Chapter 5. Climate Change and Longrun Agricultural Production

Climate change is only one of several factors that may affect global food production in the future. Rough estimates suggest that over the next 50 years or so, climate change may be a less serious threat to meeting global food needs than other constraints on agricultural systems. However, climate change could well aggravate regional agricultural problems related to these other constraints. Various authors have considered and debated how regional resource limits might constrain world agriculture from meeting the food needs of a growing population in specific regions (Bongaarts, 1994; Islam, 1995; McCalla, 1994; Norse, 1994).

Specifically, population, income, and economic growth could all affect the severity of climate change impacts in terms of food security, hunger, and nutritional adequacy. If climate change adversely affects agriculture, human effects are likely to be more severe in a poorer world with more people near hunger. In a prosperous economic environment, consumers may suffer a greater economic loss but be less likely to suffer the chronic effects of hunger.

Climate change is also likely to affect other resource problems. Weeds, insects, and other agricultural pests are likely to be redistributed, with some studies showing possible poleward expansion of pest ranges. If this occurs, there may be a greater demand for chemical pesticides unless equally effective and less environmentally risky alternatives are found. Warmer temperatures will also increase water demands for crop growth. In areas where increased water demand is not offset by additional rainfall or irrigation water supplies, climate change may further intensify the competition between growing urban, industrial, recreational, environmental, and agricultural users of water.

Finally, fostering the ability to adapt to changing climate will involve improving the ability of agricultural systems to respond to generally changing and uncertain conditions largely through existing policy instruments such as support for agricultural research, trade policy, water management, and commodity program and pricing. Few if any climate change policies will be distinct from broader issues improving agricultural productivity while minimizing environmental disruption. So-called "no-regrets" improvements in the agricultural system may be made possible when current market signals can be corrected to provide a more accurate reflection of resource scarcity and changing comparative advantage among regions and countries.

This final chapter begins by discussing interactions between economic, demographic, and environmental factors affecting future food security. The next section examines whether global food scarcity, and hence the potential costs of climate change, might be more severe several decades from now. The key issue is whether increases in agricultural supply, which will be determined both by productivity growth and the availability of inputs, can keep pace with rising demand, as appears to have been the case in the past. Existing studies are generally optimistic concerning the development and adoption of yield-enhancing techniques, and increasing quantities of agricultural inputs, to meet agricultural demand over the next 70 years. However, such projections are subject to very large standard errors. For example, projections are highly sensitive to assumptions about the average annual rate of agricultural productivity increase over the period, and there is much scientific uncertainty over potential environmental feedbacks. Moreover, a substantial expansion of infrastructure and irrigation in rural areas of the developing world will be required.

Even though they offset each other in aggregate, there are potentially significant winners and losers from climate change. Today's poor countries are likely to be the biggest losers, due to the substantial share of agriculture in their gross domestic product, their location in the hotter, drier climates, and limited ability to adjust their farming practices and locations (see chapter 2). These considerations raise questions about whether it is appropriate to aggregate impacts over different regions, and about possible compensation measures. Moreover, climate change threatens to exacerbate problems of hunger and malnutrition, since these are concentrated in developing countries. However, the proportion of the world's population suffering from such problems could be lower by the middle of next century, even under modest scenarios for real income growth. Much will depend on whether countries pursue policies that are conducive to innovation and investment throughout the economy, and whether they are rich enough to substitute imported food commodities for losses in domestic production caused by climate change. By far, the region of greatest concern is Sub-Saharan Africa, where real income growth is predicted to be sluggish, and rapid population growth threatens to compound problems of hunger and malnutrition.

Factors Affecting the Future World Food Situation

Some commentators (Erlich and Erlich, 1990) worry that rising demand for food over the next century, due to population and real income growth, will lead to increasing global food scarcity, and a worsening of hunger, malnutrition, and associated problems in developing countries. It is argued that most arable land is already under cultivation, and only a small amount of less fertile land remains to meet additional future needs.

The crucial issue is whether agricultural supply can keep pace with increases in future demand. This depends both on the scope for raising agricultural productivity (including reducing waste during distribution) and on the future availability of inputs used in the agricultural sector (land, labor, machinery, water resources, fertilizers, etc.). In the past, growth in supply has more than offset growth in demand, leading to declining global food scarcity and falling real prices for food commodities (although there has been substantial short-term variability in prices). For example, an index of food commodity prices by the World Bank (1992) shows an overall decline of 78 percent between 1950 and 1992. This trend showed no sign of faltering during the 1980's, when grain production increased by 2.1 percent per year, while population grew by 1.7 percent. However, these figures may in part reflect the spread of agricultural protection policies, that is, the underlying trend in food prices may not be declining so markedly. Moreover, the aggregate figures may mask a seriously deteriorating situation in some regions–even if global food scarcity is declining, malnutrition and the threat of famine may still be increasing in particular countries. Finally, just because global food scarcity appears to have fallen in the past does not mean it will continue to do so.

Table 5.1—Projections of real income

Region	GDP growth 1980-2000	GDP growth 1980-2060
	Percent	
World	2.9	1.8
Developed	2.6	1.6
Developing	4.3	2.4
Africa	4.6	3.0
Latin America	3.9	2.1
South East Asia	4.7	2.4
West Asia	4.4	2.8
	Per capita GDP 1990	Per capita GDP 2030
	1990 US$	
Sub-Saharan Africa	340	500
Asia and the Pacific	490	2,000
Latin America	2,180	5,500
Middle East and N. Africa	1,800	4,000

Source: Compiled by Economic Research Service from Fischer and others (1994) and World Bank (1992).

Future Population and Income Growth Scenarios

Most models used to project future population levels take the current population–with its age and sex composition, and age-specific fertility and mortality rates–as given. These models tend to yield reasonably accurate forecasts for up to three decades, since birth and death rates change slowly over time. However, projections further into the future require speculative assumptions about age-specific fertility and mortality rates, subjecting projections to a large degree of uncertainty. There is a general consensus among forecasters that world population will be 8-9 billion by 2025 (see McCalla, 1994). Based on extensions to projections by the United Nations (UN, 1994), Parikh (1994) estimates world population will be 10.3-12.8 billion by 2050, while studies projecting the impacts of climate change around the middle of the next century (Fischer and others, 1994; Rosenzweig and Parry, 1994; Chen and Kates, 1994) have assumed world population levels of approximately 10 billion. Nearly all of the predicted population increase (95 percent) is in the developing world, and the rate of growth is greatest in Africa, where population is projected to increase three- to five-fold over the 1990 level.

Over 1980-2060, real income growth is expected to be higher in the developing countries (2.4 percent per year) than in the developed world (1.6 percent) (table 5.1). However, in per capita terms, the picture is less optimistic in the developing world. The World Bank (1992) predicts that real per capita income will only increase by $160 in Sub-Saharan Africa to $500 in 2030 (table 5.1).

Predictions of Food Commodity Demands

Estimating future food demand is difficult in a number of respects. For example, as income increases, the share of the budget spent on different food items changes significantly.[19] Also, the amount

[19] That is, the income elasticity of demand varies substantially across commodities. For example, potatoes are thought to have a negative income elasticity in developed countries, while that for quality meats is greater than unity.

of food an individual can consume has physical limits; therefore, assuming food demand is as linear as income is inappropriate. Parikh (1994) predicts caloric demands to increase 150-300 percent by 2050 over 2000 levels. The projected demands for cereals in Fischer and others (1994) are consistent with these estimates (table 5.2). Even though predictions become subject to much uncertainty several decades from now, there is broad consensus on the types of models used for such forecasting (McCalla, 1994). The bulk of the increase in demand comes from the developing world. In developed countries, the average person is already well fed, so an increase in income will not add much to the demand for basic food commodities.

Table 5.2—Projected demands for agricultural products

Year	Cereals		Dairy	Sugar
	Parikh (1994)	Fischer and others (1994)	Parikh (1994)	Parikh (1994)
	Million tons			
2000	2,082	1,992	642	286
2020	2,306-2,763	2,510	641-781	219
2040		2,950		
2050	3,262		856-1,347	324-523
2060		3,285		

Compiled by Economic Research Service from the studies listed above.

The Potential for Agricultural Supply to Satisfy Demand

Parikh (1994) projects food demands in developed countries (U.S., Canada, Europe, Japan, Australia and New Zealand) to increase modestly above their current levels. Mitchell and Ingco (1994) predict that net grain exports of the developed countries will increase from their current level of 117 million tons to 194 million tons in 2010.

Table 5.3 shows estimates from a Food and Agriculture Organization (FAO) study by Higgins and others (1982) of the maximum population that could be supported by the available quantity of land and other resources in developing countries (except China). If a high level of inputs is devoted to agriculture, then these countries could, on average, support 5.11 people per hectare, which, given the total land availability of 6.495 billion hectares, implies a total population of 33.2 billion! The projected demands in Parikh (1994) imply a 50-percent higher calorie intake than in the FAO study and, adjusting for this, the population carrying-capacity of developing countries is still 22.1 billion. Therefore, in theory, the production potential for meeting projected agricultural demands does exist. However, the key questions are what might be the constraints to developing more agricultural land, to what extent can the need for this expansion be reduced by the invention and adoption of productivity-enhancing technologies, and what are the environmental costs and losses of biodiversity.

Land Resources

As emphasized by Crosson and Anderson (1994), a potentially important constraint on increasing the supply of cropland is that, compared with currently cultivated land, much of the uncultivated land is in areas that are poorly connected to existing domestic and foreign markets (for example, the tropical rainforest areas of Latin America). Therefore, a willingness to invest in infrastructure may be necessary before these areas become commercially viable.

There are also a number of important environmental constraints and feedbacks that might reduce the future productivity of agricultural land. Unfortunately, data on the importance of soil erosion (which is primarily due to water and wind erosion) on agricultural yields in developing countries are very poor. When regional soil erosion losses are expressed in terms of billions of tons per year, they imply great risk to food production. Per hectare, the losses might be modest and correctable by improved farming techniques, soil conservation, and productivity improvements. For example, one study for the United States by Crosson (1992) suggests that over the long run, these losses are typically small relative to the gains from technological progress. However, these findings should be interpreted very carefully. Soils in tropical areas are in general more vulnerable to erosion than those in temperate regions, and a given amount of erosion is likely to induce a greater decline in soil productivity. Moreover, farming practices that continuously deplete soils are ultimately unsustainable. Thus, although it would be wrong to suggest that soil erosion will inevitably become worse and exacerbate food production problems caused by climate change, complacency is also unwarranted.

Another potential threat is salinization of soils and water. This is mainly a problem for irrigated areas, but also occurs in hot, dry climates where evaporation can increase salt concentration in soils. In irrigated areas, salinization is usually the result of poor

Table 5.3—Developing country population-supporting capacities

Location	Total land area	Population in 2000	Persons per hectare in 2000	Potential population-supporting capacity in 2000	
				Low inputs	High inputs
	Million hectares	*Millions*		*Persons per hectare*	
Total	6,495	3,590	0.55	0.86	5.11
Africa	2,878	780	0.27	0.44	4.47
SW Asia	677	265	0.39	0.27	0.48
S. America	1,770	393	0.22	0.78	6.99
C. America[1]	272	215	0.79	1.07	4.76
SE Asia	898	1,937	2.16	2.74	7.06

[1] Includes Mexico.
Compiled by Economic Research Service from Parikh (1994).

construction or inadequate maintenance of canals, or excessive use of water (primarily because of inappropriate pricing). The end result is waterlogging, salinization, reduced crop yields, and ultimately the permanent loss of agricultural land. The UN (1992) estimated that 11.5 million hectares per year are lost because of this process, with another 30 million hectares at risk.

Desertification in dry areas threatens Africa and Asia, as well as some areas in Europe and North and South America (table 5.4). Of the 3,569 million hectares that have been degraded in dryland areas of the world, 29 percent is in Africa and 37 percent in Asia. Recently, a scientific consensus (Nelson, 1988; Bie, 1990) shifted toward the view that the incidence of desertification is a lot less than originally thought, and that the contribution of desert margins to food production is small. For example, low rainfall areas accounted for only 12 percent of domestic cereal production in Sub-Saharan Africa and 1 percent in Asia in the early 1980's (Norse, 1994).

Can the quantity of cultivated land be increased in an environmentally sustainable way? Sustainable agricultural production has often been difficult to achieve on nutrient-poor soils. For example, in Brazil's Amazon region, government policies in the 1980's encouraged the conversion of tropical forests to crop and livestock production. Much of this land has since been abandoned (Binswanger, 1989; Mahar, 1989; Repetto, 1988). Reducing the threat of abandonment requires careful study of the local ecosystem prior to conversion.

Finally, the environmental costs from land clearance, particularly the threat to biodiversity in tropical rainforests, are of concern to developed countries. Although efforts to persuade governments in tropical areas to slow deforestation have so far had limited success, outside pressure backed up with financial incentives might be an increasingly important constraint on the future development of potential agricultural land.

Expansion of Irrigation

Expanding irrigation will require both increasing the efficiency of existing systems and the building of new systems. There is much potential for increasing efficiency. Repetto (1986) has documented the enormous waste in existing public irrigation systems in both the developed and developing world, caused by policies that price water well below the costs of supply, and the resulting sparse investment to reduce seepage from canals.

Table 5.4—Extent of desertification and dryland degradation

Region	Total dryland area used in agriculture	Area degraded	Percentage of dryland area degraded
	Million hectares		*Percent*
Africa	1,430	1,050	73
Asia	1,880	1,310	70
Australia	700	380	54
Europe	146	94	65
N. America	578	429	74
S. America	420	306	73
Total	5,154	3,569	69

Compiled by Economic Research Service from Norse (1994).

A difficulty to expanding irrigation in developing countries is the pervasiveness of small-scale farms, for which investment in irrigation and drainage capacity is often not economical. One approach is to encourage cooperation among farmers to share investments in irrigation. However, the most promising longrun solution is steady economic growth, which will lead to a migration of workers from agriculture into other sectors of the economy and enable consolidation into larger scale farms.

At present, not much is known about how climate change might affect water supplies and irrigated agriculture. However, changes in precipitation and snowpack storage could cause droughts or floods that may render some irrigation systems ineffective, while overwhelming others.

Technological Innovation in Agriculture

The invention and diffusion of yield-enhancing technologies and farm practices has been a more important factor in raising global agricultural output over the last 50 years than the expansion in quantities of land and water (Crosson and Anderson, 1994). Biotechnology offers hope for continued development of new crop varieties that raise productivity by increasing resistance to pests, drought, and heat, and by increasing responsiveness to nutrients and moisture (Parikh, 1994). Presently available high-yield varieties often suffer from inefficient applications of chemicals and water, but new information technologies can promote more precise applications of inputs (Ruttan, 1992) and reduce the buildup of undesirable chemical residues in soils. Thus, Parikh (1994) concludes that there are few constraints, from the viewpoint of scientific knowledge, to prevent a steady increase in the rate of agricultural productivity. However, climate change may reduce biodiversity, and with it, the availability of germplasm, and the ability to generate new biotechnology.

Technological Adoption in Agriculture

Even if progress continues to be made on developing better crops and farming techniques, individual farmers may be slow to adopt them for a variety of reasons. Reilly (1995) identifies a range of adoption times for different adaptation measures. Variety adoption, conversion of land to agriculture, and transportation system adaptations can take place quickest, in as little as 3 years, while dams and irrigation projects take the longest time to implement, from 50 to 100 years. In underdeveloped rural areas, people may lack the information or education necessary to take advantage of improved agricultural methods. They also often have inadequate farm equipment to relieve labor shortages and allow timely field operations; face erratic supplies of complementary inputs like seed, chemicals and water; and confront an inadequate transportation infrastructure (Feder and others, 1985). Rural property rights are often poorly defined, and laborers may lack incentives to care about the future productivity of land they farm (Lee and Stewart, 1983). Thus, government has a potentially important role in providing information programs; developing new agricultural technologies, seed varieties, and crops; and extending property rights (Reilly and others, 1994; Repetto, 1988).

On the other hand, government policies for diffusion of technologies and techniques should be designed to work in harmony with other government policies. For example, taxes on investment income, even if only formally levied on wealthy households, reduce the supply of savings and make it more difficult for farmers to borrow in order to purchase new capital goods. In centrally planned and less developed economies, the capital market may barely function, which can effectively rule out big investments for small-scale farmers (Feder and others, 1985).

The scope for increasing farm output and reducing waste in the former Soviet Union and Eastern European countries, in particular, is thought to be substantial. Since 1980, agricultural production in this area has stagnated under political and economic uncertainties. Reforms that decentralize agriculture, increase private ownership of land, allow importation of new technologies, and promote the sale of farm products in world markets are likely to increase efficiency and production dramatically. Thus, for example, Mitchell and Ingco (1994) predict that Eastern Europe and the former Soviet Union will change from a net importer of grains in 1990 (of 27 million tons) to a net exporter (of 16 million tons by 2010).

Predictions of Agricultural Outputs in 2060

In the absence of climate change, most models do not project a substantial increase in food scarcity at the global level over the next few decades. For example, by 2060 Fischer and others (1994) predict that food commodity quantities will have increased by two to three times over their 1980 levels.[20] Despite a 240-percent increase in world population, global food

[20] Their model uses a general equilibrium framework in which various country/region models are linked by trade, world market prices, and financial flows (known as the Basic Linked System, BLS).

scarcity in 2060 is slightly less than in 1980, reflected by a slight downward trend in real food prices.

However, these long-range predictions are subject to great uncertainty; in particular, results from such models are usually very sensitive to assumed rates of agricultural productivity increase, real income growth, and population growth. Hence, results should be regarded with a good deal of caution until the completion of further sensitivity analysis.

Studies of Climate Change in Future Scenarios

Fischer and others (1994) examine impacts of climate change (from a doubling of atmospheric CO_2) on world agricultural production in 2060, using the GISS, GFDL, and UKMO scenarios discussed in the previous chapters.[21] Assuming no adjustment at the farm level or change in market prices, a 22 to 34-percent reduction in global cereal yields is predicted when there is no CO_2 fertilization effect.[22] These results are broadly consistent with those in Darwin and others (1995), which estimates that current global cereal supplies would fall by 19-29 percent under comparable conditions. Allowing for full economic and farm-level adjustment, global cereal output changes by -6 to 1 percent in the Fischer and others (1994) model, while in Darwin and others (1995) it changes by 0.2-1.2 percent. The preliminary conclusion from Fischer and others (1994) is that the proportionate effects of climate change on agricultural output several decades from now will not be substantially different from the effects had climate change been imposed on today's world.

Moreover, given the 70-year timeframe, a supply gap of even 10 percent is not that large, and could be closed by relatively minor changes in the assumed rate of technological progress. For example, the base case in Fischer and others (1994) assumes that world cereal yields increase by 0.8 percent annually, whereas the rate for 1960-90 was around 1.5 percent. If instead Fischer and others (1994) had assumed a rate of 1 percent, then the whole of a 10-percent supply gap in 2060 would be offset.

[21] The results in Fischer and others (1994) are the same, though somewhat more detailed, as in Rosenzweig and Parry (1994), since both studies use essentially the same model and climate change scenarios.
[22] Cereals are the most critical crops for people threatened by food security problems, and therefore tend to be studied more often than other crops.

Table 5.5—Projected global production of food commodities in 2060

Commodity	1980	2000	2020	2040	2060
			Million tons[1]		
Wheat	441	603	742	861	958
Rice	249	367	480	586	659
Coarse grains	741	1,022	1,289	1,506	1,669
Bovine and ovine meat	65	83	105	123	136
Dairy	470	613	750	877	997
Other animal products	17	25	33	41	48
Protein feed	36	52	64	76	85
Other food	225	326	433	538	629
Non-food	26	34	41	47	52
Agriculture	310	438	572	700	810

[1] Wheat, rice, and coarse grain in million tons; bovine and ovine meat in million tons carcass weight; dairy products in million tons whole milk equivalent; other animal products, and protein feed in million tons protein equivalent; other food in billion 1970 U.S. dollars.

Compiled by Economic Research Service from Fischer and others (1994)

Climate Change and Agricultural Sustainability

Recent debate over the sustainability of agricultural practices has been confused by at least three different notions of sustainability (Ruttan, 1994):

- One definition is the ability to meet increasing demand for agricultural products over the long run. On this basis, the tentative conclusion from the above discussion is that world agriculture probably will be sustainable over the next few decades, despite the threat of climate change.

- A more narrow definition is that an agricultural system is only sustainable if it does not deplete the stock of environmental resources passed on to future generations. To the extent that new agricultural land is developed (rather than through productivity improvements) to meet expanding future demand, then this definition of sustainability will be compromised, and compounded by the threat of climate change.

- An even more stringent definition emphasizes sustaining not only the stock of tangible resources, but also a broad range of community values. Proponents of this view regard the break- up of rural communities caused by consolidation into larger, more mechanized farms as reducing the inheritance of future generations in some aesthetic sense.

Agricultural and natural resource economists usually have in mind the first definition. The other two definitions are problematic because they rule out any investment that depletes the natural environment (or rural community), even though the costs to future generations may be far less than the benefits from inheriting a larger agricultural base.

Some Distributional Implications of Climate Change

Although the aggregate impact of climate change on world agriculture may not be that large, there could be sizable distributional effects. Indeed, it is the poorer countries, where the problems of hunger and malnutrition are concentrated, that are likely to lose most. However, since these problems primarily result from low income, rather than from constraints on agricultural production, they could be much less acute in 60 years, even under modest scenarios for per capita income growth.

Reasons Why Developing Countries are the Most Vulnerable to Climate Change

- **The level of economic development**

As per capita income rises, agriculture's share of gross domestic product declines, because as people have more income they spend a smaller proportion of it on food. Thus, an across-the-board percentage reduction in agricultural income caused by climate change would be regressive, in the sense that the proportionate income loss for a poorer country is greater. Therefore, given that food expenditure in the United States is around 15 percent of the household budget and around 70 percent in many African countries, agricultural losses from climate change threaten to increase global inequalities in income.

However, this could change dramatically in several decades when climate changes are predicted to become significant, depending on the economic growth of the world's poorest countries. Real income is expected to grow rapidly in Asia, modestly in Latin America, and slowly in Africa (table 5.1). Population growth and agricultural technology diffusion will affect how income growth affects vulnerability to climate change impacts, but the relative importance of agriculture in these regions has declined as they grew during 1965-90 (table 5.6).

Table 5.6—Agricultural income as a percentage of GDP

Region	1965	1990
Sub-Saharan Africa	40	32
East Asia	37	21
South Asia	44	33
Latin America and the Caribbean	16	10

Compiled by Economic Research Service from Norse (1994).

Higher personal income reduces vulnerability to climate change in many respects. For example, since food expenditure is a smaller share of the household budget, in periods of high food prices people are better able to cut back on other goods to maintain food consumption. Also, a higher level of income reduces dependency on regional food production. Thus, if a particular community suffers food production losses, people are better able to purchase food from other regions in the country. Similarly, people are able to afford more imported goods. In a more developed economy, imports can be paid for by shifting resources away from domestic food production into, say, manufactured exports.

- **The sensitivity of agricultural production to local climate**

The sensitivity of agriculture to climate change depends on its direction and magnitude. Higher latitude countries such as Canada are predicted to benefit from a warmer climate, since this could open regions that are currently too cold to farm. Conversely, tropical countries are likely to be losers in a warmer, drier climate.[23] Again, this threatens to compound global income inequalities, since countries located in the Tropics tend to be poor, while richer countries are generally in more temperate climates.

The potential scale of the impacts depends on:

(a) How healthy the agricultural land is. Areas where the soil is fragile, because of intensive farming, salinization, waterlogging, and wind erosion, will typically be much more sensitive to climate change than soils that have been protected and allowed to replenish. The soils in substantial parts of many developing countries have marginal physical characteristics. Further, tenant farmers may have little incentive to care for the land (farmed through share-cropping arrangements), and property rights may be poorly defined.

[23] In a sense this is a perverse result, since the amount of warming is expected to be lower in the Tropics than the polar regions.

Table 5.7—The effects of climate change on welfare

Region	With CO_2 and adaptation	With CO_2 and no adaptation	No CO_2 and no adaptation
		$ million (1989)	
< $500 per capita	-210 to -14,588	-2,070 to -19,827	-56,692 to -121,063
$500 - $2,000	-429 to -10,669	-1,797 to -15,010	-26,171 to -48,095
$2,000 but still developing country	-603 to -1,021	-328 to -878	-3,870 to -6,661
E. Europe/former USSR	2,423 to -4,875	1,885 to -10,959	-12,494 to -57,471
OECD[1]	5,822 to -6,470	2,674 to -15,101	-13,453 to -21,485
Total	7,003 to -37,623	-126 to -61,225	-115,471 to -248,124

[1] Includes United States.
Source: Reilly and others (1994).

(b) The ability to adapt to a changing climate. Regional adaptability depends on how easy it is to shift agricultural activities to other parts of the country. Typically, populations are more mobile in wealthier countries since infrastructure is more developed and household conveniences reduce the personal reluctance to relocate. At the farm level, changing planting and harvesting dates, crop varieties, and irrigation supplies in response to local climate changes is easier on more technologically advanced farms (see chapter 2).

Again, these would be important considerations if climate change were imposed on today's global economy. However, over the next century, real income growth and the development and adoption of new technologies may reduce the sensitivity of agricultural production to climate change in many developing countries. For example, if workers migrate out of agriculture and into other sectors, some marginal lands that are currently vulnerable to environmental degradation and climate change may go out of crop production, and the consolidation into larger and more capital-intensive farms can make it easier to invest in technologies that reduce the sensitivity of production to the local climate (Feder and others, 1985).

- **The ratio of population to available arable land**

A country with a higher population density may be more at risk from climate change because more people are dependent on given agricultural resources. Since many of today's poor countries also suffer from overcrowding, the impacts from climate change may exacerbate income inequalities. However, higher population densities can spur economic growth by exploiting economies of scale. For example, a larger labor force allows for more specialization of labor, that is, overall productivity increases when people specialize in what they are most efficient at. High population densities did not prevent the development of Western Europe and Japan. Thus, although population growth can lower per capita income and hence regional food security, the link is more ambiguous, depending on the particular stage of economic development indicated by the level of per capita income. Unfortunately, Africa, which has small prospects for aggregate income growth, also has large population growth, which could combine to provide a severe constraint to increasing per capita food consumption (Parikh, 1994).

Some Evidence on Differential Distributional Impacts

Empirical analysis suggests that developing countries are likely to lose most from climate change. Empirical studies use broadly defined country groups, since region-specific climate changes cannot be reliably predicted at this stage. Table 5.7 shows Reilly and others' (1994) estimates for changes in producer and consumer surplus resulting from climate change scenarios imposed on today's world, where the developing countries are grouped into three categories defined by per capita income. In all climate change scenarios, and regardless of the amount of farm-level adjustment or whether the CO_2 fertilization effect is included, the developing countries lose, and by far more than any losses in the OECD countries. For example, when the CO_2 fertilization effect and adaptation are included, economic welfare in the OECD countries changes between -$6.5 and $5.8 billion, while that in countries

Table 5.8—Recent estimates of hunger

Dimension of hunger/food security	Population	Affected
	Millions	*Percent*
Famine (population at risk), 1992	15-35	0.3-0.7
Undernutrition (chronic and seasonal)		
Food poverty, 1980	477	9
Food poverty, 1990-92	786	20
Child malnutrition, 1990	184	34
Micronutrient deficiencies, 1980's		
Iron deficiency (women 15-49)	370	42
Iodine deficiency	211	5.6
Vitamin A deficiency (children < 5)	14	2.8
Nutrient-depleting illness, 1990		
Diarrhea, measles, malaria (deaths of children < 5)	6.5	0.8
Parasites (affected population), 1980's		
Giant roundworm	785-1,300	15-25
Hookworm	700-900	13-17
Whipworm	500-750	10-14

Compiled by Economic Research Service from Chen and Kates (1994).

with less than $2,000 per capita income falls by $0.2-$14.6 billion.

The Implications for World Hunger and Malnutrition–Measuring Hunger

Chen and Kates (1994) use the following four measurements of hunger (table 5.8):

(1) *Famine*. Famine can occur when there is a food shortage, or when the food supply is disrupted by war. The number of people affected by famine is small relative to those affected by less acute forms of hunger. For example, Chen and Kates estimate that no more than 15-35 million people have been at risk of death due to famine in any given year over the past three decades. Indeed, the overall trend in famine has been downwards. For example, the total population of countries affected by famine has fallen from 700 million in 1950-56 to less than 200 million in 1985-91 (Chen and Kates, 1994). This reflects a shift in the incidence of famine away from Asia to Africa, which has a lower population density.

(2) *Undernutrition*. One way to measure undernutrition is to estimate the number of people living in households whose access to food (defined by income or food expenditures) is not adequate to meet dietary requirements for reasonable health and physical development. A UN study suggests that 786 million people were in this category in 1990. An alternative approach is to take surveys on physical characteristics. For example, in 1990, 184 million children under the age of 5 were estimated to weigh less than adequate nutrition would dictate (Chen and Kates, 1994).

(3) *Micronutrient deficiency*. Even if total caloric intake is adequate, people may still suffer from serious deficiencies in certain micronutrients. For example, iodine deficiency can lead to mental retardation and lethargy, and to very damaging effects during pregnancy. Iron deficiency can cause anemia, reduce resistance to disease, and increase risk of death for women during childbirth.

(4) *Nutrient-depleting illness*. Even if the total food intake is adequate, nutrient deficiency can still occur because absorption in the body is reduced by illnesses, such as diarrhea; measles and malaria; or intestinal parasites such as giant roundworm, hookworm, and whipworm. Table 5.8 shows some estimates of the number currently suffering from such diseases.

Predicting the Effects of Climate Change on Future World Hunger

In the absence of climate change, Fischer and others (1994) predict that the number of undernourished people will fall from 23 percent of the developing world population in 1980 to 9 percent in 2060 (table

Table 5.9—Projected number of people at risk of hunger

Region	1980	2000	2020	2040	2060
			Million		
Developing	501 (23)	596 (17)	717 (14)	696 (11)	641 (9)
Africa	120 (26)	185 (22)	292 (21)	367 (19)	415 (18)
Latin America	36 (10)	40 (8)	39 (6)	33 (4)	24 (3)
S and SE Asia	321 (25)	330 (17)	330 (13)	232 (8)	130 (4)
West Asia	27 (18)	41 (16)	55 (14)	64 (12)	72 (11)

*Numbers in parentheses show percentages of population.
Compiled by Economic Research Service from Fischer and others (1994).

5.9), although population growth is sufficient to increase the absolute numbers from 501 million to 641 million.[24] In Latin America and South and Southeast Asia, the absolute numbers affected by undernutrition decline, but they increase in Africa despite a fall in the proportion. This reflects the rapid increase in Africa's population projected over the next several decades. Allowing for the CO_2 fertilization effect and economic and farm-level adjustment, climate change increases the number of undernourished people by up to 119 million, or by 19 percent, in the Fischer and others (1994) model. These figures look much bleaker when farm-level adjustment is hindered, in which case climate change increases hunger by anything up to 60 percent. In addition, global warming may increase the frequency of droughts and floods, which are a major cause of famines.

The region most at risk from problems of food security is Sub-Saharan Africa. It is more sensitive to reduced rainfall, rainfall variability, and evaporation than other regions. Only around 2 percent of its cropland is irrigated, 50 percent is in arid or semi-arid areas, and much of its soil is very fragile (Norse, 1994). It also has the bleakest prospects for real income growth per capita. In Asia, problems could arise because of dependency on irrigation. Climate change may increase aridity and evaporation rates in areas already at risk from salinization, so more irrigated land could be degraded. Conversely, global warming-induced increases in precipitation could increase soil erosion, leading to lower crop yields and faster siltation of irrigation dams and canals. However, the poor state of knowledge on the impacts of soil erosion on crop yields makes these problems difficult to assess.

Summary

This chapter has described some projections for the world demand and supply of agricultural commodities around the middle of the next century, by which time noticeable changes in climate may have occurred. Most of the existing studies predict that increases in supply will approximately keep pace with increases in demand, and therefore the costs of climate change are not substantially different from those in studies that impose climate change scenarios on today's global economy.

Although these predictions may be the best available at present, they are subject to great uncertainty. In particular, the results are sensitive to assumed rates of productivity increase in agriculture, and real income and population growth. Moreover, achieving predicted increases in agricultural supply will require substantial diffusion of agricultural technologies, development of infrastructure, and improvements in irrigation. Predictions assume that environmental feedback effects (soil erosion, salinization, and desertification) will not be important obstacles to expansion. Much will depend on whether future government policies promote investment and increasing efficiency in agriculture. For example, the potential for increasing food production in the former Soviet Union and Eastern European countries is thought to be substantial, if waste during distribution is reduced, property rights are extended, farms are decentralized, and restrictions on food exports and the import of technologies are removed.

Lying behind the agricultural impact figures are potentially sizable increases in global income inequalities. Poor countries are most vulnerable to climate change because of the importance of agriculture in their gross domestic product; their location in the hotter, drier climates; and the difficulties in making farm- and regional-level adjustments. Moreover, climate change threatens to increase the incidence of hunger, malnutrition, and associated problems, which are concentrated in the developing world. However, to the extent that these problems are due to low income, rather than to constraints on agricultural supply, they may be much less severe by the middle of the next century, even under modest scenarios for real income growth. The potential exception is Sub-Saharan Africa, where poor incentives for farmers, slow income growth, and population growth rates of possibly 3 percent are predicted to compound the problems associated with food shortages.

[24] Since it is primarily an economic model, the BLS makes no projections about famine, micronutrient deficiencies, or nutrient-depleting illnesses.