bad. CFC's have caused reductions in the levels of stratospheric ozone allowing more ultraviolet radiation to enter the lower atmosphere. This has adverse health effects on humans by increasing incidents of skin cancer, and may reduce the growth of plants and animals such as phytoplankton and krill. On the positive side, higher levels of carbon dioxide may stimulate plant growth by increasing the efficiency of using water. Nevertheless, the magnitudes of these effects under field conditions are still a source of scientific controversy.

The sources of uncertainty discussed above reflect the current state of knowledge about the physical relations that affect climate. More research needs to be done to understand these relations better, but other sources of uncertainty are important. They include how people will react to changes in climate, and how their behavior affects emissions of greenhouse gases. These issues correspond to adaptation and mitigation which have been the focus of research in the US over the past few years. It is in these areas that the economic and social sciences play an important role. In simple terms, the physical sciences define a range of options, but social behavior determines which choices are made. For adaptation, the primary interest is on predicting how people will respond and how effective different policy instruments will be in changing responses. For mitigation, the problem is more complicated because it involves determining the goals for policies as well as effective ways to implement them. These issues are discussed in the following two sections.

3. CAN AGRICULTURE ADAPT?

There are three stages in the adaptation of agriculture to a change in climate, and at each stage there are questions of how effective adaptation will be. The first stage is to determine whether new cultivars, crops, and management practices can be developed that are better suited to the new conditions. Plant breeders and crop scientists in the US seem to be relatively confident that viable options can be developed successfully given the magnitudes of changes in climate that are anticipated and the fact that the changes will be gradual rather than abrupt.

The second stage in adaptation is whether farmers will adopt the new cultivars or management practices. In market economies, this step is governed by economic forces. In the simplest terms, the new options must be economically attractive in terms of yielding higher income. The uncertainty faced by farmers about yields and prices is also an important factor that affects these decisions. There is an important tradeoff between higher average incomes and riskiness that should be incorporated into analyses of how agriculture will respond to climatic change

A major limitation of most existing models of agricultural production is that the effects of weather variables are not explicitly represented. A series of steps is needed in research to develop appropriate models of agricultural production [Mount 1992a]. Most published analyses of the effects of climate change on agriculture modify the mean yields of major crops based on results from yield models developed by crop scientists. Results are compared with and without the changes of yield in a comparative static framework [e.g. Adams et al. 1990 and Kane et al.]. A more realistic analytical approach has been developed by Kaiser et al. by linking a model that generates weather patterns to crop yield/soil models to a management decision model. For a given region, this framework makes it possible to focus on adaptability over time, responses by farmers to variability of yield as well as changes in average yields, and the adoption of new crops and cultivars. The important point is that results are conditional on explicit specifications about climate and soil characteristics.

Table 1 shows the cropping patterns predicted for four different specifications for farms in the upper Midwest of the US, representing different physical properties for climate and soil. In all cases, the results show the average cropping pattern for a 70 year simulation. Different cultivars for each crop are considered explicitly in the analysis and aggregated in Table 1. The good soil with good weather (Case 1) gives a pattern of two-thirds maize and one-third soybeans. The hotter and drier climate with the same soil (Case 2) does not change the cropping pattern much because the soil holds moisture well. The poor soil with the good climate (Case 3) gives a pattern that has

Table 1

Predicted Cropping Patterns Under Different Physical Conditions
(Upper Midwest of the US)

SPECIFICATION		PERCENT OF TOTAL AREA			
CLIMATE[a/]	SOIL[b/]	MAIZE	SOYBEANS	SORGHUM	FALLOW
1. GOOD	GOOD	64	36	0	0
2. HOT/DRY	GOOD	68	32	0	0
3. GOOD	POOR	39	61	0	0
4. HOT/DRY	POOR	1	36	0	63

a/ Good: Scenario 3
Hot/Dry: Scenario 7

b/ Good: Ves
Poor: Dickman

Source: H.S. Kaiser, Personal Communication 1/6/92 nearly two-thirds soybeans and the rest maize. However, with the hotter, drier climate and the poor soil (Case 4), there is virtually no maize grown, soybeans are cut to just over a third and the rest is fallow. The surprise is that sorghum is not selected in Case 4 even though it is relatively tolerant to dry spells and its yield is not affected by the change of climate nearly as much as the yields of maize and soybeans. The reason is that economic considerations and aversion to risk make it unattractive to grow sorghum. Even though it is technically feasible to grow sorghum successfully, it is not worth the risk under these specifications.

The results in Table 1 illustrate the importance of the physical characteristics of climate and soil in determining cropping patterns. However, economic specifications also matter. Traditional models of market economies focus on crop prices and average yields as the key determinants of cropping patterns. The interdisciplinary framework used by Kaiser et al. shows that there are other important factors that affect costs and cropping patterns. For example, the cost of drying grain is affected by the moisture content of grain at harvest as well as the price of fuel. High rainfall in the Spring may make it impossible to plant certain crops early enough to mature successfully. These examples illustrate the potential advantages of interdisciplinary research that links economic models with models from the natural sciences. The main disadvantage is that the amount of information needed to specify a scenario for a selected region is large, and therefore, it is cumbersome to aggregate results across regions to predict national levels of production.

The third stage in the adaptation of agriculture to climate change is the most important from an economic point of view. It is the response of markets to changes in supply. Stage two deals with how farmers respond and it determines the supply of agricultural products. In Stage three, if one crop is in short supply, the price of the crop will tend to increase relative to other prices. This in turn will encourage consumers to switch to substitute crops that are cheaper and encourage distributors to import more of the crop from other countries. Higher prices will tend to stimulate higher levels of production in the future. In general, markets provide a self-regulating feedback mechanism for farmers, and help adaptation to occur smoothly. In this way, market systems can adapt in an active way without direct interventions by governments.

Research on the adaptive capacity of US agriculture to climate change [Adams et al. 1990] suggests that the overall effects on production are relatively small (equivalent to an 8% loss of income in the worst case). The results are derived from a spatial model of agriculture using different assumptions about crop yields to reflect climate change. The results are sensitive to the GCM model used to predict the regional pattern of climate change and to the specified increases of yields due to higher concentrations of carbon dioxide. Nevertheless, the main conclusion in three of the four scenarios is that US agriculture can adapt to climate change without major adverse effects. Although these results hold for total production from agriculture, there are still substantial gains and losses in different regions of the US.

Analyses of a single country or region typically ignore the economic feedback from international trade in agricultural products. Research on world grain markets [Kane et al.] suggests that the overall effects of climate change will be small, but regional differences may be substantial. For example, Kane et al. show that the US loses and the Commonwealth of Independent States (CIS; formerly USSR) gains. These results are based on an international trade model of grain markets (SWOPSIM) using supply shifts to represent climate change. Once again, the conclusion is that adaptation works through market forces, but the importance of distributional effects is also apparent. Some countries will benefit but others will not.

The results of Kane et al. focus on grain markets and do not consider the effects of climate change on subsistence agriculture. The advantages of markets in helping adaptation are lost in subsistence economies because lower yields are not offset by higher prices. In a successful market transaction, both parties benefit, but if income levels are low, it may not be possible to purchase enough food to offset reductions in production. Consequently, the full effects of climate change are borne by farmers in subsistence economies. Some may benefit, but in general, subsistence farmers in fragile environmental regions are more vulnerable to adverse effects than in market economies.

Little research has been published on the effects of climate change on agriculture in subsistence economies. Preliminary results from Cynthia Rosenzweig suggest that climate change may cause larger reductions in total grain production than the reductions predicted by Kane et al. In addition, the negative effects on agriculture in poor nations may be substantial. It follows that income differentials between rich and poor countries could be increased. In most industrialized countries, agriculture is a relatively small part of the total economy and access to international markets makes it feasible to use trade to offset shortages in domestic production of agricultural products. This is not possible in subsistence economies because income levels are too low to buy enough through trade, and access to markets is limited and expensive due to inadequate infrastructure. The tentative conclusion is that rich countries can adapt to climate change but poor countries may take it on the chin.

4. STRATEGIES FOR MITIGATION

Some research on the economic potential for reducing emissions of greenhouse gases from agriculture has been completed. Agriculture contributes methane from ruminants and rice paddies, carbon dioxide from deforestation and fossil fuels, and nitrous oxides from the use of chemical fertilizers. In all cases, these sources of emissions should be compared with the amounts of carbon sequestered through plant growth to determine the net contribution of agriculture to greenhouse gases [Drennen and Chapman]. Although there is still no general agreement among scientists about the magnitudes of sources of greenhouse gases, it is safe to say that agriculture's contribution is small compared to the emission of carbon dioxide from deforestation and burning fossil fuels in other sectors [e.g., see Kane et al.].

Research by Adams et al. [1992b] and Adams shows that the costs of reducing or offsetting emissions of greenhouse gases from agriculture in the US are relatively high ($US550/ton for methane from rice production, $US2250-4900/ton of methane from ruminants, and $US4000/ton for nitrous oxides). (It should be noted that these results are conditional on the cost assumption made about the alternative activities in the model, and new cost information could change them.) The most promising strategy is to offset emissions of carbon through reforestation. (Hall, Mynich and Williams argue that using biomass as a source of energy would be an even better policy.) Adams et al. [1992b] estimate that offsets for 20% of total emissions of carbon in the US could be achieved by 100 million acres of tree plantations at a cost of $US25/ton of carbon. (Drennen and Chapman derive an even lower cost of $US15/ton of carbon.) The analysis by Adams et al. shows again the importance of tradeoffs between winners and losers. Increasing the area for forests reduces the land available for agriculture, and higher prices for agricultural products are partially offset by lower prices for lumber products.

For comparison, consider energy conservation as an alternative option. If one ton of coal is burnt to generate electricity, two thirds of the energy is lost and one third is converted to electricity. With a heating value of 13,100 Btu/pound, one ton of coal generates 2.6 tons of carbon dioxide. This corresponds to only 1000 kWh for every ton of carbon dioxide emitted. Increasing the efficiency of electric appliances is economically viable at current prices in the US [e.g. see Nadel and Tress]. Using some of the two-thirds of total energy lost in generating electricity through cogeneration is another way to improve efficiency. Substantial increases in cogeneration are anticipated in the near future by the electric utility industry. Similar examples for improving energy efficiency exist in other sectors such as transportation and manufacturing. There is a clear economic rationale for viewing energy efficiency as the key in any policy for controlling emissions of carbon in the US. It is likely that similar conclusions would apply for other industrialized countries. An important stimulus to adopting new efficient techniques would be to internalize environmental costs into the prices paid for fuels. Reducing emissions from agriculture and carbon offsets are supplements to, but not substitutes for, using fuels more efficiently.

As a final justification for the importance of energy conservation, consider a comparison of rich and poor nations (in terms of income per capita). Chapman and Drennen use United Nations data to show that while only one quarter of the world's population live in rich countries, these countries use three quarters of all energy and produce about eighty five percent of total world income. To the extent that energy use is related to income, improving the well-being of the seventy five percent of the world's population who live in poor countries could increase levels of greenhouse gases substantially and further exacerbate the problems associated with climate change. This is a major problem underlying the future stability of economic systems on a global scale.

5. SUSTAINABLE ECONOMIC SYSTEMS

An argument was made at the end of Section 2 that the existence of technical solutions to environmental problems was necessary but not sufficient for policies to work. Success requires that a policy is also feasible from an economic and social perspective. This same argument holds for sustainability. In a general sense, sustainability implies reducing or eliminating environmental degradation, such as urban smog and soil loss, and replacing the use of finite resources (e.g. oil) by renewable resources (e.g. solar). However, the continuing divergence of living standards between the richest and poorest countries is probably the primary obstacle to reaching sustainability and to finding effective solutions to global environmental problems such as climate change.

In economic terms, questions of how income should be distributed have received much less attention in the US than questions of economic efficiency and national production. It is now acceptable politically for a large segment of the US population to live outside the mainstream of the market economy. Hence, it is not surprising that relatively little initiative has been shown in the US for solving problems of poverty in other countries. A bipolar political system has developed that protects the affluent and the truly destitute, but has not maintained the traditional paths for working one's way out of poverty. Atkinson calls this type of situation the "poverty trap."

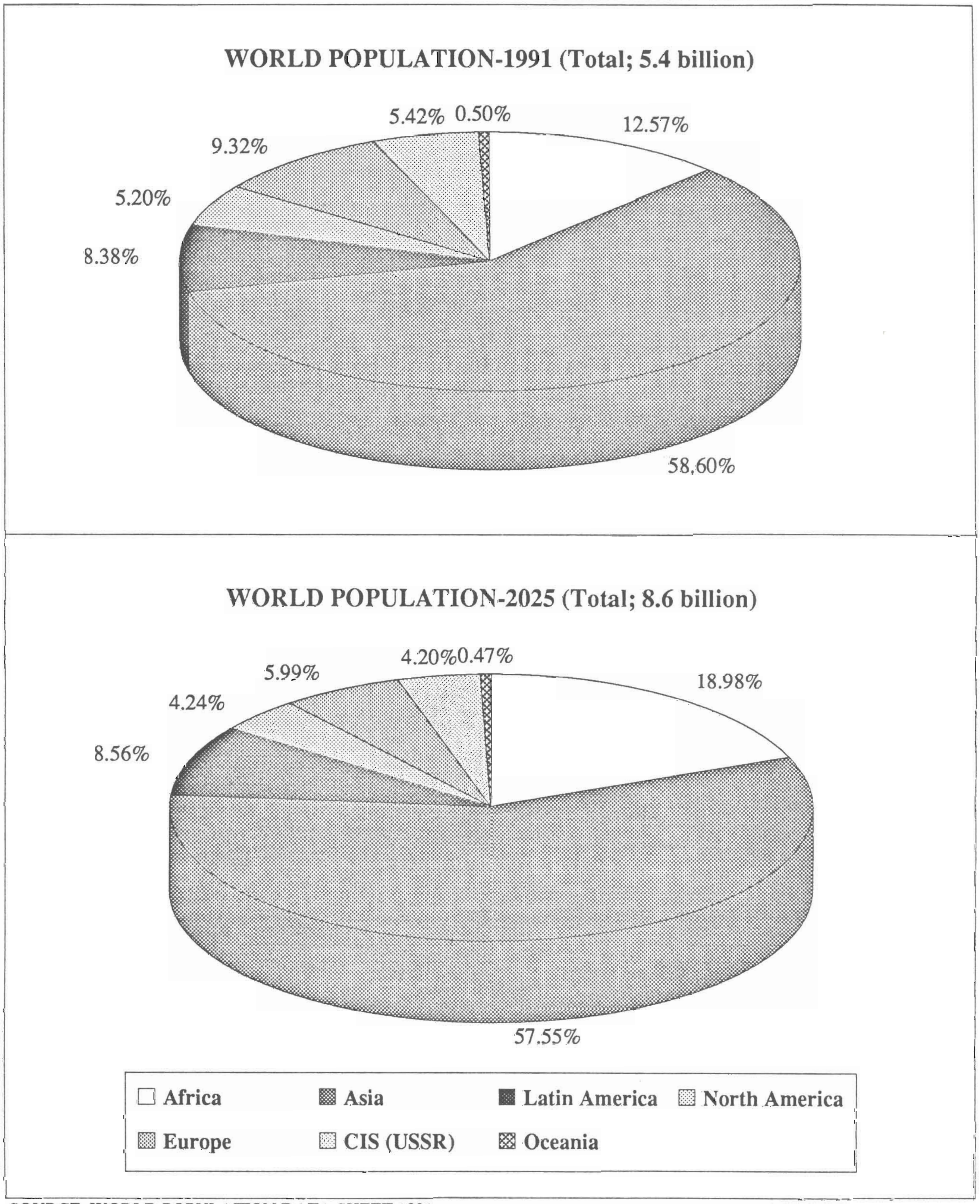
On a global scale, the lack of policies dealing with the distribution of income has resulted in famines and other localized forms of suffering. These situations occur even though total levels of production are adequate to meet basic needs [see Dreze and Sen]. Sen has proposed "entitlements" as a way to address distributional problems. (Entitlements refer to the ability to earn enough to cover basic necessities and not just the right to receive a minimum amount of food.) This concept could be developed further to cover not just food but other necessities such as energy, health, education and environmental quality. Given current political attitudes in rich countries, these proposals seem very utopian. Nevertheless, the reality of the growing world population can not be escaped.

Published projections imply that the current population of 5384 million will increase to 8645 million by 2025 (see Figure 1). The rate of growth of population is much higher in poorer regions, such as Africa, than in rich regions, such as Europe (see Figure 2). Figure 2 also shows the dramatic contrast between the regional distributions of income and population in 1991. Comparing the projections of population between the years 2025 and 2010, Europe is the only region to show a decline, and the average annual growth for Africa is still 2.4 percent for this period. This is double the corresponding rate of growth for total world population, which is still three quarters of the current rate of 1.7 percent per year.

As a first step to understanding the economic implications of increasing income per capita on the need for resources such as energy, it is useful to estimate demand models that explain how income is allocated to the purchase of different commodities. Although this type of analysis is one of the staples of applied economies, conventional models may be unsuitable for cross-country comparisons in much the same way that conventional models of agricultural production are unsuitable for analyzing climate change (see Section 3 above). Figure 3 shows the consumption patterns for a rich country, Japan, and a poor country, Tanzania. The importance of food in Tanzania relative to Japan is obvious. Expenditures in food correspond to two thirds of total expenditures in Tanzania but less than a quarter in Japan. Policies that decrease income inequality as well as increase total income will tend to increase the demand for food more than policies that stimulate growth but leave the distribution of income unaltered. Countries with the potential for expanding agricultural production stand to gain from policies that reduce income differentials in the world.

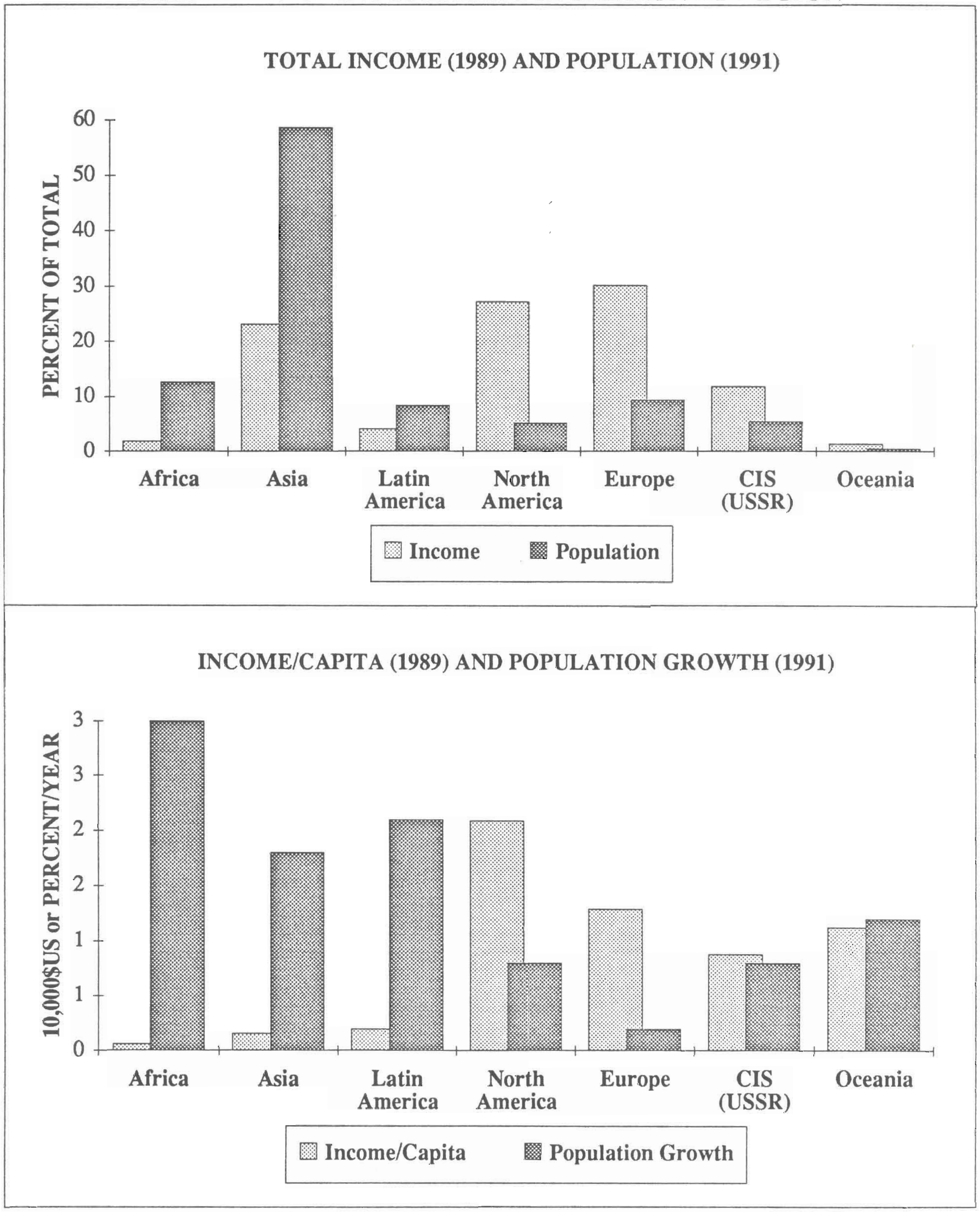
It is important for cross-country comparisons of consumption patterns to have models that are robust to a wide range of income levels. Many conventional economic models perform well for average situations (i.e. mean values of the sample used for estimation) but the economic properties breakdown under more extreme situations [see Christensen and Caves, and Tyrrell and Mount]. This breakdown is distinct from the conventional statistical problem of inaccurate predictions for values that are not close to the sample means.

FIGURE 1
ESTIMATES OF WORLD POPULATION BY REGION



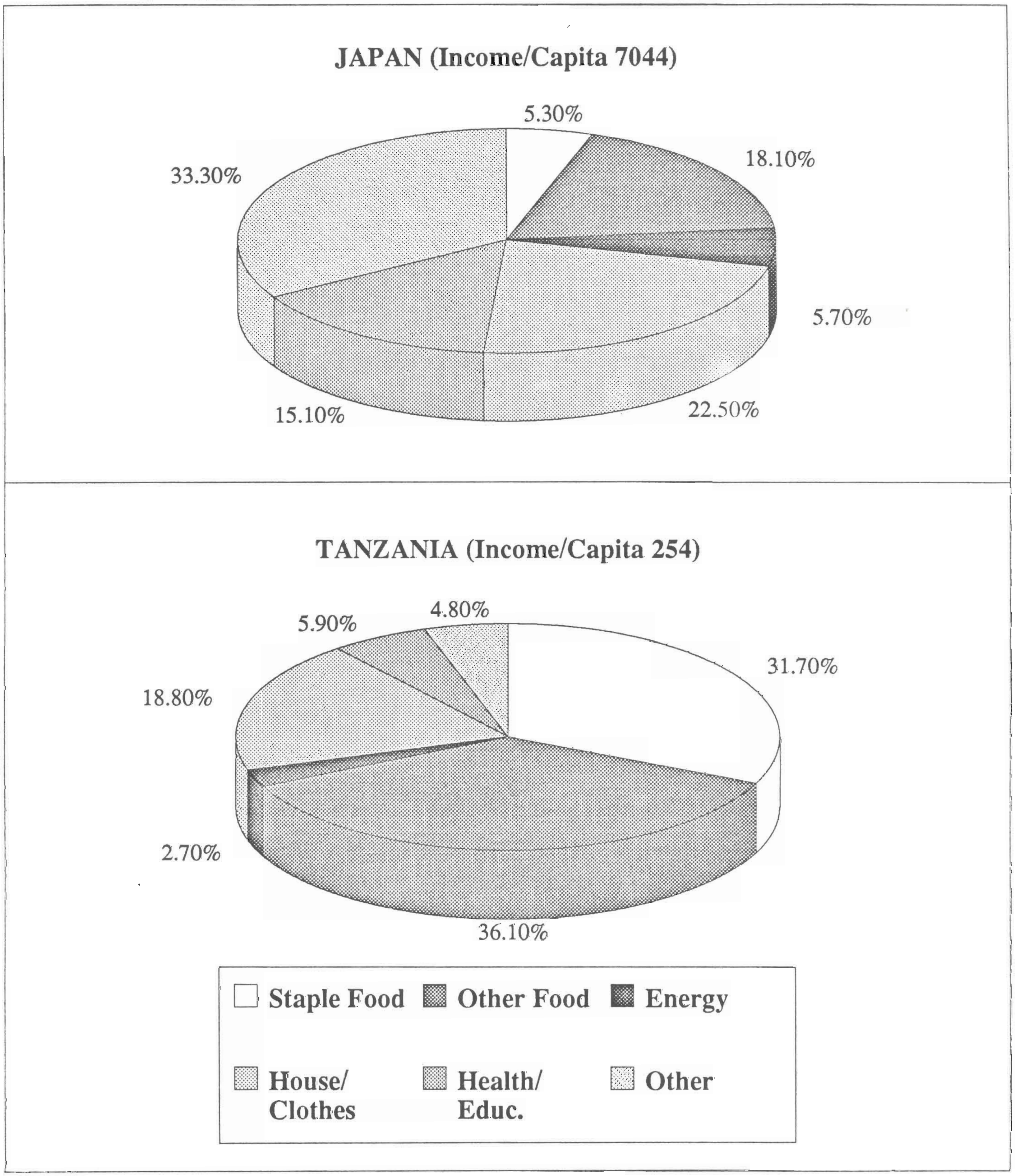
SOURCE: WORLD POPULATION DATA SHEET 1991
POPULATION REFERENCE BUREAU, INC.

FIGURE 2
ESTIMATES OF INCOME AND POPULATION BY REGION



SOURCE: WORLD POPULATION DATA SHEET 1991
POPULATION REFERENCE BUREAU, INC.

FIGURE 3
ALLOCATION OF HOUSEHOLD EXPENDITURES



SOURCE: United Nations

Using a generalization of the logit model proposed by Considine and by Dumagan and Mount, it is possible to estimate demand systems that are well behaved from an economic perspective (and data admissible) over a wide range of different systems (but not necessarily for all possible situations). Table 2 shows the direct price and income elasticities (percentage change of the quantity demanded in response to a one percent change of a price or income) for Japan and Tanzania derived from an estimated demand system for 44 different countries. Cross-price elasticities can also be derived but are not reported. The elasticities differ between the two countries because the levels of prices and income differ. In spite of these differences, both sets of elasticities obey the standard rules of economic logic. For example, the sum of income elasticities weighted by predicted expenditure shares is one. The implied behavior in Japan and Tanzania is very different. If incomes increased by the same proportion in the two countries, the consumption of staple foods would increase proportionally with income in Tanzania but only by a third of that amount in Japan. In addition, the demand for staple food is more responsive to price in Tanzania because expenditures form a larger part of the budget than in Japan. Demand systems make it possible to predict patterns of consumption under different economic conditions. Other factors, such as demographic, cultural and institutional differences, can be added to models if data are available. Demand systems are the primary tools for measuring economic welfare, and evaluating, for example, how given changes in world prices affect different regions of the world.

It was argued above that sustainability should not be interpreted as keeping things the same. Economic models of how production and consumption patterns change, as well as models of physical processes, are needed to understand environmental problems. For climate change, models of agricultural production and energy use are essential. On the production side, the conclusion in Section 3 was that economic models should be linked more closely to the physical resources that define production options and provide greater spatial disaggregation than is typically attempted in most analyses. On the demand side, models should deal with the distribution of income more effectively, and be more directly linked to demographic characteristics of the population.

6. CONCLUSIONS

The magnitudes and complexities of problems associated with the growth of population and income inequality are daunting. These problems can not be separated from the environmental problems of climate change. The use of fossil fuels is the major contributor to greenhouse gases, but is also an important factor in determining levels of income. Agriculture and forestry are the

Table 2

Estimated Demand Elasticities For Japan and Tanzania

JAPAN

	RELATIVE PRICES	PRICE ELASTICITIES	INCOME ELASTICITIES
STAPLE FOOD	1.70	-0.41	0.37
OTHER FOOD	1.23	-0.42	0.75
ENERGY	1.60	-0.66	0.80
HOUSE/CLOTHES	0.72	-0.65	1.00
HEALTH/EDUCATION	0.60	-0.74	1.24
OTHER	1.02	-1.14	1.23
TOTAL INCOME/CAPITA (7004)			

TANZANIA

	RELATIVE PRICES	PRICE ELASTICITIES	INCOME ELASTICITIES
STAPLE FOOD	1.75	-0.81	1.03
OTHER FOOD	1.95	-0.98	0.60
ENERGY	1.25	-0.71	0.98
HOUSE/CLOTHES	1.91	-0.73	1.23
HEALTH/EDUCATION	0.96	-0.41	1.47
OTHER	2.55	-1.46	1.46
TOTAL INCOME/CAPITA (254)			

Source: D. Rothman, personal communication 1/9/92.

most important economic activities that could be adversely affected by climate change. These sectors are the primary sources of well-being for a majority of the world's population. If food is expensive, the effect on the cost-of-living is much higher for poor people because the proportion of their income spent on food is larger than it is for rich people.

It is unfortunate that the issues of population growth and income inequality are not central to government policy in the US. Public concern about the environment is greater than government concern at the present time, and innovative environmental policies are being developed in California and New York State rather than in Washington, DC. Twenty years ago, the US took leadership in improving air quality through adopting The Clean Air Act in 1970. This act set strict standards on emissions from automobiles and new stationary sources such as power plants.

The Clean Air Act is still the main legislative instrument for improving air quality in the US. Although little happened during the last decade, the act was updated in 1990 to deal more effectively with emissions associated with acid rain and urban smog. There is still no equivalent legislation that deals with climate change. A possible reason for this is that acid rain and, to some extent, urban smog can be addressed by cleaning up emissions. In contrast, it is very expensive to eliminate carbon dioxide from emissions, and consequently, the most economically efficient ways to deal with climate change are to use less fuel through improved efficiency and to offset emissions of carbon through reforestation. In spite of this situation, even simple economic policies for encouraging more efficiency, such as putting higher taxes on gasoline, appear to be much harder to implement in the US than in other industrialized nations.

There are no simple solutions for dealing with the interrelated problems of climate change, economic inequality and population growth, but five issues should be considered as a basis for establishing general objectives among nations for future environmental policies. These issues are obvious to many people but are not yet reflected adequately in government policies in the US. The issues are:

1. Limiting the growth of population is essential.

A common assumption is that higher levels of economic growth will automatically result in lower rates of growth of population. However, the population problem is important enough to warrant more direct policies, particularly given recent scientific advances in methods of birth control (e.g. Norplant and RU-486). Better education about family planning and a general improvement in the status of women throughout the world are required to ensure success.

2. More handouts are not the solution.

Social programs have evolved into systems that provide a safety net for the very poor. In some situations, it appears sensible for people to be worse-off economically so that they qualify for government handouts. This is simply counterproductive and antagonizes people who are trying to make their own way without government support. There should be a return to traditional goals of providing economic opportunities for the majority of people. It is the responsibility of rich countries to see that these principles are applied globally.

3. Sustainability is not just for poor people.

Industrialized countries have developed very effective ways to use large quantities of resources such as fuels. Developing sustainable economic systems will require that industrialized countries become less extravagant in the use of resources as well as encouraging poor countries to manage environmental problems better. Changes are needed in both rich countries and poor countries to attain viable economic systems for the future. Biotechnology and computing technology both offer the potential for increasing economic productivity in environmentally benign ways.

4. Fuel prices should include environmental costs.

Many environmental problems, such as climate change, acid rain and urban smog, are related to emissions from using fossil fuels. Prices paid for fuels should reflect these costs as well as the direct costs of extracting, processing and distributing the fuels. Since energy efficiency is often embodied in the type of capital equipment used, it is essential that poor countries have access to efficient technology at affordable prices to allow for economic growth without exacerbating environmental problems. Reducing net emissions of greenhouse gases from agriculture can supplement but not replace energy efficiency as a solution to climate change.

5. Uncertainty is inevitable.

All four issues mentioned so far can be characterized as having high levels of inertia. New policies to lower birth rates, for example, will only reduce population size gradually. Policies adopted now to deal with climate change will affect the next generation more than the current one. This means that uncertainty can not be avoided in making policies even if the scientific knowledge of the physical processes that govern climate change was perfect.

The real challenge for the United Nations Conference on Environment and Development is whether policy makers will be willing to agree on objectives for the future and to link these objectives to action now. Sen's concepts of entitlements is one way to define future economic and environmental objectives if the challenge is accepted, but currently, there is little reason for optimism that this will be the case. Given the worldwide prevalence of urban smog as an important environmental problem, this is a good issue to focus on to initiate new policies. Solutions to urban smog must incorporate using fuels more efficiently, and this would be a step towards reducing emissions of carbon dioxide that contribute to climate change.

One aspect of climate change that most people would accept is the need for better scientific understanding of the problem. Additional research should involve economic and social scientists as well as physical scientists. For example, better understanding is needed of how people adapt to changes. An important implication of climate change is that industrialized economies are the major source of greenhouse gases, and must introduce changes to become environmentally stable. A major obstacle to making these changes is that industrialized countries will not be the first to suffer from the adverse effects of climate change, and they can probably afford to adapt to the changes (e.g. turn up the air conditioners).

The basic requirements for social and economic research relating to climate change are to recognize the global and long-run nature of the problems, and the interdependencies that link agricultural production, energy use and economic welfare. These issues justify research regardless of whether or not climate changes occur. If new analytical approaches are developed for these economic problems, it will be relatively simple to augment them to incorporate the effects of climate change as better information from the physical sciences becomes available.

Objectives for social and economic research on climate change can be grouped as follows:

1. Better spatial data are needed on commodity flows and the resources that place limits on economic production, particularly agriculture and forestry. Modern computing technology makes it feasible to improve access to existing data for this type of research [see Mount 1992b].

2. Economic models of production should be linked explicitly to physical resources as well as to economic variables such as prices. This is necessary to understand how climate affects agricultural production and how agriculture contributes to net emissions of greenhouse gases.

3. Economic models of demand should consider the distribution of income because of its importance for measuring welfare effects and determining the aggregate demand for necessities such as food and energy.

4. Better estimates of environmental costs, such as adverse health effects, are required to understand how to internalize these costs in market transactions, and to evaluate the benefits of different policies that affect climate change.

5. The role of energy in generating income should be understood more completely to measure and evaluate the effects of energy conservation. Better data should be collected on how efficiently fuels are used [see Mount 1991].

6. New methods are needed to understand dynamic adjustment processes in economics. Most of the existing analyses of global problems (e.g. trade distortions) are based on comparative statics.

7. New methods are needed for developing policies that recognize the uncertainty surrounding climate change and other environmental problems.

Considering these seven topics, the first is probably the most important from a practical point of view. Good research on complex environmental problems requires good data. Even when suitable data exist, they are often not available for research due to institutional restrictions or inadequate documentation. Given modern computing technology, access to these data could be established for researchers via national and international networks. Providing better access to these data should be one of the goals of the United Nations Conference on Environment and Development (UNCED) next June.

If the importance of the interdependencies linking energy use, agriculture and the environment to population, income and welfare is recognized, there is a chance that new policies for climate change will emerge at UNCED. Given the uncertainty surrounding the physical and social processes relating to climate change, it would be sensible to establish a schedule for reviewing and updating these policies on a regular basis. A necessary step in this process is to realize that the sustainability of economic systems in the future will require changes in both industrialized and developing nations. Rich countries must become less extravagant in the use of resources such as fuels, and poor countries must introduce policies to limit the growth of population. These two steps are essential components of a viable policy to deal with climate change and the growing divergence of incomes between rich and poor countries.

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