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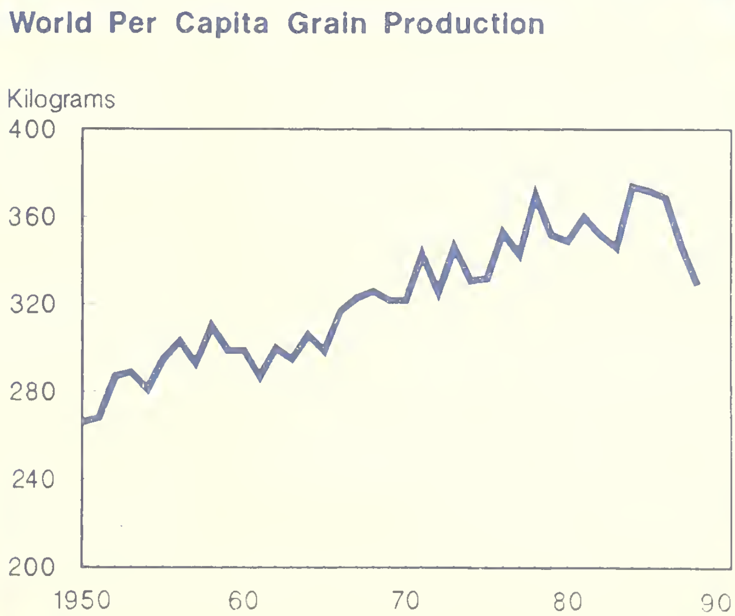

Are We Approaching A World Food Crisis Again?

World Agriculture Situation and Outlook Report. Agriculture and Trade Analysis Division, Economic Research Service, U.S. Department of Agriculture, June 1989, **WAS-55.**

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Erratum
The serial number was omitted from the cover of the *World Agriculture Situation and Outlook Report* dated March 1989. That issue should have been numbered WAS-54.

Note: Tons are metric, dollars are U.S., and rice is on a milled basis unless otherwise specified.

Summary

The world's nonrenewable natural resources, such as land, water, and energy, appear sufficient to feed a growing population at a gradually improving standard of living, assuming that world population stabilizes sometime around the end of the next century, as most projections show. Resources, however, are unevenly distributed, resulting in often prolonged, though localized, shortages.

These are some of the highlights of a review of the world food situation contained in this special issue of *World Agriculture Situation and Outlook Report.*

The world continues to raise per capita food production, but the rate of improvement has slowed. The growth rate of world food production declined from 3.1 percent per year during the 1950's to 2.9 percent in the 1960's, 2.3 percent in the 1970's, and then to 2.1 percent in the 1980's despite production increases in a number of developing countries, particularly China and in South and Southeast Asia. On a per capita basis the growth rate was 1.4 percent per year in the 1950's, 0.8 percent in the 1960's, and 0.4 percent in the 1970's and 1980's.

Agricultural technologies developed since the 1950's have brought about large increases in productivity and will continue to spread. The full benefits of the Green Revolution have not been felt. Considerable potential remains for regions bypassed by the first rounds of diffusion of high-yielding crop varieties. These crops and regions may offer smaller markets and sharper agronomic challenges, but biotechnology affords a new tool to help address them.

Land and water degradation may have little negative impact on food production potential in the industrialized countries over the next quarter century. Policymakers have the technical, financial, and political support to take effective resource conservation actions where appropriate. On the other hand, land and water degradation remains a serious problem for food production potential in much of Asia, Africa, and Latin America.

Concern that human activities will significantly change the earth's climate has increased in recent years. However, specific effects on agriculture remain difficult to predict and thus are still speculative.

Probably the most important changes in demand for food in the past have arisen from altered policies affecting prices, incomes, and income distribution. They will continue to exert major influences. Changes in income growth among low-income countries, in particular, may lead to large food demand shifts.

Multilateral trade negotiations currently underway can substantially improve the environment in which world agriculture operates, with competitiveness being fundamentally related to comparative advantage in production. If negotiations fail, however, an even more distorted competitive environment for world agricultural trade could result.

Preface

Shortages and high prices of agricultural commodities have given rise to a new wave of alarm about long-term world food prospects. There is a widespread belief that the events of the past 3 years may be the first signs of a fundamental change in the balance between world food demand and supply. In its most extreme form, this school of thought sees the world rapidly approaching the point where population growth and rising affluence will outrun the world's capacity to feed itself; where it will run out of land, water, and energy; where additional applications of fertilizer and other inputs will bring negligible returns. A more moderate version of this view predicts, not imminent disaster, but a reversal of past trends in agricultural production costs. According to this view, the era of agricultural "surpluses"—and of "surplus" agricultural production capacity—has come to an end: rapidly rising demand in both the industrial and the developing countries will put increasing pressure on agricultural resources, causing real food prices (that is, food prices in relation to general price level) to rise. As a result, it will become increasingly difficult to sustain present levels of food consumption *(5)*. [1]

It seems as if the wheel has come full circle in the 14 years since the publication of the above statement in 1975. Indeed, cycles of pessimism and of optimism are nothing new when it comes to the world food situation. Only the factors in the debate are new (sometimes).

During the last of the previous cycles of pessimism, the debate was dominated by the alarming possibility that the insatiable appetite of the world's industrialized countries (both Western and Communist) would lead to the exhaustion of natural resources and, simultaneously, the uncontrolled pollution of the world's ecosystem by industrial activities. Both these factors would contribute to the collapse of the world life support system in the more or less distant future. It was only a question of when this would occur.

Out of this debate came the most ambitious attempt up to then to model the way in which the world system behaves. This was *The Limits to Growth*, published by the Club of Rome in 1972 *(2)*. Many of the computer runs of the simulation model developed in that publication produced depletion of natural resources, falling capital availability, declining food production per capita, growing pollution, and, in the more or less near term, a precipitous decline of population. Such outcomes would, indeed, correspond to "limits" by any definition, and they provided sobering thought for those who took economic growth of nations for granted. Yet a careful examination of the model shows that under some sets of reasonable assumptions it can produce levels of all these variables that do not plunge or zoom out of control. Doom for the human race is not, after all, inevitable.

[1] Underlined numbers in parentheses refer to references at end.

A model of the world food system similarly would only be as good as its assumptions. Its equations about the physical world—crop response rates to fertilizers, protein utilization in nutrition, and so on—might be based on the most exact scientific evidence. But the model would still only be as good as its assumptions about the way human beings and their institutions do things. Taking the "worst case" assumptions, a dynamic simulation model produces collapse. Taking more favorable assumptions, it produces resilience in the face of shocks. (Resilience is the ability of a system to maintain its structure and patterns of behavior in the face of disturbance. Stability, on the other hand, is the propensity of a system to attain or retain an equilibrium condition of steady state or stable oscillation *(1)*.)

Three of the principal adjustment mechanisms that help to keep the world food system resilient are stock changes, trade flows, and price changes. The particular role and importance of each of these variables for the world food situation will be discussed in more detail in the following articles. But it will be helpful here to point out how these mechanisms contribute to the resilience of the world food system as it might be modeled.

Adjustment mechanisms of this kind correspond to what the authors of *The Limits to Growth* referred to in their world model as rate variables. Rate variables have the function of regulating the rates at which the other kind of variable in the world model, level variables, change. Examples of level variables in a hypothetical model of the world food system would be per capita food supplies, arable land, and land fertility.

A distinguishing characteristic of rate variables in a model of this type is that they are peculiarly amenable to policy adjustment. For example, policy adjustments written into the Food Security Act of 1985 helped achieve the goal of reducing the unprecedented grain surpluses that had accumulated in government hands at that time. The specific policy instruments varied, including lowering the loan rates on program commodities, providing incentives for farmers to take land out of production, and export promotion programs. But the goal was the same.

Stocks act as a buffer in the world food system, absorbing sudden shifts in supply or demand and moderating price fluctuations. Countries build up their stocks by producing themselves or by importing from abroad. Trade acts to redistribute food supplies that are initially very unevenly distributed among countries. Prices play many important roles in the world food system, but among their most important is regulating stock buildups and drawdowns and the flow of trade.

An example of how these three rate variables act together to provide resilience to the world food system is afforded by the allocation of grain to human consumption or the livestock sector. In the normal course of events, the biggest demand on grain production in countries like the United States is not from foreign importers but from the domestic livestock industry. In developed countries, over two-thirds of grain use is animal feed. In the United States, Canada, and Northern Europe, 700 to 900 kilograms of grain are needed per person per year. Among developing countries, about one-quarter of grain consumed in higher-income countries goes to feed livestock. Lower-income developing countries use less than 2 percent of their total grains this way. With a subsistence grain diet, only 180 to 230 kilograms of grain are needed to feed a person for a year. The economic tendency of stocks to go to the highest bidder—human food either domestically or overseas, or livestock feed—gives added flexibility to consumption when production is down, thereby adding to the resilience of the world food system.

But these three rate variables do not always work together as they "should." Various factors intervene to prevent them from doing so. The management of stocks so as to perform the stabilizing function they are capable of performing requires great skill, as well as (of course) financing and adequate storage facilities. The Commodity Credit Corporation (CCC) in the United States and the Food Corporation of India (FCI) are examples of organizations that have managed large-scale food stocks.

Holding stocks can be an expensive proposition. The United States held large grain stocks in the 1950's and 1960's and in the mid-1980's. Holding surplus stocks on this scale is seen by many to be inappropriate for government today. If prices are not allowed to perform their equilibrating function, when stocks build up planted area controls are introduced to reduce production.

For trade to occur, there must exist tradeable surpluses, effective demand, and exchange of information. If these exist, trade flows play an important role in rebalancing the world food system when it gets temporarily out of balance. And if they do not, the danger of imbalance is accordingly great.

Here again, the role played by policy is considerable. It is not always a stabilizing role. Where the lead time between policy decision and implementation is short, as it typically is in centrally planned economies, the impact on trade can be destabilizing to the world food situation. This was the case in the USSR's decision to import grain beginning in 1972 to feed its livestock sector rather than reducing livestock herds through slaughter. World grain stocks were suddenly drawn down. Such sudden shifts in demand among market economy countries are rare.

Agricultural prices are particularly amenable to policy intervention. Governments in industrialized countries set and change support prices for farmers as a matter of routine, just as they set and change key interest rates to manage their economies and make money scarcer or more readily available. Therefore, price policy influences stock changes and trade flows in a very direct way.

There are many other variables in a hypothetical model of the world food system besides stock changes, trade flows, and price changes, of course. One of the variables that figured prominently in the world model of the Club of Rome was soil fertility. Today, concern about soil fertility and crop yields has been renewed. Worries over loss of land fertility due to overcropping are almost as old as agriculture itself. Pliny worried about the loss of fertility in central Italy, thebreadbasket for Rome, in the first century when he lived *(4)*. The concern surfaced in the New World when Edward Lloyd, vice president of the Maryland Agricultural Society, wrote in 1818: "Lands generally in Maryland are nearly exhausted; our agriculture is sinking to its lowest stage of degradation *(7, p. 94)*."

A dynamic simulation model of the world food system today would also have to incorporate a number of variables that did not figure in the world model of *The Limits to Growth.* Climate change is one example. Another new variable is how pollution is likely to affect agricultural production, not only directly, but also indirectly through public demands for legislation curbing the use of farm chemicals that pollute ground and surface waters.

The overall picture that emerges from an examination of its recent behavior is of a world food system that shows considerable resilience in the face of long-term structural change and short-term shocks, whether nature-made, like drought and flood, or manmade, such as the steep increases in petroleum prices that the world witnessed in 1973-81. This system has historically accommodated great fluctuations in output, in quantities stored, and in prices.

Even in the best of circumstances, however, the many variables at work simultaneously render attempts at partial analysis hazardous, since *ceteris paribus* conditions rarely hold. Often countervailing effects need to be taken account of. Another complication are time lags, which make short-term results different from long-term. (A good example of the latter is a rise in the price of a staple food, which is necessary in the long run to bring additional resources into production, but in the short run may cause hardship for needy consumers.) Thus, only an analysis of how the whole system operates can provide valid conclusions about how a shock to any single part will affect any other part.

This issue contains the following articles, each of which looks at the world food situation from a slightly different perspective and attempts to show what the future might hold.

- Past trends, global and regional, are analyzed by Urban and Dommen in their article, which emphasizes the differentiating impact of weather, policy changes, population growth, and other variables on world food availabilities.

- The world food system operates within a matrix of policies and institutions which are susceptible to change. The influence of these policies and institutions is traced by Skully, who introduces the concept of contrived scarcity to distinguish manmade scarcity from natural scarcity.

- The availability of basic resources for agricultural and food production—land, water, and energy—is reviewed by Urban in his article.

- Technology has played a large part in improving food availability in both developed and developing countries, and is likely to go on providing farmers with a stream of productivity-enhancing innovations in the future, according to the article by Knudson and Anderson.

- Agriculture around the world is at the center of a growing public debate over degradation of land, water supplies, and the atmosphere in that it both contributes to this degradation and suffers from it; use of high-input methods (although there are signs that this reliance may be starting to lessen) and the cheapening of resources through salinization, deforestation, and other phenomena are evidence of this conflict, as shown by Sutton.

- Somewhat further removed from present problems, although an issue also of immediate concern, is the effect climate change is likely to have on world agriculture, a question raised by Reilly in his article.

- Changes in food demand hold the potential for sharply altering the present world food picture; the likely sources of such change are analyzed by Davison and Deaton.

- Famines have been much a part of the food picture in the past, and may also be in the future; Mabbs-Zeno indicates that while the incidence of famine is lessening around the world, famines have causes, including economic ones, that are still with us.

- The future environment for agricultural trade is being created today by multilateral negotiations under way and other developments affecting the state of the world economy, the external debt problem, and currency exchange rates, as shown by Shane and Stallings.

- One of the most shocking paradoxes of recent years is that in 1988, at a time when world grain stocks stood at 401 million tons, a near record level *(6)*, an estimated quarter of a million people died of malnutrition and starvation in Sudan, a net food exporting country *(3)*. When food production and trade fail, large numbers depend on relief, and relief is hostage to war, food does not get to people who need it, no matter how efficient the world food system is. In their article on short-term food security, Kennedy and Nightingale discuss such issues as how we measure the number of hungry and pinpoint famine threats, and how the international community attempts through food aid and other means to improve the food security of developing countries.

- What these different perspectives mean in terms of the prospects for the world food situation is summed up by White in his concluding article.

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The World Food Situation in Perspective

by

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Production Trends, Distribution, and Prices

World food production over the past four decades has more than doubled and continues to grow, although unevenly, at a higher rate than population. The rate of growth slowed between the mid-1950's and 1987, though on a per capita basis it remained stable during the past two decades. While cropland expanded, most production increases came from higher yields. Grain yields, for example, grew exponentially between 1960 and the mid-1980's, at the annual rate of 2.7 percent per year, and the decline in the growth rate to about 1.4 percent between 1983 and 1987, the last year for which data were available at the time of writing, is far from conclusive *(4)*. Still, most of the good agricultural land in the world is already in production. Nearly all the available irrigation water is currently exploited, and groundwater supplies are being depleted at rapid rates in many regions and countries, including parts of theUnited States. Thus, future increases in food production will have to come principally from new yield-increasing and resource-conserving technological advances, such as biotechnological innovations and more efficient irrigation methods.

The growth rate of world food production declined gradually from 3.1 percent per year in the 1950's *(13)* to 2.1 percent in the 1980's despite rapid production increases in China and South and Southeast Asia (table A-1). On a per capita basis, the food production rate of increase went down from 1.4 percent in the 1950's *(13)* to 0.4 percent in the 1970's, and remained at this level through 1987 *(4)*.

Regional Growth Rates

Regionally, the food situation improved dramatically in China and Southeast Asia among the world's most populous regions, and in Eastern Europe, but deteriorated drastically in South Africa, Latin America, the Near East, and, in the 1970's, in Sub-Saharan Africa. Per capita food production growth in the developing countries declined from 1.2 percent in the 1950's to 0.3 percent in the 1960's and 1970's and then to zero in the 1980's (table A-1). Only in the United States was the negative rate of per capita food production the result of public policy in response to the buildup of agricultural surpluses. In contrast, food production in Canada dur-

Table A-1--Annual growth rates of food production, total and per capita, 1962-87

Region	Total production			Per capita production		
	1962-70	1970-80	1980-87	1962-70	1970-80	1980-87
	Percent per year					
World	2.9	2.3	2.1	0.8	0.4	0.4
Developed market economies	2.1	2.0	.9	1.1	1.2	.2
United States	2.0	2.3	.3	.8	1.3	-.6
Canada	2.9	1.9	2.7	1.2	.6	1.7
Western Europe	1.8	1.8	1.1	1.0	1.4	.9
Japan	3.1	1.6	1.4	2.0	.5	.8
Oceania	3.8	1.5	1.3	1.6	-.1	-.2
South Africa	2.7	2.9	.1	0	.3	-2.3
USSR & Eastern Europe	3.4	1.4	1.9	2.3	.5	1.2
USSR	3.9	.9	2.0	2.7	0	1.1
Eastern Europe	2.4	2.1	1.8	1.7	1.4	1.3
Developing countries	2.8	2.7	2.4	.3	.3	0
North Africa	2.9	1.8	3.4	.4	-.8	.5
Egypt	3.1	1.8	2.8	.9	-.6	-.2
Sub-Saharan Africa 1/	2.9	1.3	2.4	.3	-1.4	.5
Latin America	2.8	3.1	1.9	.1	.6	-.3
Mexico	4.1	4.0	1.6	.9	1.1	-.7
Brazil	3.1	3.7	3.1	.2	1.1	.5
Argentina	1.5	2.2	.8	0	.5	-.6
Near East	3.0	3.4	2.6	.2	.3	-.6
South Asia	2.3	2.2	2.4	0	0	.1
India	2.1	2.2	2.2	-.2	.1	.1
Southeast Asia	3.0	4.0	3.3	.6	1.7	1.0
Indonesia	3.0	4.1	3.8	1.1	1.7	1.5
Other East Asia 2/	4.1	4.3	2.6	1.5	2.2	.8
China 3/	5.7	3.6	4.8	2.7	1.7	3.5

1/ Excluding South Africa. 2/ Excluding Japan and China. 3/ Excluding Taiwan.

Source: (4).

ing this time increased sharply. Still, the world is much better supplied with food now than it was four decades ago.

The developed countries, where per capita food production has been increasing at about 1 percent per year during the past four decades, produce a third of the world's food but contain only 16 percent of the world's population (table A-2). These countries, therefore, are the main food exporters. The food production to population ratio is largest in Oceania (principally Australia and New Zealand), followed closely by North America, with its two largest food producers, Canada and the United States.

Per capita food production growth in the centrally planned countries of Europe has remained consistently higher than in the developed market economies. These countries also have a very favorable food production to population ratio, although both regions, Eastern Europe and the Soviet Union, have serious internal food supply difficulties and the Soviet Union is a large food importer. This is largely due to a combination of inefficiencies in farming and in processing and distributing food. China, which represents more than a fifth of the world's population (21 percent), produces 14 percent of world food. However, China has maintained the highest growth rate of per capita food production in the last two and a half decades, around 2.6 percent per year.

Among the developing regions, Latin America and the Near East represent 8.4 and 3.4 percent of world population respectively, and nearly the same share of world food production. In both regions, however, the growth rates of per capita food production, small in the past, were negative in the early 1980's, indicating growing food supply problems. In Africa and the Far East (excluding China), the share of world food production is about half of the share of world population. However, while in the Far East per capita food production is still growing, in Sub-Saharan Africa it declined dramatically during the 1970's, and increased modestly in the 1980's.

Food Price Trends

The steady improvement in the world food situation during the past few decades has been reflected in food price trends. Since the mid-1950's, which saw the restoration of food production capacity after the devastations of World War II, real food prices showed a gentle downward trend (fig. A-1). This trend was interrupted by a strong upward surge in 1973 and 1974, and again in 1976 and 1977, brought about by a sudden change in Soviet food policy in 1972 and a severe drought in the African Sahel at times of short world grain stocks. Though real world food producer prices have fallen steadily since the mid-1950's, there were some exceptions. The most important of these were red meat prices (beef, pork, and mutton), which rose at the rate approaching 1 percent per year during the period.

According to World Bank calculations *(19, 20)*, all primary commodity prices fell during the last three and a half decades, though the decline in nonagricultural commodity prices was less pronounced. Thus, between 1948 and 1988, all real commodity (excluding petroleum) prices fell by 46 percent, food prices by 50 percent, and all agricultural commodity prices fell by over 53 percent. In general, consumers benefited from lower prices, though at times government interventions negated such benefits, supporting prices and producer incomes instead.

The opposite historical trends of world agricultural production and real food prices may seem paradoxical: production has increased as prices continued to decline. Economists have almost always found a positive relationship between

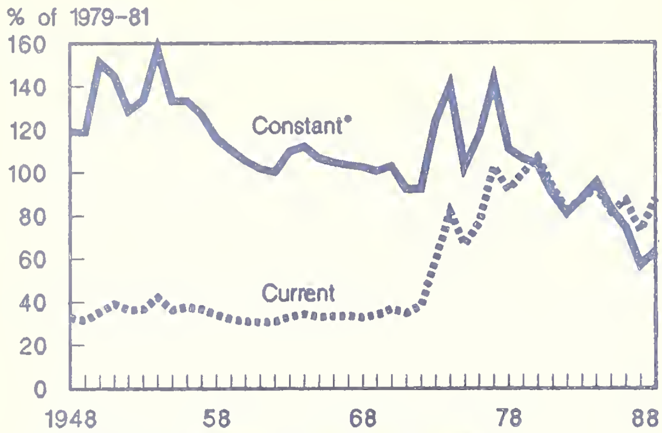
Table A-2--World population and food production, 1984-86

Region	Population	Food production 1/
	Percent	
Developed market economies	15.5	33.2
North America	5.4	14.9
Western Europe	7.2	14.6
Oceania	.5	1.7
Japan	2.4	2.0
Centrally planned Europe	8.5	17.2
Eastern Europe	2.8	6.4
USSR	5.7	10.8
Developing countries	76.0	49.6
Africa 2/	11.8	5.5
Latin America	8.4	10.0
Near East	3.4	3.2
China	21.3	14.2
Other Asia	31.1	16.7
World	100.0	100.0

1/ Percent of 1984-86 average value of total agricultural production.
2/ Includes South Africa.

Source: (13, 17).

Figure A-1
Weighted Index of World Food Prices, 1948-88



* Constant price index is weighted by manufacturing unit value.
Source: 19.

prices and production volume. If nothing else had changed, this relationship would have resulted in declining production. Agricultural production technology, however, changed dramatically. In many countries the process of technological change in agriculture has become institutionalized, so that technological progress relaxes resource constraints and raises productivity significantly on a continuing basis in all major forms of crop and livestock production. Thus, the cost of producing an additional unit of food output has declined more than enough to offset the decline in real prices, stimulating production increases. In addition, heavy producer subsidies in the European Community (EC), the United States, and some other countries provided additional stimulus.

Assuming food production continues on its upward trend, and barring anychange in the demand for food large enough to cause serious and lasting shortages on world markets, world food prices are expected to continue their slow historical decline into the next century. This obviously does not rule out short-term shocks, whose temporary effects on food availability worldwide and regionally sometimes take a year or more to work themselves out.

Times of Shortages and Times of Surpluses

The Western world has experienced six waves of pessimism about world food supply and demand since the one that was touched off by T. R. Malthus in the middle of the 19th century. The second came in the 1890's, the third a few years after World War I, and the fourth after World War II *(2)*. We could now document a fifth wave in the mid-1960's, and a sixth in the early and mid-1970's. Judging by the press, we are now in the seventh wave of pessimism.

Over half a century ago, the Depression of the 1930's brought about a crisis in world agriculture. The worldwide drop in prices resulted in lower farm income. Agricultural surpluses piled up, and then were destroyed in an effort to keep prices up, as in the case of coffee in Brazil and cotton and pigs in the United States. In the United States, farm prices and farm income dropped by over 50 percent in 3 years between 1929 and 1932 *(12)*. To keep farm income up, the Agricultural Adjustment Act of 1933 provided relief for U.S. farmers in return for an undertaking to reduce wheat area.

At the end of World War II, however, concern shifted from surplus to shortage: there were short food supplies in Europe and Asia. The war had destroyed a large part of the region's capability to produce food, and large imports were needed to avert starvation. However, U.S. stocks were low, as a result of the war and a policy decision by the U.S. Government to reduce stocks so that U.S. farmers would not be hurt by low prices as happened following World War I. In October 1945, the Food and Agriculture Organization of the United Nations (FAO) issued its first world food survey. Since then, FAO's periodic reports have done much to shape public perceptions of the world food situation *(7)*.

The crisis passed as agriculture recovered from the war. The period from the second half of the 1950's through the early 1970's was marked by rapidly accumulating surplus stocks as production exceeded demand in principal producing countries. World real food prices declined steadily from 1959 to 1972 (fig. A-1). American agriculture was again dominated by burdensome surpluses.

In the mid-1950's, national concern focused on planted area retirement programs and other means of reducing supply. The Soil Bank Bill of 1956 provided for retirement of marginal cropland. To help reduce surpluses, and to respond to demands to help developing countries, the United States passed Public Law 480 legislation which provided food to countries unable to afford commercial imports, as grants or low-interest loans.

For the next 20 years, the world depended on a system where food security rested almost entirely on the stockholding policies of the major exporting countries, policies which were largely a byproduct of domestic farm price and income support programs.

Massive movement of grain from the United States to India was the key in dealing with the major drought of 1965-66. Droughts in India and in the USSR led to reduced world grain stocks and concern about long-term prospects for feeding the world.

However, with the passing of the dry weather after 1965-66, the world returned to long-term trends. The development and spread of high-yielding varieties of wheat and rice were favored by a coordinated agricultural research effort by national and international institutions, by availability of infrastructure and fertilizer in Asian countries, and by price ratios of inputs to output favorable to farmers *(1)*. These factors brought about what became known as the Green Revolution.

Increased production in the late 1960's, however, led the United States to look for ways of reducing the burden of agricultural support programs, and land was withdrawn from cultivation. This strategy, combined with unexpectedly large Soviet purchases of U.S. grain in 1972, due in major part to USSR policy changes, led to increased import demand in 1972 and 1973 and a runup in grain prices. A drought in the African Sahel and parts of South Asia contributed further to grain import demand. This created a financing problem for food-deficit developing countries, since it coincided with a cutback in food aid supplies. At the same time, fertilizer prices rose sharply as shortages developed due to the steep increase in oil prices. Moreover, in 1974 a drought in the United States reduced grain yields and production by one-fourth, contributing to the sharp rise in food prices (fig. A-1).

As a result, a threat of worldwide food shortages and even of widespread famine was perceived. A World Food Conference was convened in Rome under the auspices of FAO. The "central problem," in the words of the Preparatory Committee, was to accelerate food production in the developing countries to close the widening gap between supplies and demand. Higher world food prices, together with rising food deficits, were threatening to impose an intolerable burden on the balance of payments of the developing countries. Food self-sufficiency was seen as a desirable goal. A second objective was to avert temporary shortages, be they global, regional, or local. A third objective was to free an estimated 400-460 million people from chronic undernutrition *(21)*.

After restrictions on cropped area were lifted in the United States, idled land area fell to less than 1 million hectares. More than 24 million hectares were brought back into production in less than two seasons, and the United States gained a large share of a trade boom in grain. Other countries also responded. Brazil, followed by Argentina, greatly increased their soybean production as they opened new lands to production. The increase in soybean production in South America was in response to the fall in fish catch off the coast of Peru, used as poultry feed protein additive, and rising soybean prices in the late 1960's and the first half of the 1970's. Thereafter, soybeans replaced fish meal in poultry feed. The crisis of the early to mid-1970's passed as normal weather returned, though it forced a fresh look at the long-term trends underlying the world food system.

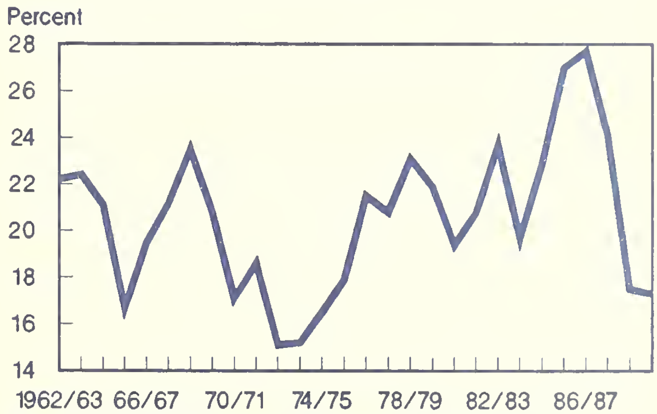
By 1976, the period of high prices was again over (fig. A-1), and world food output was up again. Trade slowed in 1978-79 and some U.S. land was taken out of production. It was put back into production in 1980-81. However, trade slowed again, and planted area controls were put on again.

The worldwide economic recession of the early 1980's cut down the rapid expansion in food demand. Production continued to grow, surpluses built up, the United States and the European Community (EC) intensified the competition for the shrinking market with export subsidies, and prices dropped rapidly. As stocks grew, the U.S. Government initiated programs that idled large areas of cropland (76 million acres in 1987, 78 million acres in 1988, or 31 and 32 million hectares respectively). Idled cropland became a "secondary" reserve supplementing stocks.

During 1988, there was a major drought in the United States, Canada, Mexico, Argentina, North Africa, and Eastern Europe, to mention only major producers affected. Lower crop yields on reduced area in the United States resulted in sharply lower crop production. The drought accounted for about 0.5 percent of the rise in the U.S. consumer price index (CPI) for food in 1988 over 1987. But even with the drought, the change in the CPI for food in 1988 was only 4.1 percent *(6)*.

The sudden drawdown of world grain stocks to meet demand, down from 28 percent of estimated utilization in 1986/87 to 17.3 percent in 1989/90 (fig. A-2), seemed to be cause for asking the question again: Are we producing enough food to feed the world's growing population? World food supplies have, on balance, adjusted to changing circumstances over the long term. However, unforeseen events can have highly visible effects on the adequacy of world food supplies. Examples that have been mentioned are the immediate aftermath of World War II in Europe and, more recently, the 1988 drought in the United States. It is usually unforeseen events that place world food supplies under strain, not the results of unfavorable trends.

Figure A-2
World Grain Stocks as Percent of Utilization



Stock data are based on an aggregate of different marketing years and are estimated for USSR and some other countries.
Source: 15.

Short-Term Shocks

While weather and other short-term shocks on grain production affect some regions or countries more severely than others, world grain production tends to be rather stable (fig. A-3). The average variation of global grain production from trend (the coefficient of variation) during 1960-88 was about 4 percent. In the 1970's and 1980's, the only below-trend global grain crop to exceed the average was the 1988/89 harvest, which was 9 percent below trend. The largest year-to-year declines were in 1974/75 (4.1 percent), 1983/84 (4.0 percent), 1987/88 (4.5 percent), and 1988/89 (3.8 percent). Even the 1972/73 and 1974/75 grain harvests deviated less than 3 percent below trend, although the shortfalls from the previous harvests were among the largest in quantity terms (38 and 51 million tons, representing declines of 3.2 and 4.1 percent). The 1987/88 and 1988/89 harvests recorded successive shortfalls from the previous year of 75 and 81 million tons, 4.5 and 3.8 percent.

Factors accounting for short-term fluctuations in grain production in major producing regions in recent years as shown in figures A-4 to A-14 (shown not to comparable scale), can be readily identified by those who follow production trends.

In North America, which accounts for about one-fifth of total world grain production, the impact of major droughts is visible in 1983 and in 1988 and that of the PIK program in 1987 (fig. A-4). In per capita terms, production has reached levels not seen since the 1950's and 1960's. However, in the United States total production was already trending downward from 1985 due partly to land set-aside programs and the financial troubles of the farm sector *(5)*.

In Central America and the Caribbean, total grain production has stagnated since 1982 because of unsettled political conditions in many of the countries and the extension of the North American drought to Mexico in 1988 (fig. A-5). Mexican production took off in the mid-1970's (the period when large-scale petroleum production was coming on stream), followed by declines in more recent years because of drought, and the impact of economic recession on prices and production. Lower petroleum prices resulted in less input use. Mexico's overall agricultural production has grown at an annual rate of only 1.6 percent in the 1980's.

In South America, grain production has been affected by the foreign debt crisis which restricted the import of inputs, such as fertilizers and machinery, low grain prices which brought about a shift to soybean production in Argentina, and drought in 1988 (fig. A-6). Argentina shows an upward trend (except for 1980) to 1982, and a rapidly declining trend thereafter. The debt crisis had an impact on Argentina's ability to import inputs. Low grain prices also affected grain production by inducing a shift of land resources to oilseeds and other more profitable crops.

In Western Europe, which normally accounts for about 10 percent of world grain production, strong growth in output continues as a result of higher yields and programs under the Common Agricultural Policy (CAP) that largely insulate farmers from fluctuations in world cereal prices and provide an outlet for surplus cereal production in the form of subsidized exports. However, low grain prices on world markets and ballooning stocks tended to depress production, particularly after 1984 (fig. A-7) in France and the United Kingdom.

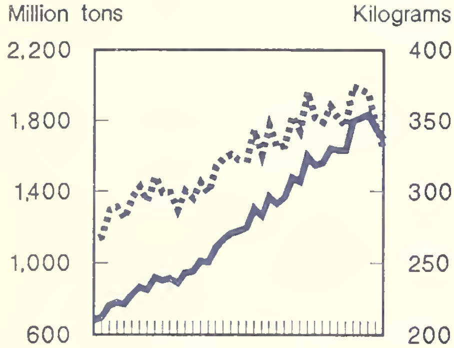
The evolution of grain production in the USSR, which accounts for about 11 percent of world grain production, shows three rather distinct trends. From 1970 to 1978, production increased significantly, although with wide annual fluctuations due to the country's notoriously unstable weather. From 1979 to 1984, production stagnated, corresponding to the last years of the Brezhnev era. From 1985 onward, there has been a distinct recovery under Gorbachev, but at a lower level than that of the 1970's because about 10 million hectares of cropland were switched from grain production to forage crops, and another 10 million hectares withdrawn to fallow.

In Africa, which accounts for less than 5 percent of world grain supply, grain production grew steadily from just over 37 million tons in 1950 to 86 million tons in 1989, or at an annual rate of 2.2 percent. However, population grew at 2.7 percent per year, resulting in a continuous decline in per capita grain production (fig. A-9). Moreover, grain production in Africa is subject to weather-induced fluctuations. Serious droughts occurred in various parts of the continent in 1966, 1973, 1983, 1984, and 1987, causing dislocations in production and forcing a need for foreign food aid. USDA research found that in 11 countries of Sub-Saharan Africa receiving food aid, the coefficient of variability of food availability in eight of them exceeded 10 percent during 1966-83, and the average was 13 percent *(8)*. This represents a high degree of variability, with serious implications for food security.

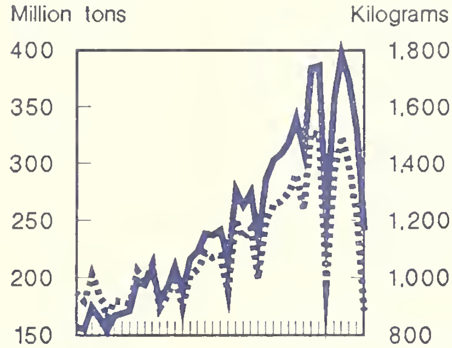
South Asia shows a steady growth of production (fig. A-11). However, the Indian trend line shows strong growth from 1972 through 1983, except for the drought year 1982, which then flattens due mainly to accumulation of surplus stocks, low prices, and switching into alternative crops. India had benefited beginning in the mid-1960's from the introduction of high-yielding varieties of wheat and rice. The spread of these varieties was typically associated with key policy changes. Farm prices were raised, fertilizer manufacture and distribution were stepped up, and seed production was improved *(9)*. In 1987, a severe drought caused a drop below trend. Bangladesh, where most grain production is rice, shows one of the smoothest upward trends in grain production over the 1970-88 period, with a flattening of the trend line in recent years due to unfavorable weather and shortage of foreign exchange to import inputs.

Grain Production

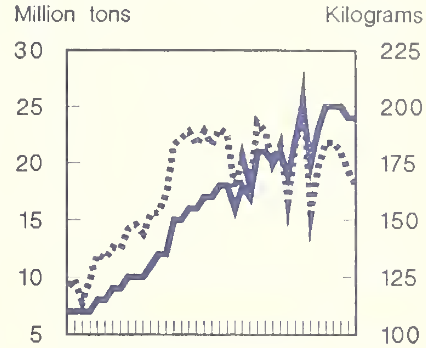
A-3 World



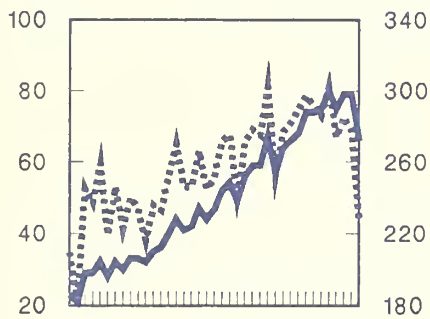
A-4 North America



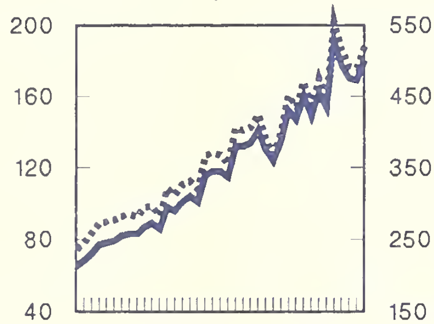
A-5 Central America



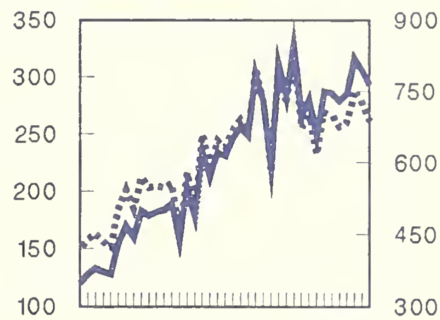
A-6 South America



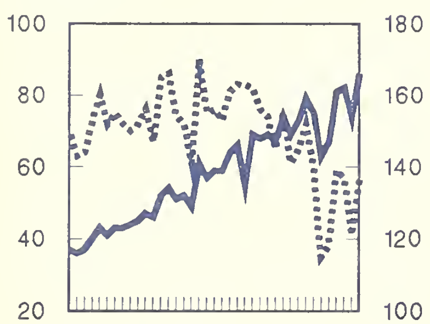
A-7 Western Europe



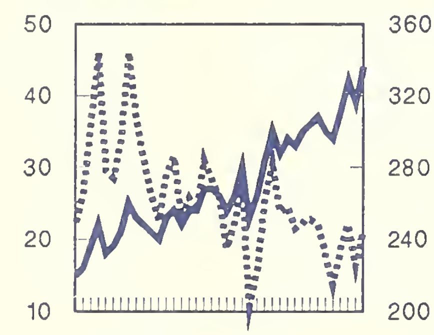
A-8 Eastern Europe



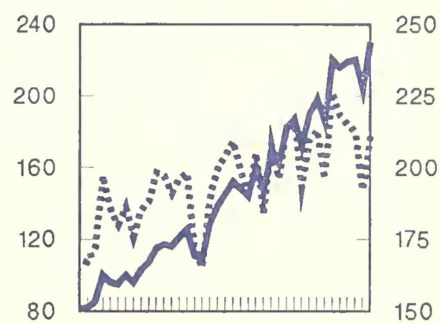
A-9 Africa



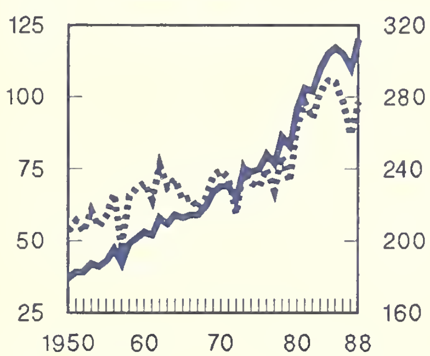
A-10 West Asia



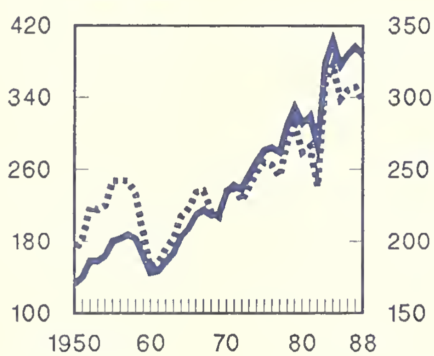
A-11 South Asia



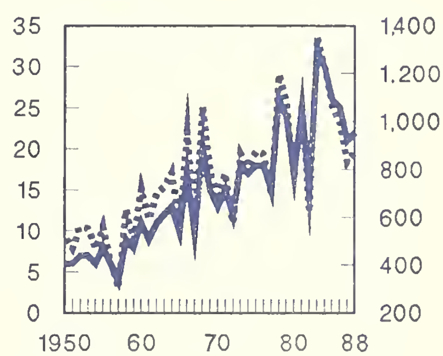
A-12 Southeast Asia



A-13 East Asia



A-14 Oceania



——— Total (left scale) ------ Per capita (right scale)

Source: 4.

In Southeast Asia (fig. A-12), Indonesia shows a smooth upward trend induced mainly by technological change in the form of higher-yielding varieties and government policies favorable to farmers. Rice production accounts for a major share of Indonesia's strong agricultural production growth of 4.2 percent per year in the 1970's and 5.2 percent per year in the 1980's. Thailand has likewise trended upward, except for the drought year 1987. Thailand's export markets for rice provide a continuing incentive to raise rice production, more than compensating from a relatively small domestic market. Other strong export commodities include corn, sugar, cassava, and poultry meat. But as the poultry industry expands, corn exports decline.

Grain production in East Asia (fig. A-13) is dominated by China, which alone accounts for about 19 percent of world grain production. Trends show the overwhelming positive effect of the reforms introduced to Chinese agriculture since 1978. Prior to these reforms, people's communes served as the basic production units. Commune members collectively owned all the production means, including labor. Income was distributed on the basis of the "work point" system under which there was little incentive to work hard. To increase incentives and raise output,the Party's Central Committee decided in late 1978 to reform the commune system and introduced the "production responsibility system" (PRS), under which farmers' remuneration was linked directly to the value of output.

These reforms created China's extraordinary 4.8-percent annual growth rate of food production in 1980-87, following a 3.6-percent rate in the 1970's (table A-1). But they produced other effects on grain production. Notable among these was the diversification of output induced by higher profitability of nongrain crops like vegetables and fruits, and of animal husbandry and fisheries. The portion of total value of agricultural output accounted for by crop farming in general fell from 76.7 percent in 1978 to 60.7 percent in 1987 *(18)*. These factors help explain the tapering off of grain production after 1984.

Australia shows wide fluctuations in grain production due to its rainfed nature, with peaks in 1978 and 1983, and declining trend after 1983 (fig. A-14) due to low prices that induced farmers to switch to lamb and mutton production.

The irregular fluctuation of world grain production, particularly in grain-exporting regions, translates into sharp movements in grain stocks, which are mainly held in the large grain-exporting countries. Since about 1960, world grain stocks moved up from about 20 percent of estimated annual utilization to about 24 percent in the early 1980's,with the all-time high rate of 28 percent in 1987. In 1966, 1973-74, and 1989, the rate fell to the 15- to 17-percent range.

The current low grain stocks situation is largely a result of recent droughts in some major producing countries, notably the United States, Canada, Mexico, Argentina, and Thailand; U.S. production controls in 1986-88; low grain prices due to stock accumulations and consequent switches from grain production to other crops in Western Europe, Australia, India, and Argentina; large grain exports from Western Europe in 1988-89; decollectivization in China; and changing land use from grain production to forage production and fallow in the USSR. None of these factors appears to be permanent.

Food and Population

Population, like food production, is unevenly distributed around the world (table A-2). The principal factors governing the distribution of food production are climate and soils, which limit the capacity to produce foods, and diets, which set the parameters of demand for various types of food. The chief factors governing population distribution, however, are historical, social, and economic.

Food Self-Sufficiency and Diets

According to FAO, the range of country food self-sufficiency ratios[1] stretched in 1983-85 from 32 percent in Saudi Arabia to 309 percent in New Zealand. In the United States, it was 112 percent. Of the 129 countries for which food self-sufficiency ratios were calculated, less than half had ratios of 100 percent, and for one-third of them the ratio was below 95 percent *(3)*.

Self-sufficiency is a neutral term. A country may have a high degree of food self-sufficiency of necessity because it lacks the income to pay for food imports, and thus its standard of living may be low. On the other hand, a country with a low degree of self-sufficiency is not necessarily to be pitied. West Germany has a ratio of 83 percent, and Japan only 62 percent, and they are relatively rich and have well-fed populations. Both countries import large amounts of grain for their expanding livestock sector. In sum, the degree of food self-sufficiency of a country must be weighed in the light of other circumstances. Similarly, food self-sufficiency as a policy goal may have appeal because of trading or defense strategies that have little or nothing to do with living standards.

Furthermore, countries have different food requirements relative to their populations. Diets vary regionally, and may be more or less costly in terms of the resources that are used to produce. People in North America, Western Europe, and the oil-rich countries of Asia are able to afford diets high in ani-

[1] Food self-sufficiency is calculated either in value or in calorie or protein terms in order to have meaning, because the varied composition of diets makes a weight measure almost meaningless.

mal protein. Diets in Africa and Latin America that are high in starch may be just as adequate from the nutritional point of view. The difference in diets is climatic and economic, reflecting tastes and preferences for foods and the ability to pay for diversity. Historically, people have moved from reliance on roots and tubers and cereals to eating more animal products like meat, eggs, milk, and butter. Moreover, as regional imbalances in food production and demand manifest themselves in agricultural trade, income becomes an increasingly significant factor in determining who gets what to eat.

Demographic Transition

In 1989, world population stood at 5.2 billion persons. Its growth rate peaked at 2.1 percent a year in the 1960's, declined to 1.80 percent in the 1980's, and declined further to 1.73 percent in 1985-90 *(16)*. Even so, it means that there are 90 million more people to feed and clothe each year. But, because of the demographic transition, world population growth is not set inexorably on an exponential growth curve. Depending on projections *(11, 20, or 22)*, it is likely to flatten either in the second half of the next century or the first quarter of the 22nd century (figs. A-15 and A-16).

This flattening is already happening in European countries and in the United States, as projections by the World Bank *(20)* and the U.S. Census Bureau show *(16)*. In Africa, where the pace of population growth increased from 2.62 percent annually in 1965-70 to 2.97 percent in 1975-80 to 3.02 percent in 1985-90, this phenomenon will likely also be repeated as the regions follow the development pattern of other regions.

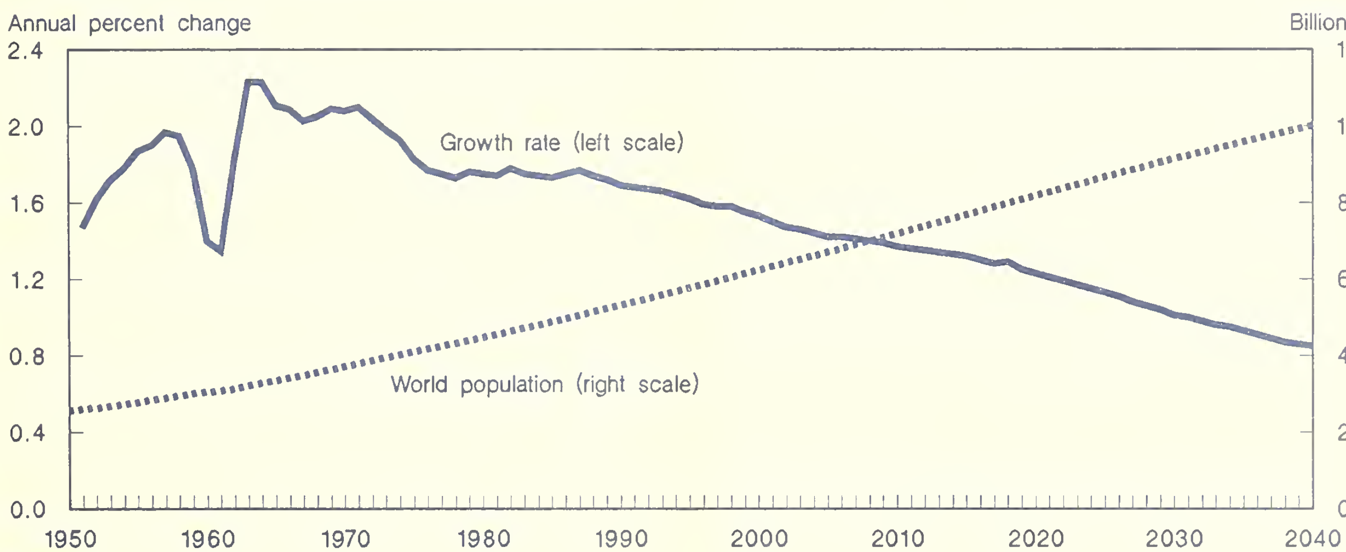
Country analyses of food production and consumption growth rates are also affected directly by the demographic transition, even while other factors are held constant.

Growth rates of food production can be useful to compare food production performance among countries at similar stages of development. However, they can be misleading in comparing countries at different levels of development because the bases from which the growth is calculated may differ considerably. As a country's food production increases, the same annual increment of food can be produced with gradually decreasing percentage rates of growth. Judgments on the sole basis of data showing food production per capita, either among countries at one point in time or in one country or region over time, will be of limited usefulness.

Food availability per capita is a good measure of how well-off people are from a nutritional or economic point of view, since it includes net food trade as well as domestic food production. A country that shows declining food availability per capita may be said to be in a situation of risk that may not apply to a country with declining food production per capita.

Judgments on the basis of food production per capita or food availability per capita over time should be subject to the caution that diets change over time. A horizontal trend of either of these measures implies an adequate diet, assuming the diet was adequate to start with. A rising trend of either of these measures may imply either that more calories, protein, and other indicators of nutrition are being provided in a diet that is composed of the same foods, or that the diet is chang-

Figure A-15
World Population and Population Growth Rate

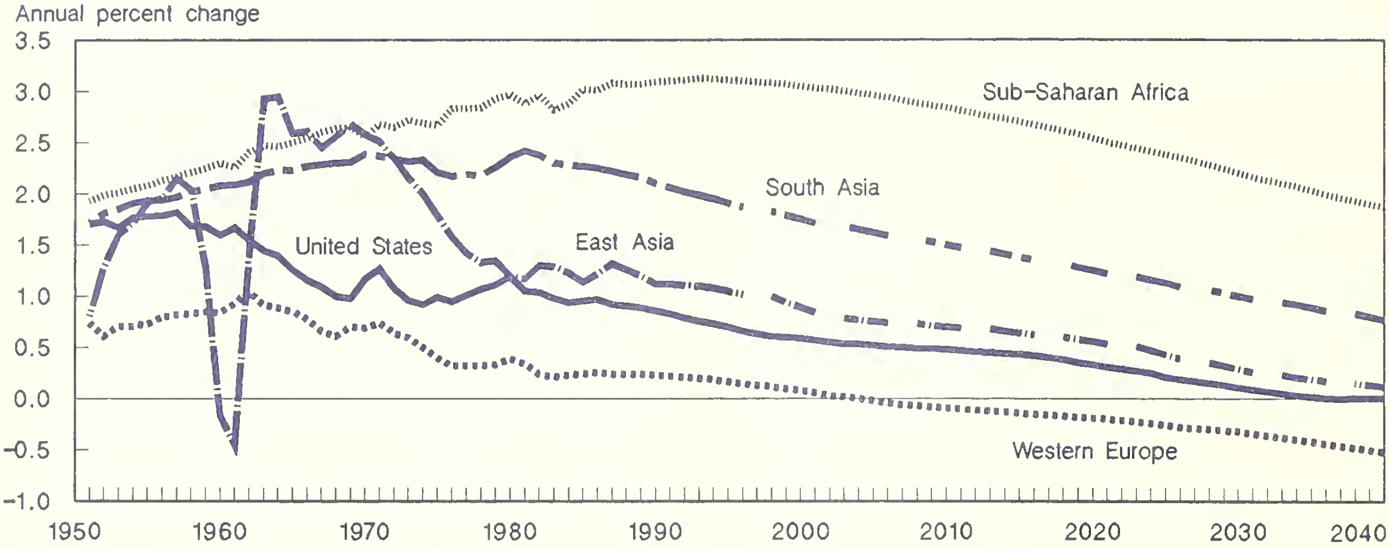


Source: 10.

ing, or both. The implications for resource use obviously differ, however, and therefore so do the implications for answering the question of whether the world has enough resources to feed its population.

Figure A–16

Population Growth Rates: Selected Regions



Source: 10.

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Policies and Institutions

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Policy and institutional factors can both encourage and discourage efficient agricultural production and adequate and equitable food consumption. This being so, man-made changes may prevent the danger that the world will run out of food foreseen by T. R. Malthus and by some people today. It was Malthus who, in 1798, noted with alarm that the human population, at least in Europe, appeared to be increasing much more rapidly than the output of food. Extrapolating these two trends, he envisioned a world in which population increased to the limit of subsistence.

Subsequent critics of Malthus pointed to his neglect of technological change and improvement in crop yields which provided for the food needs of European urbanization and industrialization. While current writers often include technological change in their analysis, they sometimes follow Malthus in omitting the important roles governments and other nonmarket institutions have both as causes of and as possible remedies for the trends they describe. As a result, the trends are extrapolated in mechanical fashion toward crisis.

Many of the trends in food production and environmental degradation result from human actions which are not subject to immutable biological or mechanical laws, but rather are susceptible to social adaptation and change *(16, 17)*. Government policies play a more obvious role in the world food system today than they did in Malthus' day. Likewise, the idea that a society's institutions affect its food situation is by now well accepted. The members of a collective farm, knowing that their production quota will be ratcheted upward next year if they deliver a surplus this year, will not rationally exert themselves to produce a surplus.

Market Failure and Government Failure

Agricultural and food policies are the collective efforts of national and international agencies to influence the actions of producers, traders, and consumers. The purposes of these interventions include improved nutrition, higher rural incomes, more rural employment, maintenance of the environment, and improved food security.

The proper role of the state in governing the actions of individuals is a topic of persistent debate among philosophers, economists, and others. While economists have long argued that markets and prices, if left alone, will lead to maximum efficiency, they have also noted that there are several instances where markets do not exist, or function imperfectly. Such "market failures" can justify the intervention of the state. The entry of government or other nonmarket institutions into the market, however, is a two-edged sword; although these institutions may, in principle, be capable of performing the public service of remedying "market failures," the governors themselves may have other interests than the public interest and employ their powers toward other ends. Such deviations from the spirit of the law can result in "government failure." What follows surveys how market failure and government failure can prevent the realization of productive potential, as well as how these failures can be remedied.

Property Rights

A common justification for government intervention is a lack of clearly defined property rights—ownership is impossible or difficult to demonstrate. Unilateral actions by any one individual cannot solve these problems. Cooperative (often coercive) effort is often required to establish property rights and resolve differing claims. Lack of clearly defined property rights can result in severe misallocation of resources. For example, contrast the practices of a fisher who is the sole owner of a lake with those of a fisher who shares ownership. One expects that the sole owner will not over-fish the lake; the optimal sustainable harvest is one which yields the most revenue in the current season, while assuring good harvests in future seasons. The fisher who does not have exclusive rights to the lake, in contrast, has little incentive to practice resource conservation. If there is no enforced guarantee that all other fishers on the lake will practice conservation, the rational strategy for each fisher acting individually is to harvest as many fish as possible in the present period. Unless some means of regulating the total catch and its allocation among fishers is devised, the fish population will quickly be exhausted.

The key term to the fishing problem is externality: the sole owner bears the full cost of his or her actions while in the many fisher situation no individual fisher bears the full costs of his or her own actions; these external effects are distributed over all fishers.

Most of the large-scale degradation of natural resources derives from the divergence of private and social costs: water and air pollution, litter, deforestation, desertification, depletion of aquifers, and much erosion are all examples. Lack of property rights can result in the under-utilization of natural resources. If, for example, no one person can enforce a claim on a plot of land to the exclusion of all others there is little incentive for anyone to improve the land, as there is no assured means of capturing the increase in productivity.

Much of the increase in agricultural productivity in Britain during the 17th and 18th centuries followed the enclosure and improvement of land which had been held in common. Individual property rights, however, are the exception rather than the rule in developing countries today. The common property regimes that prevail in these countries often are well-structured arrangements in which group size is known and enforced, management rules are developed, incentives exist for co-owners to follow the accepted institutional arrangements, and sanctions work to ensure compliance. Here, problems arise when existing arrangements are undermined or destroyed, or common property rights are appropriated by some distant authority, such as a regional or national government, or even in some cases an agency established for purposes of managing a development project in the area *(8)*.

Environmental degradation from this situation used to be attributed to population pressure or the ignorance of the local people about how to conserve natural resources. Traditional methods of husbandry and cultivation, in particular slash and burn agriculture and nomadic herding, which may have been sustainable under relatively sparse population, can result in soil fertility depletion, over-grazing, and irreversible destruction of an ecosystem under excessive population pressure *(13, 14)*. The fact that traditional agriculturalists and herders have adopted ways of intensifying their production so as to minimize damage to land and other resources is often overlooked when blame is allocated *(3)*.

Government Intervention

When local arrangements are not working properly, or have been superseded, governments are often called upon to step in with policies and programs. Government action is not free, however. The design, operation, and enforcement of laws, regulations, contracts, and incentives require considerable information and effort. When the cost of intervention exceeds the benefit, it makes little sense to intervene. This calculus is reinforced the greater and the more costly the information required for optimal regulation. For example, although an optimal harvest certainly exists for a lake, it may be very difficult, if not impossible to determine what it is: can the solitary fisher discover the actual size, age structure and sex ratio of his fish population without incurring exorbitant costs? Information problems are compounded when coordination of several individuals is required. The design of institutions, incentives, and contracts meant to internalize external costs may require information that no governor or enforcement agency could obtain. Regulation under uncertainty may be superior or inferior to an unregulated situation; there is no guarantee of improvement.

The establishment of property rights or regulatory regimes is no mean feat for governments; but even if these pre-conditions for efficiency can be effected, can one expect public agents to price and regulate resources in an optimal manner? Governments prefer the path of least resistance. Their proclivity for borrowing to avoid raising taxes, thereby shifting much of the burden of today's expenditure to future taxpayers, is well known.

Where dollars and cents are involved, natural resources, particularly in developing countries, often lack constituencies to defend them. In Sarawak, Malaysia, the Penan have for generations made few demands on the tropical rain forest in which they live by hunting and gathering. Logging is rapidly destroying this forest, and with it the wildlife. A major spur to logging was the construction in the mid-1980's of the Limbang road with financing from a 200-million-yen low-interest loan from the Japan International Cooperation Agency. The loggers make a handsome profit selling the timber to Japan, and the Malaysian Government benefits in the form of tax revenues and in other ways. The protests of the Penan that the logging violates their land rights have been ineffectual. As this example shows, the problem of environmental degradation is not simply one of poverty, as it is sometimes portrayed, even where it involves poor people.

The tendency of governments not to regulate in an optimal manner is perhaps most conspicuous, however, in the construction and operation of irrigation schemes. Because these require investment on a large scale and centralized coordination, there are strong arguments for government control. Control includes not just the allocation of water among subdivisions, but extends to setting the price charged for water. It is often the case that the authorities operating such schemes have bowed to pressure from their beneficiaries to keep prices low. Low prices signal users that water is relatively abundant. Perhaps the most egregious example of this is in Egypt, where all Nile water is provided farmers free of charge. Similarly, the price of river water in projects constructed in the western United States in the 1930's is still fixed on cost estimates made then. Both pricing systems promote waste.

Political price distortions are at least as common in product markets where there is little economic justification for government intervention as in factor and resource markets. Joan Robinson, writing on the terms of trade between agricultural and industrial goods, notes that they "are too important to be left to the free play of market forces and everywhere they are manipulated politically *(15, p. 15)*." Government intervention in agriculture is virtually universal *(18)*. There are systemic patterns of intervention: developing countries tend to contrive abundance, and developed countries tend to contrive scarcity.

Contrived Abundance

In developing countries, governments generally subsidize urban food consumption and tax agricultural production. A number of political and fiscal factors lead to this result. Food purchases account for a large share of household budgets in developing countries. Nonfarm households have a large stake in low food prices. On the production side, agricultural production accounts for a large share of gross domestic product in most developing countries. When governments need to raise revenues, it is natural for them to tax the rural and agricultural sectors. Such policies keep returns to producers and costs to consumers low. Low prices signal abundance: consumers are encouraged to consume more of the subsidized products; producers are discouraged from producing and investing in productive improvements; and migration from rural to urban areas is encouraged. Contrived abundance for consumers and reduced incentives for producers lead to the appearance of population growth outstripping food supply—the Malthusian scenario.

But there is more than illusion involved here. Eventually, policies of contrived abundance lead to a strong political demand for cheap food by urban dwellers and a neglect of rural areas which are indeed less and less able to supply urban demand. Governments, in order to retain political support, then find it necessary to spend increasing sums on subsidies and often on food imports.

Following the debt crisis of the early 1980's, many developing countries adjusted their food and agricultural policies to meet credit-worthiness requirements of the International Monetary Fund (IMF) and World Bank. Cutting retail price subsidies and encouraging investment in agriculture are typically part of an IMF structural adjustment package. Research indicates, however, that some elements of this package may have a negative impact on food-producing areas. In Ghana, dramatic devaluations were found to have raised the prices of agricultural inputs as well as of consumer goods, and to have resulted in stringent credit restrictions. In Senegal, prices of agricultural inputs rose even more steeply than official producer prices for peanuts and rice *(19, pp. 9 and 12)*. Price reforms have in some instances led to urban protests and even to the overthrow of governments.

Clearly, the costs of dissolving a contrived abundance can be great, nutritionally as well as politically. However, unless prices are allowed to reflect actual scarcities, the imbalance between production and consumption will continue to widen. When finance ministries are no longer able to underwrite the subsidization of cheap food, the food security of the population may really be at risk.

The prospects for developing country agriculture are not necessarily bleak. Japan, Taiwan, and South Korea, while taxing their agricultural sectors relatively heavily, were able to publicly fund extensive agricultural research and extension systems, as well as encourage the development of transportation and marketing services. Present-day developing countries may benefit from mechanical and biological production technologies that are many times more powerful than in the past.

Some writers argue, on the basis of average yield data, that crop yields appear to be reaching their botanical limit, and that the gains from research are therefore diminishing rapidly *(9, pp. 29-37; 12)*. What is overlooked in making such arguments, however, is that in developing countries, which account for 51 percent of world grain production, 63 percent of world production of root crops, and 62 percent of world oil crops, pulses, vegetables, and fruits *(22, table 4.1, p. 52)*, policies often provide few incentives for the development and diffusion of improved crop varieties and marketing opportunities are often severely limited. As a recent review of the work of the international agricultural research centers put it, "There was no point in working on a new technological approach to greater crop production if national policy made widespread adoption of that approach unlikely *(2, p. 116)*." The review recommended that the centers pay more attention to food policy analysis. It is always a fallacy to treat farmers' yields as identical with experiment station yields.

Even if a developing country is endowed with well-informed policymakers and well-funded development institutions this does not guarantee that the result will be abundant food. Research by Christiansen in Malawi *(10)* has shown how the parastatal marketing board invested its profits in enterprises, including the domestic banking sector, that supported the expansion of the estate sector, which mainly produced export crops. Smallholders, even though in the majority, are placed at a disadvantage in such a situation. Even in developing countries without dualistic agricultural sectors of this kind, small farmers are usually too poorly organized to capture the benefits of development. In India, the power of rural organizations dominated by wealthy wheat- and rice-growers like the Bharatiya Kisan Union (Indian Farmers Union) to obtain cheap loans and loan write-offs, higher subsidies on input prices, and a steady increase in farm prices from the Indian Government has been amply demonstrated *(1)*.

Centrally planned economies also tend to subsidize consumers and generate consumption distortions. In the USSR, state subsidies of 88 billion rubles ($145 billion), or 18 percent of government budgetary expenditures, were allocated in 1989 to cover the differences between government purchase prices for agricultural commodities and retail prices for food *(20, p. 55)*. On the production side, the state ownership and management of agricultural land that is common in centrally planned economies often results in mis-utilization of resources.

Contrived Scarcity

In contrast to developing countries, industrial market economies (IME's) tend to tax food consumers and subsidize agricultural producers. As the agricultural proportion of the population diminishes, its ability to successfully make demands on the political structures of governance increases.

The problem is that in IME's income support to producers is often not effected directly (and efficiently) through transfer payments, but rather indirectly and inefficiently through price supports. High guaranteed prices signal scarcity, but this scarcity is contrived. Just as policies of contrived abundance discourage production, those of contrived scarcity encourage production. Contrived scarcity for consumers leads to surplus production and to production controls on farmers; agricultural output must somehow be held below agricultural capacity. This is why current multilateral trade negotiations are focusing on decoupling support to agriculture from producers' production decisions.

Contrived scarcity encourages increased investment in productive assets. In the long run, the benefits to farmers of price support policies are capitalized in the value of limited productive resources, and the major beneficiaries are the owners of agricultural land. Land owners have a strong vested interest in the perpetuation of price supports. Were price supports removed, say in the interest of agricultural trade liberalization, the contrived scarcity would no longer exist and the value of farmland would plummet.

Just as low prices for water encourage its wasteful consumption, high land prices encourage wasteful conservation and investment. Farmers are led to farm land more intensively, employing more inputs, such as fertilizers, pesticides, and energy than they would otherwise. High land prices make it difficult for younger prospective farmers to enter the industry. The rising average age of owner-operators is a problem in all IME's.

Price supports in IME's tend to be in place for only a few politically important crops, what are called in the United States program commodities. Support of this kind has the following effects: (1) it weakens producers' ability to react to price signals generated by actual scarcity; (2) it introduces artificial rigidities into world trade; and (3) it distorts the direction of research and development.

Since 1985, high U.S. support payments for corn and program restrictions on planting inhibited producers from shifting into soybean production, even though world soybean demand and prices were rising. Anything that inhibits the free movement of resources like land among farm enterprises decreases efficiency.

When price-support programs depend on quotas, as in the case of the U.S. sugar program, they introduce artificial rigidities into world trade. Quotas generally harm some would-be exporting countries who in their absence would be able to take advantage of their lower costs of production to expand market share. Proponents of quotas usually weigh the perceived harm to the would-be exporter against the perceived harm to the would-be importer. Considerations then usually range well beyond the confines of agricultural trade and economic rationality. In Japan, where rice costs several times the world price due to a virtually total ban on imports, the consumers' organization Shodanren allies itself with the rice farmers' union Zenchu to oppose rice trade liberalization, a situation some would describe as perverse.

The contrived scarcity of program commodities induces research and development to focus on program commodities. There is a sizable underexploited reservoir of plant species that could be adapted to the world's evolving food system *(4)*. Crops such as amaranth *(6)*, triticale *(7)*, and tropical legumes *(5)*, to name but a few, can complement production patterns as well as supplement nutrition. One need only look at soybeans, which from an obscure Asian crop prior to World War II became a mainstay of U.S. agriculture, with a key role in rotation patterns, feed rations, and as a source of edible and industrial oils.

In OECD countries, the total cost of farm policies to taxpayers and consumers was about $200 billion in 1986 *(11, p. 173)*. Costs are shared differently between taxpayers and consumers, however (table B-1). Under the Common Agricultural Policy (CAP) of the EC, the main instruments of sup-

Table B-1--Costs of agricultural support policies in selected IME's, 1984-86 1/

Country/ country group	Direct cost to--		
	Taxpayers	Consumers	Total
	Billion U.S. dollars		
European Community	25.2	42.0	67.2
United States	49.1	17.1	66.3
Japan	7.4	34.9	42.3
Canada	3.0	2.7	5.7
Austria	.6	1.0	1.6
Australia	.6	.7	1.3
New Zealand	.4	.1	.5
Total	86.3	98.5	184.9

1/ Annual average.

Source: (21).

port are variable levies on agricultural imports that effectively restrict imports by raising their prices in the EC to above the EC's heavily supported price for the same commodity, and official purchases and restitutions that are used to direct surplus production of major agricultural products from EC markets. This support keeps farmers who, by U.S. standards, are inefficient producers in business.

The interaction of largely unpredictable natural and economic factors with the constraints set in place by national and international agricultural policies and programs contributes to instability. Take, for instance, the rise and decline of world grain production during the 1980's. The 1981 U.S. Farm Bill contained support prices for the major grains for the period 1982-1985. Because legislators were under pressure from farmers to make sure that support prices were not eroded by inflation, the 1981 legislation provided for built-in annual increases in the support price. Two unforeseen economic trends emerged in the early 1980's: first, inflation was brought to a virtual standstill in the United States and second, the value of the U.S. dollar rose dramatically relative to other currencies. Because U.S. support prices are in U.S. dollars, the combined rising support prices and high dollar meant that U.S. grain prices were high from the perspective of other grain exporters such as Argentina, Australia, Canada, China, the EC, South Africa, and Thailand.

The high prices, however, were above market clearing levels. Although signalling scarcity, the United States had record stocks of grain that were legally barred from entering the market. The vacuum created by the legislation was filled by competing exporters who expanded their area planted to grain. Given this policy and price background it is hardly surprising that world production records were set in 1984, 1985, and 1986.

The Food Security Act of 1985 remedied some of the contrived scarcity of the 1981 legislation: support prices were cut sharply and other arrangements were made to support farm income, and provisions were made for reducing the massive stocks. These two actions helped to force world prices down. Countries which had rushed into the market in the early and mid-1980's pulled back on production. When uncontrived or natural scarcity in the form of drought or frost damage and short harvests appear, prices rise, signalling scarcity. Other things being equal, world production will respond by expanding again. The land previously taken out of production under long-term government programs in times of plenty could put the United States at a temporary trading disadvantage vis-a-vis other exporters. The record of the 1980's shows that national agricultural policies and programs can be at odds with rapidly changing world markets.

Conclusion

The recent increased volatility of food production and prices is as much an artifact of government programs, policies, and institutions in many countries designed to achieve a variety of national and international objectives as it is a result of weather fluctuations. Policies of contrived scarcity and abundance can be reformed. It is by no means clear that they will be reformed. Nor, in present circumstances, is there any easy policy initiative capable of quickly arresting the processes of erosion, deforestation, and desertification.

The long-run trends belie the Malthusian extrapolations. At the same time, policies and institutions may have impacts in the short run that make Malthus look right. Thus, we conclude that while the Malthusian scenario is not inevitable, hard decisions about the policy and institutional framework in which farmers produce and consumers consume food are inevitable and require careful thought.

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Agricultural Resources Availability

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The increase in agricultural production to meet the expanding demand as population and incomes grow is ultimately a function of resource availability and technology. Agricultural resources in this article include the nonrenewable components, land, water, and energy. While these resources are scarce to different degrees, the scarcities are periodically relaxed by the reevaluation of existing resource reserves, and by technological advances that allow more efficient use of traditional resources under price pressures. Hence, any evaluation of resource constraints on agricultural production must address the problems of physical constraints of resource endowment, their regional distribution, technological advances in production and resource conservation, resource pricing, and the price pressures on the output markets *(7).*

This article, however, concentrates on the problem of natural resources availability for expanding agricultural production, on a world and regional basis, in light of current and developing technological advances and sharp differences in regional environmental pressures, such as land degradation, water pollution, and periodic energy shortages.

Land Resources

It is generally easier to project the number of people that will have to be fed in the future than the amount of land that will be needed to do it. While there exist rough estimates of potentially usable agricultural land, the methods for evaluating the land potential to produce food are still subject to arguments. In addition, there is no satisfactory global inventory of available soil and water resources. Hence, the analysis of world food production, even in the near future, must necessarily rely on approximations *(2).*

The total land area of the globe is estimated at 13,076 million hectares. This amount changes only imperceptibly since very little land can and is being reclaimed from the globe's bodies of water. Worldwide, only 11 percent of the land mass is currently used as cropland while permanent pastures occupy 25 percent. The remaining 64 percent is divided about equally between wooded areas and the category called "other land" which consists of unused but potentially productive land, built-on areas, parks and ornamental gardens, land used for transportation, and wasteland. Globally, this land use distribution has changed very little over time, though substantial changes have occurred in some countries and regions (table C-1).

Over the past quarter of a century, cropland expanded nearly 11 percent, after taking into account cropland lost due to urban expansion, especially in Europe and China. Land in permanent pastures increased during this time by 2 percent, though this number hides a slow, but steady, increase through the mid-1970's, and then a slow decline as some permanent pastures were converted into cropland or lost to other uses. Forests and woodlands declined during this time in all regions, principally through conversion to cropland. Finally, the area in the other land category decreased through about 1970, as wastelands were converted to croplands, and then began to expand slowly as urban areas and land in commercial and transportation use encroached on other land categories. In Sub-Saharan Africa, area under the other land category increased due to the rapid expansion of urban areas throughout the continent, as well as the progressive desertification in the Sudano-Sahel zone.

Today, world cropland available per person is about a third of a hectare, down from nearly half of a hectare in 1961, a very substantial drop of 32 percent in a quarter of a century (table C-2). The total cropland availability, however, varies widely among regions and countries. For example, the amount of cropland available per inhabitant in Australia is 3 hectares, while in China and Japan it is only .09 and .04 hectare respectively. This means that in China one hectare of cropland must feed over 11 people and in Japan 25 people, while in North America it must feed only about one person. Regions well endowed with cropland in relation to their population include North and South America, the Soviet Union, Australia, and New Zealand. South, Southeast, and East Asia have progressively less cropland per person. Sub-Saharan Africa has a favorable ratio, but the high rate of population growth is rapidly shrinking the ratio. This is particularly serious because the predominantly light and fragile tropical soils of the region, with its limited rainfall, can support only a sparse population density.

Over the last three decades, world cropland has expanded slowly. The annual rate of growth dropped gradually from close to 1 percent in the 1950's to 0.5 percent in the 1960's and 0.2 percent in the 1980's. Current trends indicate that over the next 25 years this rate is likely to drop to about .15 percent per year, adding some 50 to 60 million hectares of new cropland and bringing the total from 1,474 million hectares in 1986 to about 1,530 million hectares in the year 2010. Most of this expansion is likely to occur in North and South America, Sub-Saharan Africa, and Australia-New Zealand and, possibly, in the USSR. Cropland in Europe, in the Near East, and in China will likely continue to fall.

The maximum potential of arable land in the world has been variously estimated at between 2,500 and 3,200 million hectares. Most recent authorities *(1, 2, 14)* tend to favor the lower limit (table C-3). Thus, the additional one billion hectares of cropland still left for development, backed up by advances in yield-improving and resource-conserving technologies, should theoretically provide a fairly wide security

Table C-1--World land use by category

Land use	1961	1986	1961-86	1961	1986
	Million ha		Percent change	Percent of total	
Cropland	1,333	1,474	10.6	10.2	11.3
Permanent pastures	3,151	3,212	1.9 1/	24.1	24.6
Forests and woodlands	4,144	4,074	- 1.7	31.7	31.2
Other land	4,445	4,313	- 3.2 2/	34.0	33.0
Total	13,073	13,076	0	100.0	100.0

1/ Permanent pastures area expanded slowly through the early 1970's and then registered a steady decline. 2/ The area under "other land" category declined until about 1970 and then begun to expand.

Source: (3).

Table C-2--Cropland per inhabitant by region

Region/country	Ha per capita 1961	Ha per capita 1986	Percent change 1961-86
	Ha		Percent
World	0.44	0.30	- 32
North America	1.11	.88	- 21
Latin America 1/	.59	.43	- 27
Europe 2/	.35	.28	- 28
USSR	1.05	.83	- 21
Sub-Saharan Africa	.54	.33	- 39
North Africa and Middle East	.58	.31	- 47
South Asia	.33	.20	- 39
Southeast Asia	.25	.18	- 28
China 3/	.16	.09	- 44
Other East Asia	.08	.05	- 38
Oceania	1.93	1.96	2

1/ Includes Mexico. 2/ Excludes USSR. 3/ Excludes Taiwan.

Source: (3).

margin for growing world population. However, this land is unevenly distributed around the globe and the amount that can actually be brought into production is questionable. Most remaining unused or underutilized agricultural land carries serious constraints, such as poor accessibility, the presence of endemic human or animal diseases, difficult climate or topography, and soils of limited productivity under current cropping and management systems.

Environmental concerns, such as the greenhouse effect, are creating pressures to leave standing potentially agriculturally productive tropical forest lands, such as in the Amazon River delta. Overcoming these constraints will require large capital outlays and time. In addition to the constraints on the expansion of agricultural land, some land currently in use is subject to degradation which either reduces yields or may take some areas out of production altogether. While this is a subject for serious and growing concern, the effect on global food production is, and will probably remain, limited.

The land constraint is continuously being relaxed by a stream of technological innovations, including the expansion of multiple cropping (crop rotations and intercropping). Where the land constraint pinches the food supply the most is in the uneven distribution of agricultural land. This particularly applies to regions with already large populations of rural landless, like South Asia, where rapidly increasing population exerts a corresponding pressure on cultivated land.

Water Resources

The primary source of water for crop production is precipitation on land. About 65 percent of this precipitation eventually returns to the atmosphere as evapotranspiration. The remaining 35 percent recharges aquifers, streams and lakes as it flows to the sea and thus constitutes the renewable freshwater resource which supports the land-based life. The total annual precipitation on the earth is estimated at about 110,000 cubic kilometers. Of this, 71,000 cubic kilometers return to the atmosphere as evapotranspiration and 39,000 cubic kilometers represent total river runoff (table C-4).

While the global water supply is plentiful, it is very unevenly distributed. River runoff from precipitation varies from 1,425 cubic meters per hectare of land in Africa, a large part of which is occupied by deserts and dry lands, to 6,580 cubic meters per hectare of land in well-watered Europe. However, a more significant indicator of water supply is the country by country distribution since the precipitation and water runoff vary greatly within each continent. Thus, in the Americas the annual water runoff per hectare of land varies from 310 cubic meters in Peru, a southern part of which is a desert, to 14,740 cubic meters in largely mountainous Nicaragua. The United States has about the average water runoff of 2,700 cubic meters per year. Elsewhere, Northern Europe, Southeast Asia, Bangladesh, India, and Oceania (except Australia) enjoy a very high water runoff, while North Africa and the Middle East are severely and increasingly water deficient. For example, in both Egypt and Saudi Arabia, the annual water runoff per hectare is only about 10 cubic meters because of low precipitation and high evaporation rates (table C-5).

Agriculture is the largest water user, being responsible for about 70 percent of the total water use for irrigation and another 3 percent for livestock raising. Industrial and mining operations take about 22 percent of available freshwater, and domestic use the remaining 5 percent. While world cropland expanded over the past quarter of a century at the annual rate of 0.4 percent, irrigated area increased at nearly 2 percent per year. By 1986, some 15 percent of world cropland was irrigated, up from about 10 percent in 1960 (table C-6). Irrigation increased in all countries and regions, with Asia showing the fastest increase.

In the United States, irrigated area increased steadily until 1978 to reach 20 million hectares, or 11 percent of land under crops, declined some through 1984 due to the planted

Table C-3--Population and current and potential arable land

Region/country	Population 1986	Population 2050	Arable land 1986	Arable land Potential
	--- Million ---		Million ha	
World	4,967	10,805	1,474	2,500
		Percent of total		
North America	5.4	3.0	16.1	15.0
Latin America	8.5	8.9	12.1	23.4
Europe 1/	9.9	4.3	9.5	5.7
USSR	5.7	3.6	15.7	11.1
North Africa and Middle East	5.6	9.7	7.3	10.4
Sub-Saharan Africa	9.7	21.6	10.8	12.4
Asia	54.7	48.5	25.0	22.0
Oceania	.5	.4	3.5	4.6

1/ Excludes USSR.

Sources: (1, 11, and 14).

Table C-4--Annual precipitation and river runoff: Total, per hectare of land, and per inhabitant

Region/country	Precipitation	River runoff Total	River runoff Per ha	River runoff Per inhabitant
	Km3/year	Km3/year	m3/ha/year	1000m3/year
No. & Cent. America	13,910	5,960	2,786	14.5
South America	29,355	10,830	5,920	36.4
Europe 1/	7,165	3,110	6,580	6.3
Africa	20,780	4,225	1,425	7.0
Asia	32,690	13,190	4,924	4.5
Oceania	6,409	1,965	2,331	78.1
World	110,305	38,830	2,969	7.7

1/ Excludes USSR.

Source: (16).

Table C-5--Annual runoff from indigenous precipitation: Selected countries, 1987

	Total	Per hectare	Per inhabitant
	Cubic km	1,000 cubic m	Cubic m
Canada	2,091	3.15	111.74
United States	2,478	2.70	10.23
Nicaragua	175	14.74	99.97
Brazil	5,190	6.14	36.69
Ecuador	314	11.34	31.64
Peru	40	.31	1.93
Norway	405	13.16	97.40
Netherlands	10	2.95	.68
Poland	49	1.62	1.31
USSR	4,384	1.97	15.44
Egypt	1	.01	.02
Cameroon	208	4.43	19.93
Kenya	15	.26	.66
South Africa	50	.41	1.47
Saudi Arabia	2	.01	.18
India	1,850	6.22	2.35
Indonesia	2,530	13.97	14.67
China	2,800	3.00	2.58
Australia	343	.45	21.30
New Zealand	397	14.78	117.53

Source: (16).

Table C-6--Total and irrigated cropland by region, 1961-65 and 1986

Region/country	Cropland 1961-65	Cropland 1986	Irrigated area 1961-65	Irrigated area 1986	Irrigated area as percent of cropland 1961-65	Irrigated area as percent of cropland 1986
	Million ha				Percent	
World	1,334	1,474	149	228	11	15
North America	222	236	15	19	7	8
Latin America	116	176	10	15	9	8
Europe 1/	152	140	9	16	6	11
USSR	229	232	10	20	4	9
Sub-Saharan Africa	123	159	3	7	2	4
N. Africa and M. East	81	108	14	23	17	21
South Asia	201	209	40	66	20	32
Southeast Asia	62	74	9	13	15	18
China 2/	104	98	39	45	38	46
Other East Asia	80	70	22	20	28	29
Oceania	34	49	1	2	3	4

1/ Excludes USSR. 2/ Excludes Taiwan.

Source: (3).

area reduction program and the financial crisis in the farm sector, and then increased again to over 19 million hectares in 1980.

The highest proportion of irrigated land to total cultivated land occurs in Egypt, where it is 100 percent, and then in Japan, 67 percent. China comes next with 46 percent, followed by South Asia, 32 percent, Other East Asia, 29 percent, and then North Africa and the Middle East, 21 percent. In contrast, only 4 percent of cultivated land is irrigated in Sub-Saharan Africa.

Irrigation, together with increased fertilizer application and improved seed varieties, have been the principal factors in increasing agricultural production in the 1970's and the early 1980's. More than half the increase in agricultural output in the past 20 years came from new or rehabilitated irrigated areas *(2)*.

Irrigation is still considered a major factor in increasing agricultural production. According to FAO estimates, some 50 million hectares of new land could be irrigated in the next decade, and the irrigation system on about the same amount of land could be improved to support much higher yields *(2)*. This would increase the irrigated land by over 20 percent and allow intensive agriculture to spread beyond Asia. However, large capital requirements and long gestation periods that characterize irrigation projects will be needed.

Current estimates of freshwater availability to sustain the increasing world population at an improving standard of living, including expanded irrigation, increased urbanization, and industrialization, vary from one source to another. However, all sources seem to indicate that there will be adequate water available over the foreseeable future at the current water use growth rate *(1, 15)*. For example, current fresh water withdrawal in the United States amounts to 467 cubic kilometers per year, or 19 percent, out of the total available from annual runoff of 2,478 cubic kilometers *(15)*. For the world, the proportion of the annual withdrawal to the total water availability is near 10 percent *(1)*.

Thus, the principal problem is not the availability of total water, but its uneven geographic and time distribution. For many countries, prospects indeed look poor. This applies in particular to countries in North Africa, the Sahel and East Africa, the Middle East, and parts of India and China. For instance, during the next two decades Saudi Arabia is likely to face a critical shortage of water if measures are not taken soon to control the rapid depletion of the country's nonrenewable water resources. These resources consist of deep underground, non-replenishable aquifers which currently supply about 90 percent of the country's water needs. This could lead to policy changes that could put an end to irrigation subsidies and, of necessity, greater reliance on food imports. Many countries in North Africa and the Middle East face similar hard choices.

The other problem which affects water supply is water quality. Water pollution from sewage dilution, excessive use of chemical fertilizers and pesticides, animal wastes, and industrial chemicals have seriously affected fresh water supplies. In parts of Central and Eastern Europe as much as 90 percent of surface water is already polluted. A part of the pollution problem is also the increasing salinity of water resources as irrigation expands. Such pollution is certain to increase in many parts of the world with development and population growth unless preventive actions are taken. Many such actions involve close international cooperation, which is currently missing in many instances, delaying a solution.

Energy

World commercial energy supplies consist mainly of oil, coal, natural gas, hydroelectric power, and nuclear power. Wood is still important as a local household energy source, particularly in developing countries, but is insignificant in the total commercial energy supply and its share will likely keep decreasing as wooded areas contract. Also, geothermal, solar and wind energy use expanded during the petroleum crisis years of 1973-81, and these still offer a considerable scope for future expansion, but their share in total world energy use is still minuscule. Oil dominates the commercial energy situation, and in 1987 supplied 43 percent of the total world energy requirements. Coal's share stood at 31 percent, and that of natural gas at 22 percent. The remaining 5 percent came from hydroelectric and nuclear power (table C-7). Nuclear power stations increased rapidly in the 1970's and the beginning of the 1980's, but their growth slowed as serious problems with the disposal of nuclear radioactive wastes and nuclear power station accidents multiplied.

World commercial energy reserves have been estimated to last, at the mid-1980's consumption rates, 33 years for oil, 59 years for natural gas, and 226 years for coal (table C-8). Domestic oil reserves are estimated to last from as little as 9 years in North America to 86 years in the Middle East, and natural gas reserves from 6 years in the smaller communist countries to over 100 years in the Middle East and Africa. Coal reserves, however, are much more abundant and are expected to last from over 100 years in Eastern Europe to well over 300 years in North America, Africa, the USSR, and China. The extraction rates used to determine the duration of reserves were calculated at the time where petroleum prices declined from their all-time maximum of $34.50 per barrel in 1979 to about $15 dollars per barrel in 1986, and the total world energy consumption per year, which declined from its all-time high of 8.8 billion metric tons (oil equivalent) in 1979 to 8.5 billion tons in 1982, was on the rise again. In contrast to the 1970's when the growth in energy consumption reached 5.2 percent per year, in the mid-1980's the annual rate went down to 2.8 percent.

Table C-7--Composition of world energy production, 1987

Source	Production	Share
	Million Mtoe 1/	Percent
Crude oil and n. g. l. 2/	3,010	43
Coal and lignite	2,172	31
Hydroelectric power	179	3
Nuclear power	144	2
Total	7,036	100

1/ Mtoe = metric ton oil equivalent.
2/ N. g. l. = Natural gas liquids.

Source: (12).

In addition, world energy reserve estimates have been adjusted upward in recent years. The most recent estimates of 1989 for proven oil reserves were increased from 95 to 123 billion tons, extending the duration of supplies from 33 to 42 years *(6)*. Still, even if energy consumption rates used to calculate the duration of reserves are overstated and the proven oil reserves adjusted upward even more, there is little doubt that the next two decades will witness a decline in oil production and a gradual transition to a new energy era where each country will have to tailor its energy use much closer to its individual mix of resources and improve substantially the energy use efficiency. This is particularly important for agriculture, which relies principally on oil and natural gas for fuel and in the manufacture of fertilizers and other agricultural chemicals.

Agricultural production activities use between 3 and 6 percent of all commercial energy consumed, depending on country and its degree of industrialization. This includes gas used in the production of nitrogen fertilizers. The food sector as a whole, however, including production, transportation, storage, processing and marketing, accounts for 16 to 22 percent of all commercial energy used *(5)*. About 80 percent of the energy used in agricultural production is oil-based, the rest is equally divided between natural gas and electricity (some of which is also oil-based).

During the oil crisis years of 1973-81, substitute sources of energy, and particularly fuel alcohol from biomass, such as sugarcane, corn, and sweet sorghum, received considerable attention as alternative sources of energy. Few energy deficit countries, however, have sufficient cropland base to adopt this solution. Brazil has made the most intensive effort in this direction, reserving at one time some 4 million hectares of land planted to sugarcane, or 0.5 percent of its cropland, to produce alcohol to replace 45 percent of its gasoline needs. This effort, however, lost ground as petroleum prices dropped steadily after 1981. For the foreseeable future, cropland will remain more valuable for food and fiber production than for energy production.

The energy outlook indicates that supplies will generally remain adequate over the next two to three decades, for the projected levels of agricultural and industrial activities consistent with current trends in population growth. However, currently low prices, particularly for oil, are unlikely to hold for long. They will probably start creeping up, even at the current rate of world total demand growth of under 3 percent per year, or at 1.1 per cent per year on a per capita basis. Though the proven world oil reserves are periodically being adjusted upward, and for now production outpaces demand, some oil shortages may appear in the next two decades and the proportion of total energy supplied by oil will certainly decrease. In some parts of the world, this will aggravate the already serious problem of air pollution caused by burning fossil fuels through the emission of such gases as sulfur diox-

Table C-8--Proven commercial resources by region, 1986
(Million tons oil equivalent and years)

Region/ country	Oil Reserves	Oil R/P	Natural gas Reserves	Natural gas R/P	Coal 1/ Reserves	Coal 1/ R/P	Total Reserves
	Mtoe	Yrs	Mtoe	Yrs	Mtoe	Yrs	Mtoe
North America	5,130	9	7,420	16	135,380	313	147,900
Latin America	12,400	38	5,100	72	3,230	241	20,730
Western Europe	5,400	12	5,750	36	43,380	212	51,530
Middle East	54,800	86	24,210	100+	-	-	79,010
Africa	7,300	29	5,300	100+	43,860	362	565,460
Asia/Oceania	2,500	14	5,200	54	42,750	211	50,450
USSR	8,000	13	40,710	64	117,820	344 2/	166,530
China 3/	2,400	19	740	64	108,770	312 2/	111,910
Other 4/	300	11	370	6	36,800	110 2/	37,470
World	95,200	33	94,800	59	531,990	226	721,900

Notes: Conversion factors to million metric tons oil equivalent (mtoe):
1 billion cubic feet of natural gas = 24,445 mtoe.
1 metric ton of hard coal = .645 mtoe.
1 metric ton of soft coal = .325 mtoe.

R/P = Ratio of proven reserves to 1986 production rate

- = Not known. 1/ Hard and soft coal. Soft coal represents 27.5 percent of world total coal reserves and is concentrated in North America (33.3 percent of the regional coel reserves); Western Europe (46.5 percent); Asia (24,2 percent); USSR (38.4 percent); and in other countries, principally Eastern Europe (41.8 perceent). 2/ Author's estimate. 3/ Excludes Taiwan. 4/ Albania, Bulgaria, Cambodia, Czechoslovakia, Cuba, East Germany, Hungary, Laos, Mongolia, North Korea, Poland, Romania, and Yugoslavia.

Source: (16, table 7.2, p. 111).

ide, oxides of nitrogen, and carbon dioxide. Hence, environmental and price pressures will certainly influence both energy production and consumption. Such pressures, added to the increasing shortages of oil and natural gas will profoundly change the agricultural production process.

Conclusions

An analysis of agricultural resources availability and use indicates that the earth is reasonably well endowed with basic, nonrenewable natural resources such as land, water, and energy. These resources appear sufficient to feed the growing world population at a gradually improving standard of living, assuming that the population growth will stabilize sometime around the end of the next century, as most population projections show *(9, 15, 16)*.

These resources, however, are unevenly distributed around the globe, resulting in often prolonged, though localized shortages. Consequently, agricultural trade will be increasingly important. Yet many of the countries which lack agricultural resources also lack foreign exchange to import food. Though the natural resources are thought to be fixed, the constraint is being constantly relaxed by technological advances and improved management techniques. There is no reason to believe that such advances are coming to an end. Still, technological advances and improved management practices are no less evenly distributed among countries than the resources themselves. Also, resource substitution as well as technological developments often require massive capital investments while new capital is increasingly expensive.

In this sense, while world resources are sufficient to feed the projected world population, the provision of food of required quality and its distribution will be increasingly expensive and the problem is being reduced to who will bear the cost and how.

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Technology: Are We Running Out of Steam?

by

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Technological innovations have greatly increased the efficiency of world agricultural production. In the most recent past, technologies associated with the Green Revolution provided an unprecedented increase in crop yields and production. However, due to differences in farming systems, environment, and institutions, benefits were spread unevenly among countries. Yields in some countries are just beginning to increase, while in other countries yields are high and growth is slowing, and in still other countries yields are declining. The availability and transfer of current and emerging technologies hold the key to reversing these declines and sustaining agricultural growth.

World agriculture operates at several technological levels simultaneously, depending on resource availabilities and costs. Technologies currently in use range from intensive irrigated monocultures yielding many tons of grain per hectare with high production costs to complex mixed cropping systems where the yield of any one crop may amount to no more than a few kilograms per hectare, rainfall provides the only water, and input costs are minimal. Even for a single crop like rice, yields range from 0.8 tons per hectare to more than 4 tons per hectare depending on the technology used *(20, table 4.5, p. 62)*. Biotechnological innovations are an important emerging element.

The Impact of the Green Revolution

The Green Revolution refers to a package of technologies that include improved crop varieties, chemical inputs, irrigation, new tillage practices, and improved management techniques. The core of the Green Revolution is the development and dissemination of new shorter, high-yielding, lodging resistant varieties of wheat and rice in Mexico and Asia during the 1950's and 1960's. Other crops improved by the use of new germplasm sources and hybridization techniques include maize, sorghum, beans, groundnuts, cassava, and potatoes. High-yielding varieties of wheat have been widely adopted in Bangladesh, India, Nepal, Pakistan, Guatemala, Mexico, and Argentina. Improved rice varieties have been adopted in much of Asia, and improved maize varieties are commonly used in the United States, Europe, South America, and some African countries.

Since the mid-1960's, average world grain and root and tuber yields have increased 65 percent and 24 percent, respectively (table D-1). In Asia, grain yields increased 80 percent and root and tuber yields increased 57 percent. In Africa, grain and root and tuber yields increased, but grain yield increases were below the world average because the relatively small area under irrigation in Africa did not maximize the potential of new varieties developed for irrigated agriculture. In most cases, yields increased more from 1974-76 to 1984-86 than from 1964-66 to 1974-76.

The Green Revolution technologies have enabled some developing countries to become more self-sufficient in food production and, as recent studies show, may have helped reduce the year-to-year variability in yields *(1)*. Benefits from this agricultural growth extend beyond the farm sector in the form of low-priced food for consumers and as increases in income levels and exports provide developing countries with much needed foreign exchange.

The Green Revolution has been criticized for encouraging input intensive agriculture, neglecting locally important crops, and bypassing severely impoverished regions. Green Revolution-type technology uses monoculture cropping patterns that have relied heavily on pesticide use. Such practices may be environmentally damaging over a prolonged period. For other crops, such as rice and wheat, new varieties resistant to new diseases are continually developed, and, hence, do not depend as much on increased pesticide use.

In addition, some critics argue Green Revolution-type technology is more accessible to successful, large farmers who adopt these methods at a faster rate than smaller farmers *(12)*. However, some recent studies show that for scale neutral technologies, such as high yielding varieties, small farmers adopted new technologies at least as fast as the large farmers, but for non-neutral technologies, such as tractors, large farmers adopted new technologies faster *(11)*.

Finally, not all Green Revolution-type technology was available in some crops, such as millet, and in some areas, such as Sub-Saharan Africa, due to inadequate research facilities and lack of irrigation infrastructure *(2)*. Many developing countries were formerly colonies which emphasized the development of cash crops over staple crops. Hence, development of cash crops was favored over staple crops. Recently, however, national programs have increased research expenditures on staple crops *(12)*. Also, some regions have not benefitted from technological innovation. In particular, the rainfed drylands where agricultural production is highly uncertain have not received the same research attention as more fertile areas *(20)*.

Table D-1--Global grain and roots and tuber yields, 1964-66 to 1984-86

	Grains			Roots and Tubers		
	1964-66	1974-76	1984-86	1964-66	1974-76	1984-86
	Kg/ha					
World	1,547	1,948	2,552	10,297	11,400	12,768
Africa	841	1,007	1,077	6,139	6,611	7,735
North & Central America	2,444	2,885	3,837	15,651	18,091	19,720
South America	1,415	1,644	2,038	11,227	11,011	11,452
Asia	1,401	1,828	2,523	8,885	12,026	13,950
Europe	2,326	3,183	4,234	16,728	18,301	21,412
USSR	1,152	1,644	1,625	10,601	11,070	12,509
Oceania	1,290	1,415	1,599	9,567	9,915	10,906

Source: (20, table 17.1, pp. 272-273).

Current and Emerging Technologies

Future food production is a function of, among other things, current and future technologies, which in turn are constrained by technology adoption and transfer. The technology is divided here into conventional, high-input monoculture farming, and unconventional farming systems and agroecosystems.

Conventional plant technologies focus on increasing output per unit of input (land, labor, and capital) in a specific commodity. Often these technologies, as Green Revolution technologies exemplify, come in a package (table D-2). Wheat, rice, maize, beans, cassava, sorghum, potatoes, and pearl millet yields, in particular, continue to improve using conventional technology *(2)*. The new technologies, on the other hand, may increase yields, expand the production area for some crops, stabilize yield under drought and heat conditions, or provide resistance to disease and insects.

Some work has been done on the international and national level to increase conventional cattle production, particularly for Sub-Saharan Africa. Because of the tsetse fly, a large amount of the African continent is not farmed, including some well watered, fertile land *(10)*. Researchers are using a method that eradicated the screw worm from livestock in the United States to attempt to eradicate the tsetse fly *(2)*. If the tsetse fly is eradicated, much land will be released for livestock grazing in Africa.

Recently, the Food and Agriculture Organization of the United Nations (FAO), the World Bank, and the international agricultural research centers (IARC's) have researched farming systems and agroecosystems *(20)*. Such research is process-oriented (as opposed to commodity-oriented), assessing how appropriate a new technology is for a particular farming system, including tillage and crop-rotation research. Tillage and crop-rotation research is important to increasing soil fertility and water storage, and decreasing soil erosion *(2)*. In the African Sahel, for instance, as research in USDA has pointed out, improving soil moisture and maintaining soil fertility in the long run are the most pressing needs of agriculture, and crop breeding for drought tolerance offers little hope in this regard. Thus, the emphasis must be placed initially on soil and water management technologies *(7)*. Agroecosystem research also evaluates broad (as opposed to on-farm) ecological and economic consequences to technology adoption. However, the drawbacks to farming systems and agroecosystems research include high research costs and limited local orientation.

Table D-2--Some crops subject to improvement using traditional crop improvement techniques

Crop/improvement technique	Description	Type of region affected
Triticale	A hybrid between wheat & rye, high yielding, protein rich.	Cool temperatures, such as foothills of Himalayas, and acid soils such as campos cerrados in South America.
Wheat	Resistant to aluminum soils.	Tropics.
Rice	Can grow in areas previously could not.	Upland rice regions.
Legumes & pasture	Higher yielding, grow in areas previously could not, increase livestock production.	Semi-arid tropics.
Faster maturing varieties	Increase number of crops grown in a year, i.e. from 1-2 to 2-3.	Most areas.
Crossing domestic and wild species	Introduction of new genes into domestic varieties, new sources of resistance to disease and insects, tolerance to salinity, high temperature and drought.	Most areas.

Source: Adapted from (2).

In the general sense, biotechnology is the manipulation of genes, including traditional plant and livestock breeding. Today, however, this term is usually reserved for manipulating genes via genetic engineering, such as cutting and transferring deoxyribonucleic acid (DNA), the basic genetic material which governs the growth of living organisms and transmits their characteristics to offspring. We refer to it in this sense in this article.

Agricultural biotechnology falls into three categories; plant, animal, and microbial. Plant products from biotechnology are listed and described in table D-3. The first three areas, herbicide resistance, pest resistance, and disease resistance, currently use only single-gene traits. The last trait, modified composition, is often controlled by more than one gene. Most of the work has been done in the single-gene traits.

In plants, transferring the genes for these products and regenerating plants is relatively easy, and, hence, many transfer techniques exist. Nevertheless, many hurdles still exist, such as incorporating foreign DNA and passing it onto the next generation; expanding the types of plants amenable to biotechnology, including wheat and rice; and manipulating multi-gene traits. Unfortunately, wheat and rice are the two most widely grown crops in the world and the most significant agronomic traits, such as yield and stable pest or disease resistance, are usually multi-gene controlled. Work in new biotechnology techniques should help overcome some of these problems.

Animal biotechnology includes three major areas; embryo technology, gene technology, and hormone and immuno technology with embryo technology being the most advanced. Embryo biotechnology has benefitted from a 20-year knowledge base, including recovery, storage, and implantation of embryos, and artificial insemination. With the use of these techniques, there has been an increase in the number of births per cow. In the future, these techniques may increase the twinning rates in cows, expand the transfer and stock of rare genes and genotypes, and decrease the environmental shock to imported genotypes *(6)*. New embryo technologies on the horizon include sexing embryos and semen, *in vitro* fertilization, embryo splitting for identical individuals, and embryo cloning *(4, 6, 15)*. Overall, these techniques will improve animal gene pools and breeding.

Animal gene biotechnology is relatively new. Animal gene transfer relies mainly on direct injection of foreign DNA. However, once these genes are transferred, the animal cell incorporates the foreign DNA and transfers it to the next generation more easily than plant cells. Some of the potential benefits include: (i) synthesizing new proteins that have some value either to animals or humans; (ii) identifying and transferring genes that are beneficial to the recipient animal; and (iii) identifying and producing genes at a lower cost in a bacterial or fungal culture. Much work is still needed in identifying more valuable single genes, and in identifying and transferring multi-gene traits such as milk production or growth rate *(6)*.

Hormone and immuno technologies are used to improve productivity and to develop vaccines for both animal and human diseases. One of the most prominent examples of hormones is the recombinant growth hormone for dairy, cattle, and pigs. Other hormones increase fertility in animals. Some of

Table D-3--Description of plant biotechnology products.

Plant resistance to:	Description	Specific products	Examples of crops
Herbicide	A plant that is resistant to a herbicide. Hence, a farmer can apply a herbicide to a crop that previously would have been damaged from that particular herbicide.	Resistance to glyphosate, atrazine, sulfonylurea, imidazolinone, and bromoxynil.	Corn, Soybeans, Rice, Cotton, Rapeseed, Tomatoes, tobacco.
Pest	A plant that produces toxins to its natural insect predators. Consequently, pesticides no longer have to be applied.	Bacillus thuringensis toxin protected crops - resistant to caterpillar larvae pests; seeds with enhanced anti-feedant content to reduce losses to insects while in storage.	Tobacco, Tomatoes, Potatoes, Corn, Soybeans, Rapeseed, Alfalfa.
Disease	A plant that is resistant to diseases,which helps to maintain yields.	Resistance to crown gall; tobacco mosaic virus; potato leaf roll virus.	Tomatoes, Potatoes, Alfalfa.
Modified	A plant's protein, fat, starch, or nutritional level may be altered, or its yield increased.	Tolerance to salt; drought; temperature; heavy metals.	Corn, Sorghum, Soybean, Tomatoes.

Source: Adapted from (16) and (3).

the vaccines battle diseases such as foot and mouth disease, enteric diseases, and ectoparasites *(6).*

Microbes, such as bacteria, viruses, and fungi, can also benefit agriculture. They can be used as pesticides, plant symbionts, and vaccines for animal diseases. Microbes are amenable to biotechnology because their genetic structure is well understood and easy to manipulate. However, microbes also pose problems because they transfer genetic material and adapt to new environmental conditions so easily that control and predictability of genetic transfer are difficult. Many scientists refute this concern by citing the lack of negative consequences from using microbes already introduced in the environment *(16).*

Technology Adoption and Transfer

A country's ability to adopt agricultural technology depends on agro-climatic, institutional, and economic factors. Domestic and international technology transfers occur through a variety of public and private sector channels and can be facilitated by government policies including technology policy, fiscal and monetary policy, trade policy and patent laws. International technology transfer occurs because some countries lack the scientific expertise or research infrastructure required to conduct domestic research. In the short-run, it is frequently cheaper to import technology than establish a domestic research program or production facility.

Technology transfer in the public sector is channeled through government supported research centers and extension services, direct aid programs, universities, and the IARC's. In the past, the public sector developed a majority of the agricultural technologies. For example, the IARC's helped develop and disseminate Green Revolution technologies. Today, they continue to focus on applied research in crops, livestock, and farming systems for developing countries and on disseminating technology. Developed countries continue to dominate public agricultural research spending, but developing countries have steadily increased their share of total research expenditures (table D-4).

Recently, the private sector has become an important player in developing and transferring technologies. Its participation will affect the development, adoption, and transfer of future technologies because different factors drive private sector technology development than public sector research. The private sector is motivated by profitable opportunities that usually focus on patentable research such as machinery, chemicals, and seeds. In addition, the patentability of biotechnology may have helped induce the private sector to become the principal developer of emerging biotechnologies (table D-5).

Table D-4--Global agricultural research expenditures

Region	1959	Year 1970	1980
	Million U.S. dollars, 1980		
Western Europe	275	919	1,490
Eastern Europe and USSR	8	1,282	1,493
North America and Oceania	760	1,485	1,722
Latin America	80	216	463
Africa	119	252	425
Asia	261	1,205	1,798
World	2,064	5,359	7,390

Source: (20, table 4.3, p. 56).

Table D-5--Firms and public institutions involved in agricultural biotechnology research, 1986

Country or region	Animal agriculture: Private firms	Public institutions	Total	Percent private	Plant agriculture: Private firms	Public institutions	Total	Percent private
	Number			Percent	Number			Percent
United States	451	62	513	0.88	727	111	838	0.87
Europe	121	12	133	0.91	180	26	206	0.87
United Kingdom	50	2	52	0.96	98	21	119	0.82
Japan	36	0	36	1.00	52	4	56	0.93
Canada	22	4	26	0.85	49	12	61	0.80
Australia	15	3	18	0.83	24	6	30	0.80
Other	14	12	26	0.54	46	16	62	0.74

Source: Adapted from (20).

The public sector invests in research that the private sector is unwilling to undertake due to risk factors, market failure, or few monetary returns *(13)*. The public sector often carries out basic research (which is associated with delayed and uncertain payoffs), develops unpatentable innovations (which are easily appropriated by those not bearing the costs), and assists firms during the early stages of growth or through periods of unanticipated shocks *(8)*. The public sector also provides local research programs aimed at adapting technology to local market conditions to guarantee the successful adoption of technology.

A patent system affects the direction and structure of research and the transfer of technology and international patent agreements facilitate the sharing of research among countries. Patents grant exclusive marketing rights to the patent holder for a specific period of time. In return, the patent holder is required to make the details of the innovation public. Although patents preclude the appropriation of a particular innovation for a period, they often motivate imitative research. International patent agreements facilitate the sharing of research among countries.

Patent laws vary considerably across countries and products and can affect the domestic and international flow of technology. For example, chemicals and chemical processes are not eligible for patent protection in India *(15)*. Tropical countries often exclude themselves from international patent agreements. In some cases the importation of needed technology can be severely constrained because firms that develop technology are less likely to market their products in countries with weak patent laws. This may be particularly true for biotechnologies which are frequently developed within the private sector.

Regulatory issues may provide additional constraints to the transfer of biotechnology. Regulations governing biotechnology are being developed with research organizations and a concerned general public pressuring regulators as to how restrictive the regulations should be. Poorly defined regulations delay progress, unnecessarily increase the costs of research and adoption, and may stop research in an area completely *(17)*. If regulation on biotechnology continues to be unclear or becomes inflexible, then the pace or focus of biotechnology research may change. In either case, the date of transferring multi-gene traits would undoubtedly be pushed back.

Future Impact of Current and Emerging Technology on Agricultural Production

The U.S. Office of Technology Assessment estimates that during the next 20 years world agricultural output will increase at an annual rate of 1.8 percent with over 60 percent of the increase resulting from higher yields. The pressure to increase yields will compete with pressures to reduce environmental damage, manage agricultural surpluses, and control food prices.

Conventional technology and farming systems technology will continue to increase output in developing countries while developed countries will likely benefit more from biotechnological innovations. The level of productivity increases will depend on each country's ability to adopt new technology, constrained by available technology, agro-climatic factors, policy incentives, environmental concerns, and the strength of domestic research programs.

Current Technologies

Developed regions like North America, Australia, and Western Europe may find it difficult to match productivity growth comparable to that recorded in the 1960's and 1970's. Crop production in these countries is input intensive. Future productivity increases are not likely to depend on more land or input use, but will rather focus on adoption of biotechnologies.

Environmental concerns in the developed countries may induce farmers to adopt technologies that use the farming systems or agroecosystems approach, and, hence, may not be aimed at increasing yields. Health problems, water pollution, and soil erosion have been linked by some researchers to chemical use in agriculture. In the United States, 40 agricultural chemicals have been found in groundwater sources *(5)*. Both regulatory and technology-based solutions are being advocated to reduce negative environmental and health impacts.

Low input sustainable agriculture (LISA) and similar production systems have increasingly been identified as an environmentally sound direction for productive agriculture. The conditions under which LISA production systems are currently economically acceptable and the extent to which regulatory approaches are needed to limit environmental impacts remain uncertain. While one can hope for technologies that solve both environmental problems and increase productivity, there are likely to be tradeoffs.

China's success in increasing its food production is due in part to increased use of appropriate high-yield technology and investment in agricultural research *(2, 21)*. The USSR may be recognizing the need for farmer incentives and an increase in agricultural research investment with a focus on high input monoculture.

Developing countries will likely continue to benefit from conventional agricultural technologies developed and transferred by IARC's and other public sector institutions *(2)*. Improved hybrids of millet and sorghum were developed for the semi-arid areas of India during the 1960's and by the 1980's have spread widely. Some hybrids have recently been adopted in Africa and have resulted in yield increases for these two important staple crops. Demand for U.S. hybrid corn seed in South America is also growing *(9)*. Hybridization research has recently led to new, high-yielding rice varieties suited for temperate China (table D-2) *(13)*, and to a new crop, Triticale (table D-2), which allows cool and acid soil areas to grow grain that formerly could not *(2)*. Crops that are more tolerant of aluminum and drought will likely be released and expand crops to other areas for example, wheat varieties suitable for the tropics (table D-2). In all cases, as we learned from the Green Revolution, these countries can benefit only if the proper incentives and required inputs, for example fertilizer, are available. The countries that are likely to benefit the most are East Asian countries, particularly China, because they have more market-like incentives that induce agricultural research and diffuse the results.

The need to increase production while minimizing environmental stress has prompted increased funding of farming systems research ($750 million from 1972-84) in the developing countries *(20)*. Regions in Africa and South America have been encouraged to use intercropping techniques to increase yields, reduce soil erosion, and reduce reliance on pesticides. The ability to benefit from current and emerging technology is constrained in many developing regions by macroeconomic factors and the inadequacy of domestic research programs. Many African countries need to invest in agricultural research, water resource development, input production and distribution systems, grain marketing, and storage facilities *(2)*. However, some increased research activity will come from a growing private sector.

Biotechnology

Table D-6 shows the possible impacts of emerging technologies on U.S. agricultural production, and table D-7 provides further insight into when to expect new biotechnology to be released— technically and commercially—and, hence, to begin affecting agricultural production. Biotechnology offers environmental benefits because the products it creates can substitute for herbicides or insecticides that are potentially environmentally damaging. Many of the same factors constraining current technology as well as additional constraints created by property rights issues and regulatory concerns affect the successful adoption of biotechnology.

Benefits from biotechnology are likely to accrue faster in those developed countries where R&D and dissemination of biotechnology is promoted. Because embryo and hormone and immuno biotechnology is very advanced in livestock (compared to gene biotechnologies in plants and animals),

Table D-6--Production and productivity increases of emerging technology on U.S. agricultural production

Type of Production	Actual 1987	Projected 2000
Animal agriculture:		
Beef		
Lbs. meat per lb feed	0.075 1/ 2/	0.072
Calves per cow	0.946	1.000
Dairy		
Lbs milk per lb. feed	1.01 2/	1.03
Milk per cow per year (1,000 lbs)	13.80	24.70
Poultry		
Lbs meat per lb. feed	0.40 2/	0.57
Eggs per layer per year	248.00	275.00
Crop agriculture:		
Corn (bu/acre)	119.4	139
Rice (bu/acre)	123.4	124
Soybeans (bu/acre)	33.7	37
Wheat (bu/acre)	37.7	45

Note, these projections from the Office of Technology Assessment (OTA) are based on new information management techniques and biotechnologies. Animal information technologies will help in animal identification, reproduction management, and disease control and prevention. For crops, information technologies include pest and irrigation management.

1/ The original OTA table had 1982 statistics. We updated them using a similar methodology. However, on updating them, the beef statistic is now greater than the projected. This unexpected result is due to increased efficiency of feed uptake and leaner beef. Furthermore, this estimate is probably an underestimate since it was assumed all cattle slaughtered were on feed.
2/ 1986 estimates were made here because 1987 data were not available.

Source: Adapted from (14).

Table D-7--Release dates of emerging technologies 1/

Output	Technically feasible	Commercially available
Plant pest resistance	1987	1992
Growth, nutrition and reproduction of food-producing animals	1988	1991
Genetic improvement of food-producing animals	1988	1993-96
Plant herbicide resistance	1987	1991
Improved nutritional content of plants	1988	1993-96
Improved yield/processing characteristics of food-producing plants	1988	1991
Increased variety and quality of food-producing plants	1987	1991

1/ Time estimates are mean time period predictions.

Source: Adapted from (18).

this sector, if allowed, will receive the initial benefits from biotechnology. Livestock biotechnologies should improve animal gene pools and breeding, help develop vaccines for humans and animals, and increase animal productivity *(4, 6)*. Adoption of livestock biotechnology in developing countries will lag behind the developed countries, but they will still benefit from livestock vaccines *(19)*.

In plant biotechnology, plant resistance to drought and freezing and plant pest resistance are expected to have a large impact on agriculture *(18)*. However, until plants like wheat and rice are amenable to biotechnology, developing countries will not benefit greatly. Developing countries are likely to benefit from vaccines created via microbial biotechnology.

Are We Running Out of Steam?

Agricultural technologies developed in the 1950's, 60's, and 70's, which brought about large increases in agricultural productivity and production, will continue to spread. The full benefits of the Green Revolution have not been felt. Considerable potential for regions bypassed by the first rounds of high-yielding varieties exists. These crops and regions may offer smaller markets and sharper agronomic challenges, but biotechnology offers a new tool for addressing these problems.

The lessons from the Green Revolution demonstrate the effect appropriate technology and good institutional infrastructures have on technology transfer. The effect of technology depends on a country's ability to direct research and development and distribute technology. While the gains in agriculture in some areas are lagging behind food demand and population pressure, there will be continued technological improvements in crops and livestock that should be widely adopted and should foster continued agricultural productivity increases.

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Environmental Degradation and Agriculture

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As agriculture around the world becomes more productive, concern about agriculture's impact on the environment grows. This impact takes various forms, ranging from contamination of groundwater supplies through leaching chemical fertilizers and pesticides, which can show up rather quickly and constitutes a relatively recent problem, to air pollution from brushfires in Africa, which are an age-old method of land clearing, but whose role in acid rain formation is only now beginning to be studied and documented. This article reviews the degradation of land, water, and air which are the main natural resources on which all agriculture depends. It then discusses the relationship between policies and environmental degradation.

Land Degradation

Land degradation is often presented purely as a physical concept, for example, severe erosion due to removal of tropical forest cover. In the context of agricultural supply, an economic concept, the term requires greater attention to its economic content. In that context, land degradation occurs when the resource's ability to produce agricultural commodities falls, given use of economically available production techniques. Market or policy changes that revise the economic set of techniques may change use of farming practices and hence land degradation.

Degradation is resource-specific. Thus, continuous cultivation of the deep, loess soils of western Iowa may not produce crop yield losses for many years but the same practice on many tropical soils would quickly do so.

Under the current economic set of practices, high levels of soil erosion, large-scale removal of forest cover, salinization, and agricultural chemical use are major causes of land degradation in some regions. Accurately measuring levels of erosion, deforestation, salinization, or input use is difficult. For example, erosion varies with differences in soil structure, placement of soils in the landscape, intensity and duration of precipitation, and effects of alternative cropping and livestock practices. Fairly reliable estimates of water erosion in temperate regions such as the United States, Canada, and Europe can be made with the Universal Soil Loss Equation. Wind erosion estimates are less reliable. Hence, global erosion estimates are broad indications only relying largely on extrapolations from small research plots and observation.

"Desertification" is a popular term that suggests severe land degradation. As degradation progresses, water and wind erosion worsen, vegetative cover lessens, and crop yields fall dramatically. Desertification is commonly associated with arid regions like Africa's Sahel, but it can occur in any type of climatic region, including the humid tropics like the Amazon River Basin.

The rate at which land degradation is occurring is not known, but some general estimates of its extent are available (table E-1). Africa, Asia, and South America in particular have suffered severe degradation and reduction in agricultural potential.

Soil Erosion

Soil erosion and its effect on agricultural potential varies greatly among the world's regions. Effects of soil erosion on crop yields should be small in the United States and Europe.

In the United States, corn, wheat, soybean, and cotton yields would fall less than 5 percent from current levels over 100 years at 1982 erosion rates *(5, p. 36)*. In parts of southern Europe, water erosion is severe but productivity is so low in many areas that further degradation would have a minor impact on yields.

Agricultural potential in large regions of Africa, Latin America, and Asia is the most threatened by soil erosion. Continuation of current practices and erosion rates could reduce agricultural production by 25 percent in Central America and Africa, 21 percent in South America, 12 percent in Southeast Asia, and 5 percent in Southwest Asia by the year 2000 *(8, p. 14)*.

Table E-1--Estimated land degradation in the late 1970's

Continent	Slight 1/	Moderate 2/	Severe 3/	Total
	Percent of land surface			
Africa	60	23	17	100
Asia	56	28	16	100
Australia	38	55	7	100
Europe	69	25	6	100
North America	70	23	7	100
South America	73	17	10	100

1/ Little erosion; good or better range condition; yield potential given current technology reduced less than 10 percent.
2/ Moderate water erosion; fair range condition; yield potentials reduced 10 to 50 percent.
3/ Severe water erosion and occasional blow-out areas; poor range condition; yield potentials reduced from 50 to over 90 percent.

Source: (7, p. 5).

Africa

Some 130 million acres of cultivable land could be lost to food production if soil conservation is not practiced *(8)*. Except for parts of eastern and southern Africa, soils are inherently poor, highly leached, and low in nutrients, clay content, fertility, and water-holding capacity *(23, p. 22)*. While productivity may be low, the amount of land that could be affected makes this an important issue.

Over one-third of the land area north of the equator is subject to severe wind erosion *(4, p. 8)*. Overgrazing, especially around waterholes, greatly shortened fallow periods, removal of trees for fuelwood, and drought are major causes. Water erosion is a serious threat in nearly all of Sub-Saharan Africa when vegetation is removed and hillsides are cultivated. Both are common practices. Usable pastoral area in arid and semi-arid zones has contracted 25 percent since 1968 *(2)*.

Asia

Desertification in arid southwestern Asia appears to be advancing as overgrazing and abandonment of irrigated land due to salinization and wind erosion continue. Yield-reducing wind erosion is widespread in many areas of the USSR's Central Asian republics, western China, Mongolia, India, Pakistan, and Afghanistan *(24, p. 79)*. Hilly and mountainous zones of central, northern, and western China as well as of the Ukraine, northern Caucasus, India, Pakistan, and Southeast Asia have long produced high levels of water erosion. Evidence that severe erosion does not always directly lead to falling crop yields is suggested by practices in the North China Plain. In spite of centuries of high levels of erosion, this region continues to be one of the most intensely populated and cultivated areas of the world *(9)*.

South and Central America

Water erosion can be or often is severe where cultivation is practiced on steep slopes and on forest soils exposed by deforestation to torrential tropical rains and sun. Cultivation of food crops on steep slopes is common due to a widely dispersed population and to the expansion of export crops such as coffee, cacao, bananas, cotton, and beef that has forced small farmers out of fertile bottomlands. Because mountain and tropical forest soils are generally thin with limited levels of natural fertility, their cultivation can exhaust soil productivity in less than 5 years.

Argentina, a world producer of beef and grains, is an important exception to the Latin American degradation pattern. Although soil erosion is severe in some zones, major soils are so fertile and deep that little reduction in soil fertility has occurred.

Deforestation

Deforestation of tropical rainforests and overly intensive use of the cleared land rapidly lowers ecosystem productivity. Tropical forest soils are often very low in natural fertility. Luxuriant plant growth occurs because nearly all organic matter is in the plant *(17)*. Overstocking the cleared land with cattle causes loss of vegetation and soil compaction. When ranchers abandon their degraded pastures, settlers plant food crops. Irreversible desertification can result until the land is capable of producing only a very poor forage.

The rate of tropical deforestation—currently an estimated 11 million hectares annually—appears to be rapid and rising (table E-2). Of this, 6.1 million hectares is closed moist forest, primarily in Brazil, West Africa, Central America, and Indonesia. The remainder is in open woodlands mostly in the drier zones of Brazil and West Africa.

Commodities that may be most affected by deforestation include tree crops like cocoa, oil palm, and citrus and even natural rubber and annuals like cotton and rice. All of these crops are typically cultivated in large plantations, a practice that normally involves complete clearing of tropical forest stands. Tobacco's production potential would also be reduced because of the crop's need for fuelwood for drying. Goodland estimates that worldwide the equivalent of 1.2 million hectares of open forest is cut for this purpose *(10, p. 57)*.

Salinization

Irrigation of poorly drained land in hot climates is a prime cause of soil waterlogging and salt build-up. Globally, about one-fifth of irrigated land is either waterlogged, affected by salt, or both *(8, p. 6)*. Soil waterlogging results from excessive water application and/or poor drainage. Rapid surface water evaporation deposits salts in the topsoil.

Regions and countries with major waterlogging and salinization damage include Soviet Central Asia, Iran, Iraq, Egypt, India, Pakistan, and Australia (table E-3). Globally, salinization seriously reduces crop yields on 20-30 million hectares of the world's irrigated land *(23, p. 116)*. Rice and cotton production are especially affected.

Some 7 million hectares of the Aral Sea zone in Soviet Central Asia are irrigated, providing the USSR with 95 percent of its cotton, 40 percent of its rice, and 35 percent of its fruit. Continued large-scale production is seriously threatened. Massive water diversions from major rivers feeding the Aral Sea have caused that body to lose 60 percent of its water volume in the past 30 years *(15)*. The salt desert formed by the exposed seabed is the source of massive salt-sand storms that seriously damage crop yields. Furthermore, unlined irrigation canals require increasingly greater water use to flush salts from the root zone. In the southern USSR as a whole, it is estimated that 105 million hectares of agricultural land have degenerated into cracked solonets (salinized soils) *(12)*.

Table E-2--Annual rates of tropical deforestation, 1976-80

Region	Closed forests		Open woodlands	Total
	All	Moist		
	Millions of ha/year			
Africa	1.33	1.20	2.34	3.67
Asia-Pacific	1.82	1.61	0.19	2.01
Latin America	4.12	3.30	1.27	5.39
Total	7.27	6.11	3.81	11.08

Source: (24, p. 71).

Agricultural Chemical Use

Although reliable estimates of fertilizer and agricultural chemical use are available only for some Organization for Economic Cooperation and Development (OECD) countries and local sites in the Third World, global use appears to be increasing. Nitrogen fertilizer use in OECD countries increased 22 percent from 1975 to 1985 and 62 percent globally *(24, p. 135)*. Overuse of mineral fertilizers and insufficient use of organic fertilizers and lime can cause long-term land degradation. This loss has been documented for extensive areas of the western USSR *(19)*.

Pesticide data are not as complete but anecdotal evidence suggests that worldwide use is increasing. Use in developing countries would probably not exceed 15 percent of total global use *(3)*. The problem in developing countries is that pesticides are often used without the safeguards applied in developed countries and by farmers who are often illiterate or uninstructed in their proper handling. A recent survey by the Food and Agriculture Organization of the United Nations (FAO) found that "very toxic pesticides" are "widely available" in at least 85 developing countries. The survey found that 80 of these countries have no adequate system to approve, register, or monitor the material. They also lack information about hazards and do not have people trained to evaluate them *(16)*.

Irrigation, monocropping, tree crop plantations, and high-yielding cereal varieties associated with the Green Revolution each require more chemicals than did traditional

Table E-3--Percentage of irrigated land affected by salinization, selected countries, 1984

Region/country	Percent	Region/country	Percent
Africa:		Europe:	
Egypt	30-40	Portugal	10-15
Senegal	10-15	Spain	10-15
Sudan	15-20		
		United States	20-25
Asia:			
China	15	South America:	
India	27	Colombia	20
Iraq	50	Peru	12
Iran	25-30		
Pakistan	35-40	Australia	15-20

Source: (23, p. 280).

practices and crops. Crops commonly irrigated include feed grains, cotton, tobacco, rice, fruits and vegetables. Major crops increasingly monocropped or grown on plantations in the Third World also include banana, coffee, cacao, oil palm, and citrus. The United States and the EC increasingly monocrop corn and wheat. High-yielding varieties of wheat and rice introduced to the Third World as part of the Green Revolution usually require high levels of fertilizer and water and are not resistant to local pests. Heavy application of broad-spectrum pesticides developed in the United States and Western Europe has been shown to eliminate plant and animal species beneficial to crop growth or natural predators of pests like the brown planthopper.

At times, in developing countries, especially in the production of tobacco, cotton, and coffee, chemicals applied are banned for use in the selling country *(3)*. India still manufactures DDT for fighting malaria. Dieldrin, which is banned in many countries, was used by United Nations technicians to fight a locust plague in North Africa *(16)*.

Water Degradation

Water degradation occurs when existing production practices pollute water and reduce the supply for agriculture. In the United States, agricultural runoff accounts for about three-fifths of nonpoint pollution to surface waters that are either actually or potentially impaired *(24, p. 134; 1, p. 7)*.

Nutrients from fertilizers and animal wastes and sediments are the primary pollutants. Water pollution from agriculture is being increasingly recognized in the European Community (EC) *(6)*. In Germany, for example, the number of water authorities in which nitrate contamination exceed maximum EC standards more than quadrupled from 1979 to 1983 *(25, p. 33)*.

Activities that directly reduce water supply to agriculture reduce future agricultural potential. Groundwater mining (withdrawals exceed natural replenishment) due to irrigation in major agricultural areas of China (the North Plains), India (Tamil Nadu State), and the southern U.S. Great Plains is of considerable concern.

Massive deforestation also reduces water supply. Removal of vegetative cover in steeply sloping watersheds speeds water runoff and reduces water storage in crop root zones. Erosion and sediment reduce reservoir storage for irrigation and cause increased flooding. This sequence is particularly acute in Central and South America, East and Southeast Asia, Indonesia, and West Africa. Some argue that large-scale rainforest clearing can dramatically lower local precipitation *(17)*.

Atmospheric Degradation

In 1980, the industrialized OECD countries produced over one-half of the world's emissions of three regularly monitored atmospheric pollutants—carbon monoxide, nitrogen oxides, and sulfur oxides—and over one-fourth of global particulate matter. The United States and Canada alone accounted for 51-66 percent of total OECD emissions *(23, p. 144)*. OECD countries are gradually reducing sulfur oxide emissions but are less successful in lowering emissions of hydrocarbons, nitrogen oxides, and carbon monoxide. Progress in other world regions in reducing pollutant levels is unclear.

Atmospheric deposition of acidic pollutants—"acid rain" is a popular term for this phenomenon—on agricultural productivity is unclear *(24, p. 172)*. While some research shows that acid rain lowers crop yields under laboratory conditions, other research indicates that the impact of ambient acid rain on agricultural crops is negligible. At the same time, ambient acid rain is blamed by scientists for widespread damage to forests and aquatic ecosystems in Europe and North America.

Photochemical oxidants, particularly ozone, also reduce crop yields *(24, p. 172)*. Research suggests that average ozone concentrations in the eastern United States reduce sorghum and corn yields less than 1 percent, cotton and soybean yields about 7 percent, and alfalfa yields over 30 percent. Combinations of ozone, sulfur dioxide, and nitrogen dioxide may reduce crop yields more than any of the pollutants separately.

The concentration of these chemicals in the lower atmosphere (troposphere) appears to be high and increasing throughout urban areas of the industrialized world. Their extent in nonurban areas and in the developing world is generally unknown. The two primary ozone-forming chemicals are nitrogen oxides and volatile organic compounds (VOC). OECD data indicate a consistent, though slight, increase in VOC emissions since 1970 in most OECD urban areas except in the United States, where VOC levels fell.

In sum, environmental degradation caused by production practices that are economically available is likely to reduce commodity supply in areas of Africa, Asia, Eastern Europe, and Latin America over the next quarter of a century. Less degradation will be found in the industrialized countries of North America and Western Europe and effects of degradation on food supply should be slight. Effects of atmospheric degradation on commodity supply are less certain. Whether environmental degradation can be checked depends in part on policies that governments may institute to change resource use.

Agricultural Policies and Environmental Degradation

Policymakers face difficulty in knowing the true social values of environmental resources. In market economies, markets that price commodities and production inputs generally fail to price environmental resources like clean water and air. In spite of this "market failure" and absence of markets in nonmarket economies, the presence of conservation policies suggests that some societies do place significant values on their environmental resources. Policies that price environmental resources at less than their social value encourage commodity producers to use more of these resources than otherwise. Degradation occurs if use is excessive for the particular resource. This section provides an overview of agricultural policies that most directly have led to environmental degradation.

In the OECD countries, one of the broad goals of agricultural policy in recent years has been to support farm incomes either by supporting prices, directly supplementing incomes, or subsidizing inputs. Over the 1982-1986 period, the ratio of total farm subsidies for major commodities to total farm returns was 0.72 for Japan, 0.35 for the EC, 0.31 for Canada, 0.25 for the United States, and 0.11 for Australia *(20)*. Important input subsidies (within total farm subsidies) include those for irrigation in the United States, drainage in the EC, rail rates for wheat and coarse grains in Canada, and tax and investment credits for land conversion in Australia. Among other things, such farm income support has promoted conversion of environmentally fragile lands to commodity production and intensified use of agricultural chemicals and irrigation water on existing cropland *(18)*.

In developing countries, agricultural policies that levy taxes on agricultural exports, set low producer prices, and neglect improvements to input delivery systems limit farm profits and reduce incentives for long-term resource husbandry *(24, p. 208; 4)*. In centrally planned economies, emphasis on meeting unrealistic annual production quotas has the same negative effect on long-term environmental protection.

Developing country projects and policies that subsidize purchased inputs (and so partially offset policies that hurt profitability) can also degrade the resource base. Chemical fertilizer subsidies of 50-70 percent of delivered cost are very common *(23, p. 87)*. Pesticide subsidies are widespread. Overvalued exchange rates specific to these inputs promote the import and use of fertilizers and chemicals frequently not appropriate for a country's plant, animal, and pest populations. Projects that promote use in the tropics of farm machinery developed for temperate climate soils in the United States and Europe have caused soil degradation *(21)*. Policies commonly applied are preferential tariffs and allocation of foreign exchange for machinery imports, as well as accelerated depreciation provisions.

Investment tax credits were a powerful incentive allowing Brazilian corporations to take up to a 50-percent credit against their federal income tax liabilities if the resulting savings were invested in the Amazon and approved by the Superintendancy of the Development of the Amazon. Most of the approved projects were in the livestock sector *(11, pp. 13-16)*.

Finally, irrigation, drainage, and flood control encourage more intensive land and water use, with consequent danger of resource degradation. Between 1985-2000, developing countries are expected to invest an estimated $100 billion in irrigation, primarily with public funds *(22)*. In most projects, user fees are subsidized and do not cover operating costs.

Resource conservation policies act to counter environmental degradation. High-income industrialized countries are more apt to enact resource conservation policies than are developing countries because environmental quality is a "superior good," the demand for which grows as income increases *(14)*. In the United States, for example, the Food Security Act of 1985 attempts to reduce soil erosion, improve water quality, and enhance wildlife habitat. It does this by paying producers to retire highly erodible land for 10 years and by declaring producers who convert wetlands to cropland as ineligible for commodity program benefits. The EC has agreed that agriculture should be subject to controls designed to reduce environmental deterioration and that the "polluter pays" principle should apply *(6)*. Leaders of the EC and the United States pledged in March 1989 to stop using chlorofluorocarbons (CFC's) by the year 2000 *(13)*.

In lower income countries, in contrast, demand for improved environmental quality has much less support than policies that address pressing economic and social issues. Such issues include increasing current incomes and employment, holding down staple food costs in burgeoning cities, and meeting foreign debt service requirements. With respect to CFC's, for example, several Third World governments made it clear that they will need technical assistance and even subsidies to stop using CFC's. With many demands on limited national budgets, environmental policies that have immediate cash costs, uncertain cash benefits at some future time, and require technical skills and institutional frameworks that are in very short supply have had great difficulty finding political support.

Concluding Comments

Land and water degradation may have little negative impact on food production potential in the industrialized OECD countries, particularly the United States, Canada, Japan, and the EC over the next quarter century. Given the economic set of production techniques, natural resources are relatively rich, degradation from erosion, salinization, and deforestation is limited; chemical formulations are appropriate to crop needs; and policymakers seem to have the political, technical, and financial support to enact effective resource conservation policies.

Food production potential in much of Africa, Asia, and Latin America, on the other hand, is seriously threatened by land and water degradation. Soils are often either poorer or more susceptible to degradation given current economic practices than the soils in industrialized OECD countries. National policies often reduce farm income and provide no incentives for long-term resource husbandry. Conservation policies that promise uncertain benefits at some time in the future cannot compete with activities that meet more immediate economic and social needs.

In the humid tropics, deforestation, overgrazing, and continuous cultivation can destroy much of a soil's productive capacity in 3-5 years and dramatically reduce water availability to crops. Heavy application of pesticides and mineral fertilizers formulated for temperate ecosystems has unintended side effects on beneficial plants and animals. In arid and semi-arid zones, uncontrolled cutting of open woodlands, overgrazing, and shortened fallow periods degrade the land resource. Improper use of irrigation water has caused widespread wind erosion and soil salinization that has and will lower crop yields. Ground water depletion is severe in large areas of China, India, Pakistan, and the USSR.

Effects of atmospheric degradation on food production potential are poorly understood, but appear to be negative. International discussions to learn about and control this degradation are recently underway.

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Climate Change and Agriculture

by

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Concern that human activities will significantly change the earth's climate has increased in recent years. Agriculture has been identified as an emissions source for some gases associated with climate change. But agriculture also depends on climate conditions in a way that manufacturing does not.

Increasing concentrations of carbon dioxide, chlorofluorocarbons (CFC's), methane, nitrous oxide, and other gases in the atmosphere from all sources are believed to lead to warmer surface temperatures and changes in precipitation, cloud cover, and other climate variables. These gases have been increasing for a century or more in some cases, and the rate of accumulation has increased significantly in the past few decades, leading to the general expectation that changes of the kind mentioned above may occur in the next several decades. The relative contributions of natural and manmade activities to the increase in these gases are still under investigation by scientists.

Except for CFC's, which were developed in recent years, the major gases affecting climate are associated with both natural sources and human activities. The presence of a certain amount of these gases in the atmosphere is necessary to maintain the present climate. This feature distinguishes these emissions from many familiar forms of environmental pollution—such as pesticides, toxic wastes, and carbon monoxide—where the substance clearly constitutes a human health hazard.

Perspectives on Climate Change

Not all changes in climate are bad. Human populations have successfully adapted to a wide variety of climates. Milder winters and longer growing seasons may be significant improvements for some climates, while hotter summers and increased storm intensity may make other climates less hospitable in some respects. From the perspective of global food, fiber, and forest product supply, the concerns raised by climate change are twofold. First, will changes in climate result in a significant net decline in arable land area and the inherent productive capability of the land? And second, will the climate of a region change so rapidly that the responses and adaptations people have taken be rendered obsolete or insufficient to deal with the new environment?

The first of these concerns is based on a view that after a period of change the climate will be or can be stabilized. In balancing the costs of reducing and eliminating emissions of radiatively active trace gases against the costs (or benefits) of experiencing possible climate change, there may be some acceptable degree of change. The idea of "stabilizing" climate is inconsistent with the fact that there are natural cyclical variations ranging from seasonal, annual, and decadal, to intervals of thousands of years. But, while climate has always varied, the changes have not been of the magnitude that global circulation models (GCM's) predict will occur over the next 50 to 100 years if concentrations of gases in the atmosphere increase at the rate of recent decades.

The second of these concerns accepts climatic change, seeing both opportunities and costs in any change. Human populations have adapted to wide geographic variations in climate. Concerns arise, however, because the adjustments required by human populations and ecosystems are not cost-free, and the cost of adjustment is likely to rise rapidly with the greater rate of change. For example, water resources in one area may dwindle so rapidly that water projects become obsolete long before they would naturally depreciate and

REGIONAL CLIMATE CHANGE PREDICTIONS BY LATITUDE

REGION		CLIMATE AND AGRICULTURE
Northern Latitudes	70° N	Increased Precipitation [positive yield effects]
Mid-latitudes	40° N	Interiors of Continents Warmer and Dryer [negative yield effects]
Tropics	0°	Little Temperature Change [uncertain yield effects]
Mid-latitudes	40° S	Negligible Land Area
Southern Latitudes (Antarctica)	70° N	

before new projects can be completed in areas where water has become more abundant. Flood control projects may be overwhelmed by increases in precipitation and storm intensity in one area, while projects in other areas may have been significantly overbuilt. In general, the penalties of climate change, if it occurs, will be inflicted on society. However, many of the actions to limit the negative effects or to take advantage of the potential benefits will only occur if there is specific recognition of the climate change and if appropriate actions are taken by farmers, water resource managers, research and development planners, and others in society.

Trace Gas Accumulation and Climate Change

The principal trace gases directly responsible for altering the radiative balance of the atmosphere are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and CFC's. Not often mentioned in this connection is water vapor, the most abundant of the "greenhouse" gases, which plays a vital part in giving us our current climate. The radiative properties of all gases determine their effect on the flow of energy from the sun in the form of light to the surface of the earth and the reradiation of heat into space. Accumulation of gases that block the reradiation of heat into space tends to warm the earth's surface. Such warming then affects the complex interactions of cloud formation, weather patterns, ocean temperatures and currents, prevailing winds, and the jet stream.

The radiative role of the gases implicated in climate change is well known. The climatic impacts due to complex interaction in the atmosphere of increasing emissions and accumulation of the gases are highly uncertain, however. The degree to which the radiative forcing is reflected in changes in air temperature or ocean temperature, or is dissipated through changed albedo, cloud formation, increased storms, or stronger ocean currents, is poorly understood.

Based on direct and indirect measurements of concentrations of carbon dioxide and CFC's, and to a lesser extent methane and nitrous oxide, it is known that these gases are accumulating at unprecedented levels in the atmosphere. Carbon dioxide levels in the atmosphere have increased from between 270 and 290 parts per million (ppm) 100 years ago to approximately 345 ppm today. Since 1958, when direct measurements began, concentrations have increased from about 315 to 345 ppm. Over the past million years, carbon dioxide levels are believed to have varied between 200 and 270 parts per million with the exception of the higher levels of the past 100 years *(3, p. 27)*. Methane levels are estimated to be increasing at a rate of 1 percent per year, nitrous oxide levels at .25 percent per year, and since 1978 CFC's have been increasing at 4 percent per year *(5, pp. I-9 to I-12)*. It is clear in the case of carbon dioxide and CFC's that human activities emitting these gases into the atmosphere have increased. Knowledge of the sources of methane and nitrous oxides is less, but human activities associated with their emission have also been growing.

Trace Gas Emissions and Agricultural Sources

The possible climatic effects of changes in the concentrations of these gases can be compared based on their radiative properties and accumulation rates. The radiative forcing properties offer an approximate equivalency basis to compare, for example, CO_2 concentrations of parts per million with CFC concentrations of only parts per trillion. The CO_2 accumulation in the atmosphere during the 1980's contributed about half of the total estimated radiative forcing, methane contributed 18 percent, CFC's 14 percent, nitrous oxide 6 percent, and other gases about 13 percent (fig. F-1). The other gases include halons, changes in ozone, and changes in stratospheric water vapor. There are considerable uncertainties in the other category *(5, p. II-5)*.

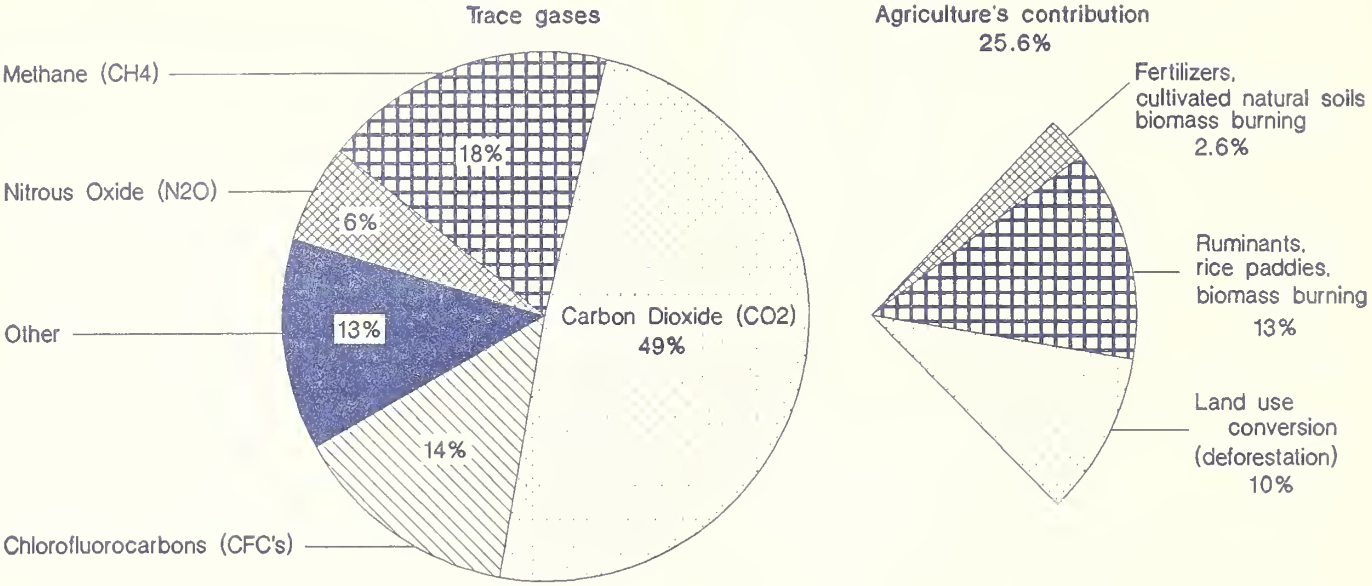
Regionally, the United States is estimated to have contributed the largest share to trace gas emissions, 21 percent of radiative forcing emissions during the 1980's. The USSR and the European Community (EC) each contributed an estimated 14 percent, China 7 percent, and Brazil and India each 4 percent. All other countries combined contributed an estimated 36 percent.

The increase in concentrations during the 1980's can be attributed to different human activities. To make such a calculation, it is necessary to assume that atmospheric accumulation of trace gases is related directly to human activities (natural sources alone are approximately balanced by the rate at which the gases were eliminated from the atmosphere). Based on these calculations, agricultural activities are estimated to contribute roughly one-quarter of the radiative forcing increase during the 1980's *(13)*.

These estimates provide a rough approximation of the sources of trace gas concentration increases. The midpoint estimate of the net CO_2 contribution from land use conversion is 10 percent. But, the range is from 0 (carbon uptake from forest growth is balanced by deforestation) to 17 percent. The bulk of CO_2 emissions come from fossil fuel consumption, and these are relatively well estimated. The midpoint estimate for nitrous oxide emissions shows agricultural activities to contribute about one-half of the emissions related to human activities. Both the industrial sources (from fossil fuel combustion) and the agricultural sources of nitrous oxide are uncertain. In addition, the estimates are for nitrous oxide emissions from cultivated soils. Changed cultivation practices and reduced nitrogen fertilizer applications could reduce nitrous oxide emissions, but even in their natural state these soils would be sources of nitrous oxide.

Figure F-1

Contributions to Increases in Radiative Forcing in the 1980's



Most of the known sources of methane are directly related to agricultural activities, primarily enteric fermentation in ruminant animals, biomass burning (principally related to forest clearing), and release of methane from rice production. Nonagricultural sources of methane include primarily releases from methane associated with coal seams, releases from land fills, venting of natural gas associated with oil deposits, and leakages from the production and distribution of natural gas. A complicating factor in the case of methane is the possible indirect effects of climate change on methane release. As warming of northern latitude areas occurs, methane naturally stored in permafrost could be released to the atmosphere.

Based on current trends and expectations, agricultural sources may increase slowly in the future but are likely to fall as a share of total emissions with CO_2 emissions from fossil fuels increasing. Regionally, the share of emissions from the developing countries is likely to grow relative to the United States and other developed countries. The contribution of deforestation is ultimately limited by the stock of carbon in forests. Burning of brush by farmers during the dry season in Africa, however, is a somewhat different case since it does not usually involve destruction of forests.

Methane from rice production is thought to be related more to the area under paddy cultivation than the yield. Basic constraints on agricultural land area limits areal expansion of paddy rice production. Ruminant animal production is likely to expand at a modest pace. Nitrogen fertilizer demand growth has slowed in recent years. Technologies that increase the effectiveness of nitrogen may be pursued to reduce both fertilizer costs and the amount of nitrates reaching water supplies, thereby limiting nitrous oxide emissions from fertilized soils.

Other Effects of Trace Gases

Other atmospheric effects of trace gases complicate analysis of their impact on agricultural systems. CFC's deplete the level of ozone in the stratosphere. Ozone depletion has implications for climate and allows increased levels of ultraviolet (UV) light to reach the earth's surface. UV light has damaging effects on plant and animal life. Under the Montreal Protocol, steps have been taken to reduce CFC emissions worldwide. CO_2 has some positive effects on plant growth. While climatic effects of increased concentrations may be negative, these effects may be partially or fully compensated by the CO_2 "fertilization" effect.

A report by the U.S. Committee on Earth Sciences accompanying the 1990 budget explicitly recognizes the need to consider the complex ecosystem and human activities that can alter it *(12)*. But, a comprehensive assessment of the outlook for emissions of these gases and their combined direct and indirect effects has not been attempted.

Evidence of Climate Change

Based on the accumulation of CO_2 over the past 100 years, scientists expect to observe an average temperature increase between .5 and over 1.0 degree centigrade *(6, p xxi)*. The climate record appears to show a warming of about .3 to .7 degrees centigrade *(6, p. xxi)* with several particularly warm years in the 1980's, including 1988 which tied 1987 for the warmest year for which direct measurements are available *(4, p. 891)*.

Scientists have not, however, conclusively detected climate change attributable to accumulating concentrations of these gases. In fact, the temperature record shows a slight cooling trend between 1940 and the late 1970's despite the fact that most of the increase in CO_2 occurred during this period.

There are at least three reasons why it is difficult to establish a relationship between accumulation of trace gases and historical changes in temperature. First, the expected amount of warming is highly uncertain, and warming may not be the most significant or earliest detectable sign of changing climate. Second, the level of expected temperature change likely to have occurred thus far is within the range of natural temperature variations. Third, the accuracy of the temperature record has been questioned. Heat island effects (weather stations located near expanding urban areas) on global temperature averages may mean that the actual warming trend was .15 to .3 degrees less than indicated by the uncorrected record *(7)*. Also, long-term temperature records for much of the world (particularly over oceans) are scattered, fragmentary, and subject to greater measurement error.

It remains unclear how much of the calculated increase in temperature has actually occurred, and whether the recent warm years are part of a climate trend or coincidentally warm years with the underlying climate unchanged.

Likelihood and Timing of Future Climate Change

Despite these difficulties, there is reasonable scientific certainty that climate will change significantly in the next 50 to 100 years. A doubling of carbon dioxide in the atmosphere from preindustrial levels will likely increase temperature 1.5-4.5 degrees centigrade *(6)*. These expectations are based on GCM predictions, which generally agree that global warming will result from greater concentrations of the trace gases. However, the models differ widely in their predictions of the magnitude of the warming and on the degree and direction of other climate variables for local regions. The still limited knowledge of fundamental interactions of atmospheric, oceanic, and terrestrial factors leaves room for surprises in predicting climate change.

Temperature change has been the principal summary measure of climate change. But even small changes in global temperature could be accompanied by significant changes in weather variability, storm intensity, rainfall, seasonality, and regional weather patterns.

The timing of future climate change depends on the rate of accumulation of the trace gases. Once emitted, many stay in the atmosphere for years. The average resident time for carbon dioxide is about 500 years;[1] for nitrous oxide, about 150 years; for CFC's, 75 to 110 years; for methane, 7 to 10 years; and for ozone, hours to days *(13)*. Accumulation also depends on human activities contributing to emissions. Changing these will be neither cost-free nor quick.

The long residence time of most of the trace gases in the atmosphere means that stabilization of atmospheric concentrations of gases would require that emissions be reduced substantially. For CO_2 the reduction would have to be more than 75 percent *(5, p. I-11)*. Such a decrease is unlikely to occur without severe steps to limit fossil fuel consumption. Thus, atmospheric concentrations are likely to keep rising.

The best available estimates suggest that a doubling of CO_2, or effective doubling through a combination of trace gas increases, could occur toward the middle of the next century. Early extrapolations, focusing only on CO_2 emissions, suggested that a doubling of atmospheric concentrations from preindustrial levels could occur as early as 2020 *(2)*. Succeeding work, recognizing fossil fuel constraints and demographic factors, estimated that doubling of carbon dioxide would most likely not occur until after 2075 and was unlikely to occur before 2050 *(10)*. The most recent work has recognized the role of trace gases other than CO_2 *(5)*, and their inclusion means that radiative forcing equivalent to a doubling of CO_2 will occur considerably before doubling of CO_2 levels. Thus, effective doubling could occur before 2050, even though recent evidence suggests slower rates of fossil fuel use and CO_2 emissions.

While further human alterations of the atmosphere are likely, the speed with which climate will change and the specific type of changes (temperature, cloud cover, precipitation, and storm intensity) remain uncertain. But the potential for climate change can be limited by controlling trace gas emissions.

Climate Change, Doubled CO_2, and Agriculture

Existing estimates of the effects of climate change on agriculture suffer from a variety of limitations but, on balance, suggest that world agriculture can cope with the types of changes in climate that might accompany an effective doubling of CO_2 concentrations. Charles Cooper concluded that the effect of a doubling of CO_2 "... is about as likely to

[1] The 500-year resident time for carbon dioxide is the relevant period for considering impacts on concentrations. Short resident time estimates (i.e., 2 years) are consistent with the 500-year estimate. The much longer estimates recognize that, once removed from permanent deposits in fossil fuels and the like, carbon will cycle through the biosphere and shallow ocean many times before returning to permanent desposits in such places as deep oceans. The 2-year resident time estimates count only the time in the atmosphere in one cycle.

increase global food, at least in the long run as to decrease it. It is certain, though, that some nations, regions, and people will gain and others lose *(1, p. 300)*." Two major studies of the effects of doubling of carbon dioxide on agriculture have recently been conducted. The U.S. Environmental Protection Agency (EPA) *(11)* focused on U.S. agriculture, and Parry and others *(9)* focused on "marginal" agriculture regions around the world. These studies have not provided strong evidence against Cooper's conclusion.

The regions examined by the studies contrast global regions likely to be affected differently by climate change. Much of U.S. agriculture is located in mid-latitude, continental interiors which are forecast to be warmer and dryer, while increased precipitation is probable in the upper latitudes *(8)*. While not a comprehensive global assessment, the studies indicate the changes that might occur across broadly different agricultural systems (fig. F-2).

Parry and others examined the effect of climate variation on agriculture in semi-arid regions in Ecuador, Brazil, Kenya, India, Australia, and the USSR, and northern latitude agriculture in Canada, sub-Arctic USSR, Finland, Japan, and Iceland. In general, the effects of predicted climate change were positive on northern latitude agriculture. In Iceland, yields of hay were estimated to increase by 50 percent. In Finland, barley yields increased in the north and were unchanged in the south. For the country as a whole, spring wheat yields were estimated to increase 6 to 20 percent. In the sub-Arctic region of the USSR examined in the study, rye yields decreased 15 percent due to excessive soil moisture. Climate effects on spring wheat were estimated to increase yields 3 percent, but inclusion of the CO_2 fertilization effect increased yields 17 percent. Japanese rice yields suffered a slight decrease. By choosing an alternative variety adapted to warmer temperatures, however, Japanese yields increased 23 to 26 percent.

In the semi-arid regions examined by Parry and others, estimates for a doubled CO_2 were made for wheat in Canada, the USSR, and Australia. Both the USSR and Australia showed increased yields due largely to the predicted increase in precipitation. Canada showed decreased yields of spring wheat of about 20 percent due to adverse effects of increased temperature. The Canadian result did not consider crop or variety changes that might have been better suited to the warmer climate.

The EPA study compared the agricultural effects of predicted climate under effective CO_2 doubling based on two different climate model forecasts. Both the Goddard Institute for Space Studies (GISS) and Geophysical Fluid Dynamics Laboratory (GFDL) climate models predicted warming and drying for most agricultural areas of the United States. The GFDL model predicted more severe warming and drying with heightened effects during the summer growing season. In general, climate effects alone showed corn and soybean yield declines of 5 to 25 percent under the GISS climate prediction and yield declines generally in the range of 25 to 60 percent (up to 90 percent at some point in the Southeast) under the GFDL. Inclusion of the positive effects of CO_2 on plant growth (CO_2 fertilization) generally balanced yield reductions in the GFDL scenarios or resulted in modest to large increases (135-percent increases in the Lake States with up to 390-percent increase in Duluth, Minnesota) under the GISS scenario. The major exception was the Southeast under the GFDL scenario where even with CO_2 fertilization yield declines were generally in the range of 20 to 80 percent for soybeans.

The study showed irrigated acreages less negatively affected by climate change. Only limited analysis of substitution of alternative crop varieties was explored. Where examined, the study found that choosing a crop variety suited to higher temperatures reduced the negative effects substantially. Increased insect and pest problems were identified as potentially associated with warmer climates, but yield effects were not incorporated.

Four observations can be drawn from these studies. First, Northern climates, currently limited by short growing seasons and cool temperatures, are likely to benefit from climate change. Second, given the irrigation results for the United States and the yield increases in semi-arid regions under combined temperature and precipitation increases, soil moisture changes are likely to be more important for estimating agricultural productivity effects than temperature changes alone. As a result, mid-latitude drying is likely to adversely affect these regions. Third, minor technological adjustments, generally adopting existing crop varieties more suitable to higher temperatures, can have significant ameliorative effects. A more complete examination of existing adaptations to new climates would likely generate a larger offset to negative effects or additional positive benefits of climate change. Fourth, modest warming may have positive agricultural effects for many regions, but more severe climate change (predicted by the GFDL model) may have negative effects, at least in interior regions likely to have reduced precipitation.[2]

Some Broader Considerations

The case of effective CO_2 doubling has been a convenient but arbitrary tool for comparing climate models and effects. Even if the GISS predictions of modest climate change with a CO_2 doubling are accurate, further accumulation of trace gases could intensify climate effects. Stabilization of concentrations at an effective doubling does not appear to be highly likely in the absence of relatively stringent pollution

[2] USDA is developing a plan for research on the links between agriculture and potential changes in climate.

control policies. In addition, the predictions, particularly at the level of regional detail necessary to assess agricultural effects, remain uncertain. Given these uncertainties and estimation of direct agricultural effects in only a few areas, our current knowledge of the effects of increasing concentrations of trace gases can be best labeled as informed speculation.

A variety of potential indirect effects, including greater competition from weeds, increased plant and animal disease, and expanded ranges of insect pests are possible but probably controllable. Yet we are far from concluding what such indirect effects may do to the cost of agricultural production and how these changes will affect agricultural resources and the environment. Existing conflicts for available water may be intensified by tighter water resources. Small negative effects on agricultural production in countries with large populations living near subsistence may result in food shortages and starvation, even if global food resources are adequate. But other such countries may find that changing climate delivers more rain to areas regularly stricken by drought.

Conclusions

Carbon dioxide, CFC's, methane, nitrous oxide, and other gases are accumulating in the atmosphere. Agricultural activities are an apparently significant component of the increase in concentrations, contributing approximately one-quarter of the increased radiative forcing during the 1980's. While agricultural emissions may grow in the future, their share is likely to fall as energy use increases more rapidly. Based on the accumulation of trace gases over the past 100 years and scientific understanding of the climate system, scientists believe that trace gas accumulation may have already contributed to warming of .3 to over 1.0 degree centigrade. An apparent warming of about .5 to .7 degrees has occurred, but scientists have not conclusively attributed the increase to accumulating concentrations of trace gases.

Despite the difficulty of detecting temperature change in the historical record, there is reasonable scientific certainty that climate will change significantly over the next 50 to 100 years, warming 1.5 to 4.5 degrees centigrade by about 2050 if accumulation of gases in the atmosphere continues. Weather variability, storm intensity, rainfall, seasonality, and regional weather patterns are also likely to change.

The specific climate effects remain difficult to predict and, therefore, the agricultural effects of climate change are speculative. With this caveat, it appears that there will be positive as well as negative effects. The most serious effects may result from reduced soil moisture in the mid-latitude, continental interiors. Small changes in regular storm tracking could reduce moisture available to important agricultural areas, but such changes are hard to predict. The CO_2 fertilization effect, changes in crop varieties grown, and improved agricultural conditions in other areas of the world will tend to offset these negative effects. Over the next 50 years, it is unclear whether the net effect will reduce or increase global food availability. Small negative effects on agricultural production in countries with large populations living near subsistence may cause food shortages and starvation even if global food resources are adequate. Dislocations and other adjustment costs of climate change have not yet been assessed, nor have the effects of climate change beyond that of doubling of CO_2. Due to such uncertainties and unknowns, the effects of potential climate change on agriculture remain a concern.

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Changes in Food Demand

by

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Over most of the past three decades, per capita food consumption rose across developed, developing, and centrally planned countries. Per capita red meat consumption has been growing in the centrally planned countries (fig. G-1), with significant increases in pork consumption in Eastern Europe, the Soviet Union, and particularly in China. Growth in poultry consumption in the developed countries has been rapid and continuous (fig. G-2), spurred by falling poultry meat prices, increased incomes *(2)*, and, probably, health concerns. U.S. per capita poultry consumption (27 kg/year, boneless weight) is swiftly approaching declining beef consumption (29 kg).

Most of the rising grain use in developed countries consisted of coarse grains fed to livestock (figs. G-3, G-5). Although grains are the primary foods in developing countries, pulses, roots, and tubers (not included in the figures) are also important. Per capita consumption measures quantities of foods used at the prevailing prices at various times. In countries that control food prices, food shortages may not be reflected in higher prices as in free markets. Consequently, per capita food consumption could be less than food demand (the quantity of food an individual wants at a specified price and time). Global and regional food disappearance can be termed consumption, but not aggregate demand except under free market conditions. Even though they are not always the same thing, changes in aggregate food demand affect world food prices and consumption, and thus are important to an understanding of the world food situation.

This article notes, with some examples, how changes in per capita food demand (that is, leaving population growth out of the analysis) are induced by changes in relative prices, income and its distribution, population characteristics, policies, urbanization, and other factors; and draws inferences for the future. In this analysis, food price is constant, for changes in quantities of a particular food demanded resulting from changes in the price of that food are not, by definition, changes in demand.

*Authorship shared equally.

Relative Prices

Relative prices among foods strongly influence the demand for a particular food. Relatively high prices for beef may increase the demand for pork and poultry meat. The price of food relative to nonfood items affects the quantities of food and nonfood items consumed.

Prices sometimes act indirectly. New food processing technology may make a particular food cheaper: margarine's capture of a large share of the butter market after World War II is a classic example. Sometimes foods become cheaper through reduction of home preparation time: the switch from millet to rice consumption by urban-rural migrants to Dakar has been attributed to shorter food preparation time.

Income

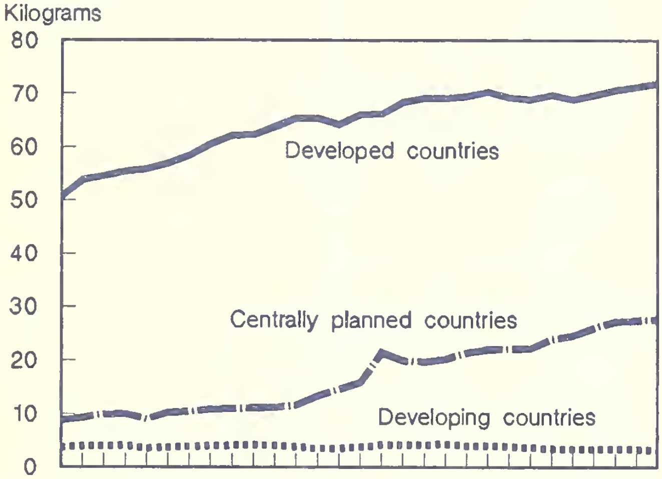
Numerous empirical studies have documented the vital relationship between income and per capita food expenditures. Although the magnitudes vary among countries, commodities, and income levels, as per capita incomes rise food expenditures per capita also rise, other things being equal.

In developing economies, increased income boosts the demand for livestock products more than the demand for legumes, grains, and tubers. In Colombia, for instance, quantities of livestock products purchased (butter, pork, eggs, and beef) were found to rise faster than quantities of beans, grains, and potatoes in both high- and low-income households with rising income (table G-1). Purchases of tubers (potatoes and cassava) by the high-income group declined as income rose.

Rapidly rising per capita income was a principal reason for much of the increase in world food consumption during the 1960's and 1970's. During 1950-86, the world economy grew at 4.2 percent per year, almost double the 2.2-percent rate during 1870-1950 *(9, pp. 148-49)*. Incomes grew rapidly not only in the industrial countries and centrally planned economies, but also in the developing economies, where the

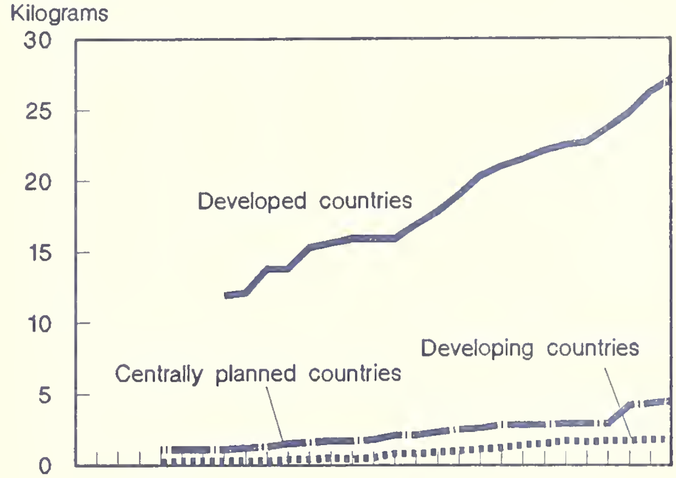
Per Capita Consumption and Utilization of Products in Developed, Less Developed and Centrally Planned Countries

G-1 Red Meat



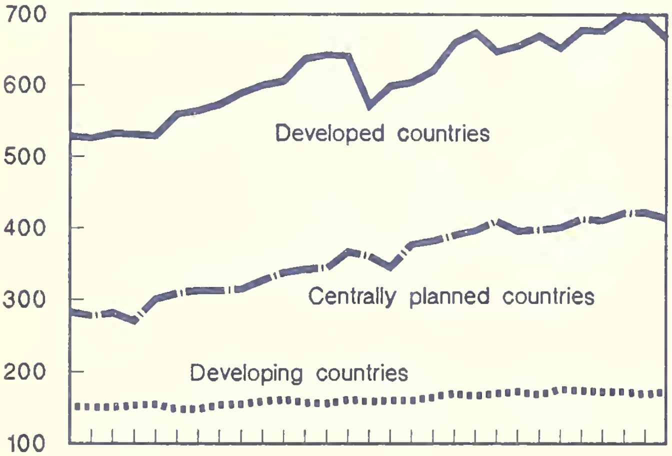
Carcass weight.

G-2 Poultry

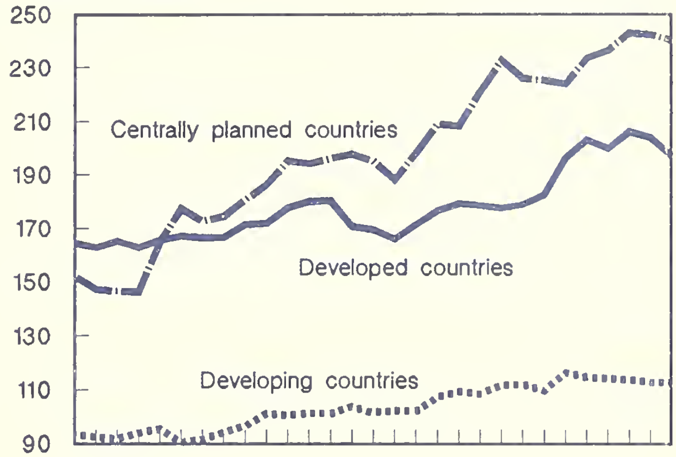


Retail weight.

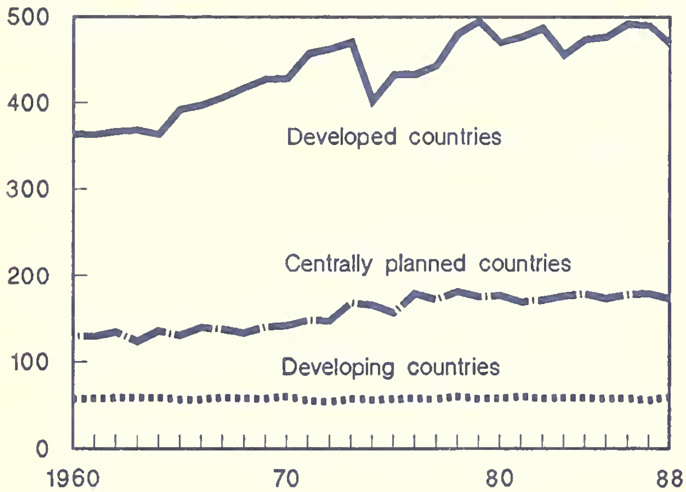
G-3 Total Grains



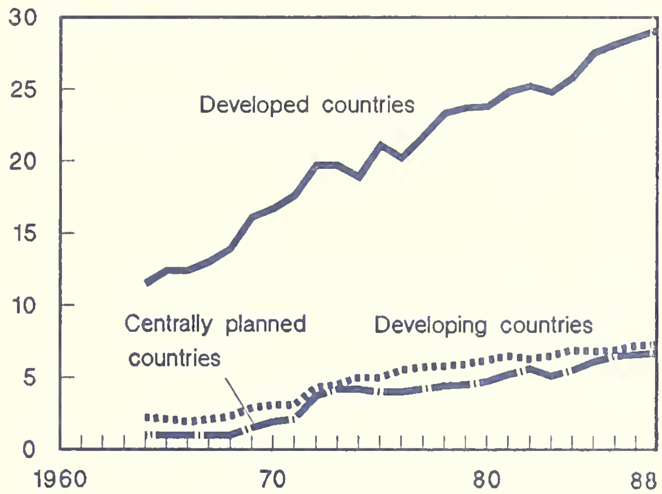
G-4 Food Grains



G-5 Coarse Grains



G-6 Total Oils



Source: 21, 22.

Table G-1--Per capita food consumption response to a 1-percent rise in income in Cali, Colombia, and the United States

Commodity	Household income-- Colombia			U.S.
	Low	High	Average 1/	Average
	Percent change in food purchases			
Butter & margarine	2.85	0.39	1.09	2/ 0.11
Pork	1.94	.69	1.02	.44
Eggs	1.37	.35	.93	-.03
Beef	1.52	.47	.84	.45
Milk	1.83	.20	.77	-.22
Other fruits	1.31	.49	.75	--
Oranges	1.14	.29	.69	.49
Vegetables	1.12	.20	.68	.18
Beans	.80	.25	.60	3/ .59
Other grains	.86	.25	.47	--
Maize	.63	-.43	.39	--
Rice	.42	.19	.34	-.37
Potatoes	.40	-.31	.16	.16
Cassava	.22	-.44	.12	--

Note: Sample data for 1969-70 in Colombia, 1953-83 in U.S.A.

-- = Not available. 1/ Includes data for three intermediate income strata not shown. 2/ For margarine alone: 0.02 for butter. 3/ Dried beans, peas, and nuts.

Source: (12, 17).

average growth rate exceeded 5 percent from the mid-1960's to the mid-1980's.

Three billion people, over 60 percent of the world's population, live in 40 developing countries where average annual per capita real gross national product (GNP) growth rates equaled or exceeded 1.8 percent from 1965 through 1987 (table G-2). The group includes both high- and low-income countries. Since these countries are largely agrarian (although China and India, the two largest, have significant industrial sectors), income has been expanding rapidly in the agricultural sector.

As low-income, agriculture-dominated countries develop to higher levels of per capita income, food demand may be expected to grow faster than population. A vast movement of population into the medium-income stage producing rapid growth in food demand would test the supply responsiveness of the world's major food exporters *(15, p. 309)*. However, such a phenomenon appears unlikely within the next decade. Many developing countries have been plagued by deteriorating terms of trade, soaring external debt, and increasing debt service obligations, which have constrained and absorbed income growth.

Regional income growth will continue to follow different patterns. Many of the Asian economies—particularly the newly industrialized countries—have demonstrated policy changes necessary for continued economic development. Most of Sub-Saharan Africa may continue to flounder, although some observers see encouraging results from policy reforms undertaken in some African countries. Latin America has bountiful natural and human resources, but again changes in policies are required to achieve its potential. The

Table G-2--Fastest growing developing countries, selected characteristics, 1987

Country and rank 1/	GNP per capita Growth 2/	GNP per capita 1987	Population	Income distribution	Food exp. 1986
	Percent	Dollars	Millions	Ratio 3/	Percent 4/
1 Taiwan 5/	14.6	4,358	20	--	6/ 37
2 Botswana	8.9	1,050	1	13.4	--
3 Oman	8.0	5,810	1	--	--
4 Singapore	7.2	7,940	3	7.6	21
5 South Korea	6.4	2,690	42	4.9	37
6 Hong Kong 7/	6.2	8,070	6	12.1	16
7 Jordan	8/ 5.5	1,560	3	--	9/ 37
8 China	5.2	290	1,074	2.6-3.0	48
9 Lesotho	4.7	370	2	--	--
10 Yemen A.R.	8/ 4.7	590	7	--	--
11 Indonesia	4.5	450	180	7.5	--
12 Congo	4.2	870	2	--	--
13 Brazil	4.1	2,020	147	27.7	--
14 Malaysia	4.1	1,810	16	16.0	--
15 Saudi Arabia	4.0	6,200	15	--	--
16 Thailand	3.9	850	54	11.2	36
17 Cameroon	3.8	970	10	--	--
18 Hungary	3.8	2,240	11	5.2	--
19 Yugoslavia	3.7	2,480	23	5.5	--
20 Tunisia	3.6	1,180	8	--	--
21 Egypt	3.5	680	52	8.3	--
22 Paraguay	3.4	990	4	--	--
23 Syria	3.3	1,640	11	--	--
24 Algeria	3.2	2,680	23	--	--
25 Ecuador	3.2	1,040	10	--	31
26 Mauritius	3.2	1,490	1	15.1	--
27 Portugal	3.2	2,830	10	9.4	--
28 Greece	3.1	4,020	10	--	35
29 Sri Lanka	3.0	400	16	8.4	44
30 Colombia	2.7	1,240	31	--	10/ 31
31 Turkey	2.6	1,210	53	16.2	--
32 Israel	2.5	6,800	4	6.6	--
33 Mexico	2.5	1,830	82	15.4	11/ 32
34 Pakistan	2.5	350	105	--	--
35 Panama	2.4	2,240	2	30.9	--
36 Burma	8/ 2.3	8/ 200	39	--	--
37 Dominican Rep.	2.3	730	7	12.6	--
38 Kenya	1.9	330	22	23.2	--
39 India	1.8	300	800	10.1	53
40 Morocco	1.8	610	24	--	--

-- = Not available. 1/ 1987 population over 1 million. 2/ Annual average, 1965-87, in real terms. 3/ (Income of highest quintile)/(income of lowest). Years vary. Botswana data for rural areas only; China, Israel, and South Korea for urban areas only. For comparison, U.S. ratio in 1985 was 9.5. 4/ (Expenditures for food at home)/(personal consumption expenditures). For comparison, U.S. percent in 1986 was 10. 5/ Province of China. 6/ (Expenditures for food, beverages, and tobacco)/(private final consumption expenditures). 7/ British Crown Colony. 8/ 1986. 9/ 1985. 10/ 1983. 11/ 1984.

Sources: 1987 GNP per capita and growth rates (23, 1989, table 1, pp. 164-165; except for Taiwan, which were calculated using data from 8, p. 26; 9, p. 312; and 5, following the method in 23, 1989, p. 231, to ensure comparability); population (22); income distribution (25, table 14.4); food expenditures (10, p. 111; 19).

Middle East, because of the large number of oil-exporting countries, and the USSR are the only major regions that stand to benefit from higher energy prices.

Income Distribution

Since income exerts a major influence on food demand, income distribution strongly affects food demand within a country and has unequal effects on particular foods. People living near the subsistence level spend their food budget on relatively low-cost sources of calories and protein, such as cereals and legumes. As income grows, the percentage of additional and total income spent on food declines. For example, in the Colombia study, families in the lowest income group spent 87 percent of their income on food, while those in the high-income group spent 35 percent *(18)*.

Although national income and population estimates are available for most countries, income distribution data are relatively scarce. Average per capita income does not reveal how income is distributed among the population. For example, the average per capita annual income in the Colombia study sample (table G-1) was $225. However, the low-income group ($60 per capita per year) contained 18 percent of the population, but only 5 percent of the total income. The high-income group ($706 per capita per year) had 13 percent of the people, but 42 percent of the income *(17, 18)*.

The effects of additional income on food demand among low-income groups often differ markedly from those in the high-income groups (table G-1) The Colombia study suggested that if total income were increased, the effect on food demand would depend on how the increase was distributed. If all of the increase went to the low-income group (plan A), the boost in food demand would be substantially greater than if it were allocated to all groups under the current income distribution (plan B). If total income were not increased but funds (equivalent to the increase in plan A) were transferred from the high-income to the low-income group, the growth in total food demand would be substantially more than under plan B, but somewhat less than under plan A *(17)*.

In the United States, where 10 percent of personal consumption expenditures is spent for food at home (excluding beverages and tobacco) (table G-2), Hahn found evidence of income distribution affecting the demand for beef, using 1960-84 data *(11)*. As in the Colombia study, demand for beef is more sensitive to income changes among low-income people, and transferring money from the rich to the poor increases beef consumption.

Population Characteristics

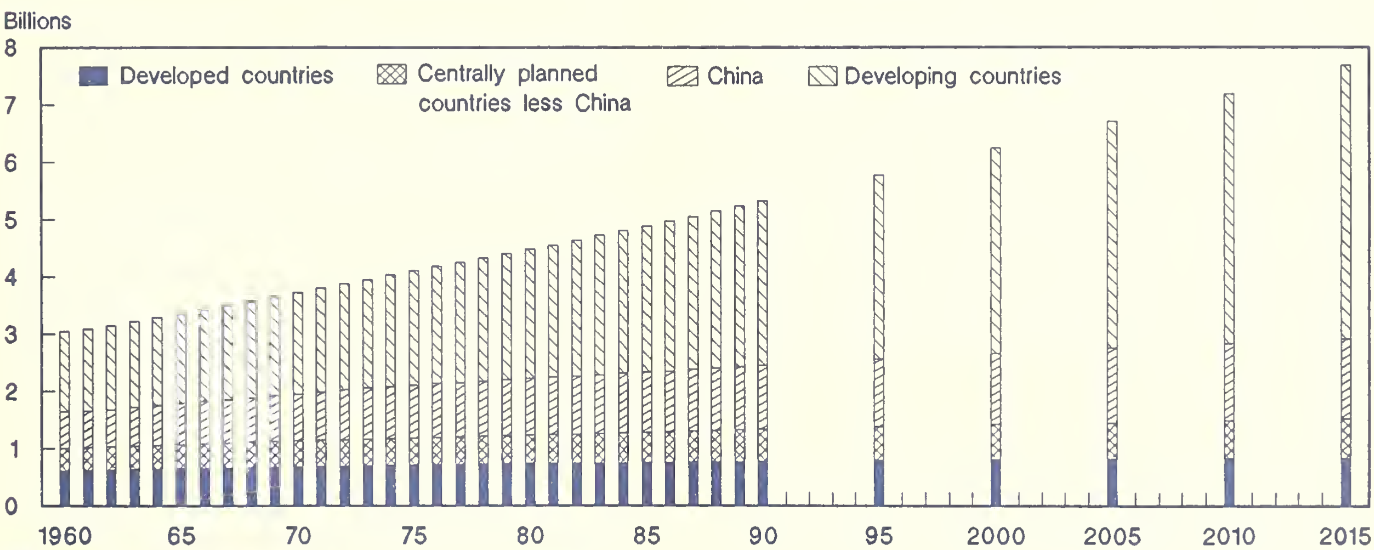
Food demand is also affected by socioeconomic and demographic characteristics of population, including age, sex, religion, work status, and urban or rural location. Consequently, there is not necessarily a one-to-one correlation between population growth and aggregate food demand. The effects of future population growth are mixed because demographic trends differ greatly among countries.

In many of the rapidly growing African countries, the average age has been declining, and more than 45 percent of the population is under 15. Since children require less food than working adults, aggregate food demand increases less rapidly than population. As growth rates slow and the population ages—and a higher percentage moves into the workforce—aggregate food demand will increase, other things remaining equal.

The industrial economies and many of the Eastern European countries have aging populations that will require more resources for health care and proportionately less for food. China and the developing countries, however, are very different. In spite of China's birth control program, the population will continue to grow for decades because it is relatively young, and will still be one-fifth of the world population by 2000 *(22)*. The declining proportion of China's population that is composed of children could result in per capita consumption growth above current projections *(16, p. 56)*.

Most of the world's population growth since 1960 has occurred in developing countries, including China (fig. G-7). Most of these people subsist on barely adequate diets.

Figure G-7
World and Regional Population



Source: 22.

World population growth, unevenly distributed among regions, will continue to occur most rapidly in the developing countries, where the potential growth in food demand is greatest because of current low income levels. However, "Rapid population growth tends to decrease labor productivity in agriculture, reduce the pace of transformation of the economy from agricultural to nonagricultural, and hence, discourage growth in per capita income, in food intake, and in nutritional status *(15, p. 307)*."

Interrelated Effects of Population, Income, and its Distribution

How income, income distribution, and population relate to one another in influencing food demand is not completely understood, but various hypotheses have been suggested.

Population growth in the absence of income growth cannot generate increasing aggregate food demand unless demand for nonfood items decreases. Per capita income growth alone, on the other hand, does not guarantee a commensurate unlimited rise in food demand. A person can only eat so much per day, as demonstrated by the proclivity of people to spend less of their incremental income on food as income rises. Diet changes that occur with rising income, particularly the shift to consumption of livestock products, introduces a further complication.

During 1966-80, increased consumption of animal products caused feed use of basic food staples to grow faster than food use in all major regions and subregions of the developing countries *(16, p. 26)*. Greater consumption of pork and poultry meat, which account for more than half the total meat production in developing countries, implies growing feed grain demand as incomes rise *(14, p. vi; 16, p. 56)*.

In contrast to direct consumption, the amount of indirect per capita grain consumption in industrial countries is virtually unlimited. For example, in the United States, Canada, and Northern Europe, 700 to 900 kilograms are used per person per year, including grain fed to livestock. Even among higher-income developing countries, about one-quarter of grain consumed goes to feed livestock.

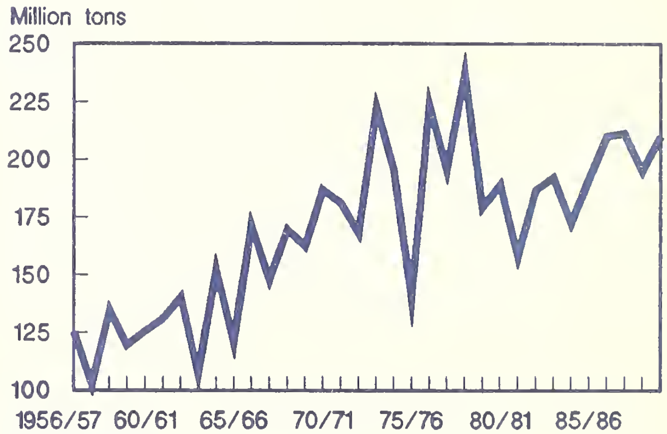
Lower-income developing countries use less than 2 percent of their total cereals for livestock. With a subsistence diet, only 180 to 230 kilograms of grain are required to feed a person for a year. It may well be, as Islam says, that on a per capita basis more than twice as much grain was fed to animals in developed countries as was fed to human beings in developing countries *(13)*.

Policies

Government policies affect per capita food consumption and/or demand. For example, in 1972 the Soviets decided to increase supplies of livestock products through increased grain imports (fig. G-8). This boosted per capita demand for both grains and livestock products.

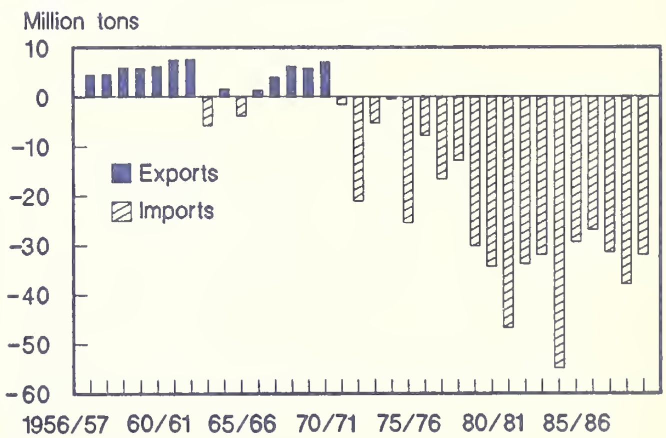
In developed countries, policies such as tariffs, quotas, and price-support programs, contrived scarcity to support prices and income for farmers, have taxed consumers of grains, dairy products, sugar, and meats in the United States, the European Community (EC), Canada, and Japan *(14, fig. 2, p. 6)*. Artificially high prices for products such as sugar and beef increase the demand for substitutes such as high fructose corn syrup and poultry meat, thereby changing consumption patterns. In the case of grains and dairy products, effects on consumption may be less clear-cut. Consumers pay for price-support programs in the form of taxes, but they also benefit from the consequent higher production. Price effects are difficult to estimate, therefore. Moreover, the price and income impacts on consumers in developed countries may be limited by the relatively small proportion of household budgets spent on food.

Figure G-8(a)
USSR Grain Production



1989/90 projected.
Source: 21.

Figure G-8(b)
USSR Net Grain Trade



1988/89 preliminary. 1989/90 projected.
Source: 21.

Changing policies are affecting food demand in centrally planned economies. Inflationary policies are boosting incomes in the Soviet Union, and, combined with the continued state control of retail food prices, are creating unmet demand for foods such as meat and butter *(7)*. The effect of these policies is to ration quantities purchased, which limits per capita consumption.

China's per capita sugar consumption has more than doubled over the past decade because of rising per capita incomes and increased availability of sugar-containing products in the food supply. China's sugar imports have grown as consumption exceeded domestic supplies. Continued rising consumption will depend on income, pricing, and import policies *(4)*.

According to findings by USDA, developing countries such as Argentina, India, and Nigeria tax the production and subsidize the consumption of wheat and/or rice *(20)*. These policies of contrived abundance tend to discourage domestic grain production and stifle agricultural development, which retards growth in per capita incomes and food demand. A recent study of 37 developing countries by the Food and Agriculture Organization of the United Nations (FAO) found that 31 were subsidizing food, with most subsidies going to the urban poor *(1)*, thus mixing the effects on food demand of subsidization policies with those of urbanization. Egypt, for example, subsidized its urban consumers with transfers of about $2 billion annually in recent years.

International lending institutions, such as the International Monetary Fund and the World Bank, sometimes require borrowing countries to institute policy reforms that would eliminate or modify food subsidies, effectively raising food prices. Proposals for reducing trade-distorting agricultural policies are now a focus of the Uruguay Round of negotiations under the General Agreement on Tariffs and Trade (GATT) involving the world's major exporting nations.

Urbanization

Cities of the developing world grew rapidly in the 20th century. By 1985, Mexico City had become the world's largest city, and more than half of the world's largest cities were in the developing countries *(24)*. Urbanization in the developing countries involved: (1) major migration from the countryside, transforming small cities into large cities (as in most of Latin America); and (2) population growth within cities (as in cities of East Asia).

Urbanization is a major, but not always easily measured, influence on food demand. Since urbanization is often accompanied by higher income, their individual effects on food demand can be hard to separate. Urbanization usually increases consumption of some animal products, fresh fruits and vegetables, a greater variety of foods (including snack foods), and foods quicker and easier to prepare. Consumption shifts from grains perceived as inferior when consumed directly (like corn and sorghum) toward rice and wheat *(6, pp. 44-45)*.

Urbanization often decreases the production and consumption of traditional food staples. Migration from village-oriented agriculture often removes labor necessary for maintaining traditional staple commodity production, leaving fewer farmers to produce more food for growing demand; it also exposes new urban residents to foods rarely seen before.

Urbanization has increased the cost of cooked food, particularly in South Asia and Africa, where all the trees around the larger cities have been cut for fuel. About 1.5 billion people in 63 countries depend on wood for cooking. As prices of fuel for cooking have increased, the cost of *cooked* food has also increased in these countries *(3, p. 44)*.

Between 1950 and 1986, the number of people living in the world's cities increased from 600 million to 2 billion. At this rate, by the year 2000, half of the world's projected population of 6.2 billion will live in urban areas, compared with 33.6 percent in 1960 and 39.9 in 1980 *(1, 3, and 24)*. In the developing countries, where urbanization is more rapid, FAO projects that the proportion of the population living in cities will rise from 31 percent in 1980 to 44 percent in 2000 *(1)*.

Other Influences

Other factors affecting food demand include cultural influences and technology. Cultural influences on food demand differ greatly across countries and among groups within a country. Cultural influences emanate from religion, family living patterns, employment, education, age, and other socioeconomic factors.

In many countries, some foods are not commonly eaten because of religious beliefs. Examples include beef in India and pork in many Middle Eastern countries. Consumption patterns rooted in religious and cultural beliefs are often the most resistant to change. However, as consumers are exposed to new foods, consumption patterns may change. For example, foods such as wheat bread have caught on in many countries where they weren't traditionally eaten. Rice consumption in Japan and other East Asian countries has declined as the popularity of bread increased. Likewise, in Africa, manioc consumption is falling as the demand for bread grows.

Technology has aided food advertising, such as television advertising designed to increase demand for specific foods. Technology has also affected relative prices among foods—such as butter and margarine, sugar and other sweeteners—and thus the demand for particular foods and their substitutes.

Conclusions

Prices, income, income distribution, and policy changes, probably the most important sources of demand changes in the past, will likely continue to exert major influences on food demand, although the exact nature of the relationships among these influences is still poorly understood.

Income growth among the low-income populations of the developing countries may well be the factor activating that potential for increased food demand. Policy reforms that permit or encourage economic development, and subsequent income growth, will determine where and when food demand will grow. Rapid income growth across many developing countries by 2000 appears unlikely because of the political, institutional, and structural changes that would be required. However, some individual developing economies may emerge, as South Korea and Taiwan have in recent decades, and become important sources of increased aggregate food demand over the next 25 years.

From the point of view of estimating food demand, income growth and policy reforms are linked. Policy reforms proceeding in the Soviet Union and in some of the East European countries introduce a major new uncertainty into the world food situation, however, because they could result in increasing consumer incomes faster than available supplies and some of this demand might suddenly be shifted to world markets. At a minimum, meaningful reforms in these countries presuppose a realignment of input and output prices, but a large unmet aggregate demand might become effective through higher food imports and thus drawdowns on world food stocks. Income growth in China and other developing countries that are experiencing the most rapid growth, partly resulting from policy reforms, will also be a major factor driving food demand for much of the next two decades.

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Famines Past and Famine's Future

by

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How far has the world progressed in controlling its most acute form of food crisis—famine? Famine still occurs, yet this ancient threat seems misplaced in a time of chronic food surpluses in major agricultural producing nations.

The term "famine" is generally reserved for the most extreme incidents of starvation and associated diseases. It applies to episodes of unusually high death rate resulting from these causes over a large area. This usage allows explicit contrast of famine with chronic malnutrition and with food shortage, important but distinct aspects of hunger.

Improved understanding of these episodes is clearly necessary for formulating policies to prevent them or to mitigate their impact. It is also important because these and other disasters are as much determinants of national development as they are results of development. The marginal changes and steady trends resulting from the parameters typically studied by economists have often been completely offset by the discontinuities of a disaster.

Why Famine Occurs

The earliest theories throughout the world on why famines occur came from theological interpretations, generally resulting in prevention strategies based on adherance to religious doctrine. For example, Ethiopian priests in 1625 were influential in the government with their interpretation of famine as a message from their deity that the people ought to respect the religious laws more rigorously. Since then, individual factors which may contribute to famine vulnerability have formed the basis for many separate theories of famine.

Although each of these single-source theories may be valid in a particular place or time, none of them explains famine generally.

Other researchers have fitted more elaborate theoretical structures to the famine phenomenon in an attempt to account for interactions among causes and for threshold effects. The dominant theory of famine causality, as indicated by the policies of most governments, is based on food availability decline (FAD). In this approach, famine is closely linked to an unusual decline in aggregate food available within a country or region. The proximate cause is generally reduced food production due to drought or, in some cases, floods, crop diseases, or pests. This view of famine generates a prevention strategy to stabilize food availability despite variation in the food production environment. Increased trade, development of drought-resistant plant species, increased food storage, and closer monitoring of aid needs are typical programs within this strategy.

Numerous researchers have criticized the FAD approach. The linkage between climate and famine has been shown to be weak and declining. In a rare case of systematic research across time, Buchinskiy identified 60 major droughts in or near Russia between 994 and 1954 *(1)*. Less than a quarter of those droughts were a factor in famine; drought was a major factor in only 16 percent of the Russian famines since 971. Sufficient food to feed India was produced even in the famine years of the 19th century. Food supplies were apparently adequate during famines in the Sahel in the early 1970's, in Bengal State, India, in 1943, and in Ethiopia in the 1970's.

Furthermore, most of the recent cases where famine was associated with major aggregate declines in food availability could not be explained on the basis of variation in natural factors. The Soviet Union in 1947 and China in 1959-60 suffered from human actions as much as from nature. Vietnam, Cambodia, and Biafra (Nigeria) cannot claim any natural disaster among the causes of their last famines. A recent critique of the FAD approach emphasized three points: (1) it ignores regional and class differences; (2) it minimizes internal solutions in favor of foreign aid; and (3) it diverts attention from normal suffering of some groups.

The major alternative model has roots dating to the last century by Amartya Sen under his term "entitlement approach" *(4)*. The emphasis in this model lies with the rights to food which various groups possess. This approach distinguishes between failures of direct entitlement, that is, the loss of rights to food by farmers due to their reduced productivity, and failures of exchange entitlement, that is, the loss of rights to food by anyone who normally depends on trade which is no longer available. This view brings price analysis into the heart of the discussion of who suffers during famine.

The two models are partly reconciled by regarding them as characteristic of different time periods. The FAD model might have been appropriate in an age without recourse to the productivity and redistribution opportunities of today and without pressures from input markets and dependency on output markets.

Long-Term Trends in Occurrence

Analysts generally infer the trend in famine occurrence from the trend in some causal variables. The central concern of most famine research today is specifying the relative importance of famine causes and how they are changing. Yet, no consensus has emerged indicating how much the contributing factors that are growing offset those that are declining *(2)*. Contending factors that are cited as contributing to increased occurrence of famine include environmental degradation, population increase, and the spread of market economies. Factors decreasing vulnerability to famine include improving technology, increasing trade,increasing foreign aid and, again, the spread of market economies. Factors that are controversial both for how they contribute to famine and for whether they are increasing include dependency on dominant states and militarism.

An alternative method to analyze the likelihood of famine begins by observing the pattern of occurrence over time. The experience in various regions is sufficiently different that several different explanations of famine trends are suggested.

The trend in Europe has not been smooth, although it is clear that the likelihood of famine declined dramatically outside of Russia after 1850. This experience suggests a relationship between industrialization, general development, and famine avoidance. Of course, it also assumes there will not again be a breakdown of political institutions on the scale of World War II, which instigated the most recent famines there.

When this interpretation of European success is transferred to the world regions most vulnerable today, economic growth and higher technology are emphasized. The immediate increase in vulnerability which is associated with cash cropping and dependence on international markets may be underestimated. Similarly, useful techniques, such as improved on-farm storage, may not be recognized because they do not provide growth even though they reduce variation in food availability.

The problem of famine was addressed more directly by governments of the Indian subcontinent, achieving much success without as much economic growth. The trend in famine occurrence remained steady until an abrupt decline in 1900. The two recurrences since then demonstrate, as World War II did in Europe, that famine protection is not complete.

In India, the British intentionally followed a policy of non-intervention in food marketing even through the crisis in Orissa and Hyderabad during 1865-67 when 10 million people perished from famine. Active policies to mitigate major production shortfalls were instituted after 1867 and accumulated experience led to revisions in procedures and, eventually, to relative security from famine.

The measures adopted in India are often considered as a model for other areas which have not sufficiently reduced the threat of famine by general development. India's example is more appropriate than Europe's because it promises more immediate protection and because it was employed in a relatively modern trade and technology environment. India's and Bangladesh's techniques include monitoring regional food deficits and prices, maintaining national food stocks, improving transportation, instituting rural employment programs, and diversifying production.

Ethiopia makes no claim of having controlled famine. Its series of past famines shows no clear trend of increasing or decreasing in frequency orintensity. The number of major famines is higher already in this century than in the 19th, although the worst famine was in 1888-92, in which about a third of Ethiopians died.

Some of the contributing factors in Ethiopia have been reduced, but, apparently, other factors have arisen. In the three famines from 1747 to 1783, for example, locusts were responsible for sharp declines in food harvest. Today locusts are controlled well enough by a United Nations program to prevent widespread disaster. Similarly, international relief efforts have been able in recent crisis periods to contain diseases such as typhus, cholera, and dysentery, which were the major causes of death in the 1916-20 famine. Today environmental degradation, population density, and cash cropping play a larger role in famine.

The experience of regions that have greatly reduced their vulnerability to famine demonstrate alternative strategies. Neither in Ethiopia nor in any other country does the long-term pattern of famine occurrence indicate increasing vulnerability. On a year-to-year basis, the likelihood of famine rises and falls based on short-term phenomena. Some long-term causal factors, such as environmental degradation, may be gaining in importance, but the evidence of famine incidents fails to demonstrate a positive relationship between time and famine in any country.

Recent Patterns of Occurrence

A closer focus on the period since the end of World War II sharpens the image of the impact of short-term phenomena on famine occurrence. No trend in frequency of famine is apparent over this period, but the number of lives lost seems to decline with time. Apparently, mitigation efforts have been more successful than prevention efforts.

A relatively timely and generous international response is now typical as information travels more rapidly, but the need for such responses continues. Moreover, organizing such a response can be extremely difficult, as the case of Cambodia in 1979-80 proved, and even a well-organized international relief effort can fail, as southern Sudan shows today.

A review of the case histories of the most recent famines clearly establishes that widespread institutional breakdown is now typical prior to mass starvation. An analysis of famine cannot rely on random variation in economic variables which assumes a relatively fixed institutional environment. Weather, ecological deterioration, prices, exchange rates, and interest rates are clearly insufficient for predicting modern famines.

Although the government blamed drought at the time, the largest famine in the postwar period, that in China in 1959-60 (fig. H-1), is now acknowledged to have been triggered by the massive disruptions in the countryside produced by Mao Tse-tung's Great Leap Forward, when peasants were mobilized to produce steel in backyard furnaces and otherwise prevented from concentrating their labor on food output. The famine is estimated to have taken 30 million lives *(2)*, and its effect shows up clearly in China's population growth rate trend (fig. A-16).

In January 1979, Cambodia had been effectively isolated from the world at large for almost 4 years. Cambodia's people were moved around the countryside regardless of their home villages and towns, and made to take part in collective labor on a gigantic scale. All food aid was cut off to a country already ravaged by years of war. The new regime followed a policy of self-sufficiency to the extreme, even to the extent of abolishing money. Total paddy production from the two annual crops in 1979/80 was 637,000 tons, according to official figures cited by Shawcross *(6, pp. 299-300)*, compared with 3.8 million tons of production in a normal year before the war. A country listed as a major grain exporter in a 1967 USDA report *(8, p. 2)* was on the brink of famine.

Another recent instance was Bangladesh. In 1988, Bangladesh experienced the worst flooding in its history, affecting 46 million people. Despite massive breakdown of physical infrastructure, effective and timely relief probably kept human deaths associated with malnutrition or, indeed, associated with the floods in any way to a few thousand.

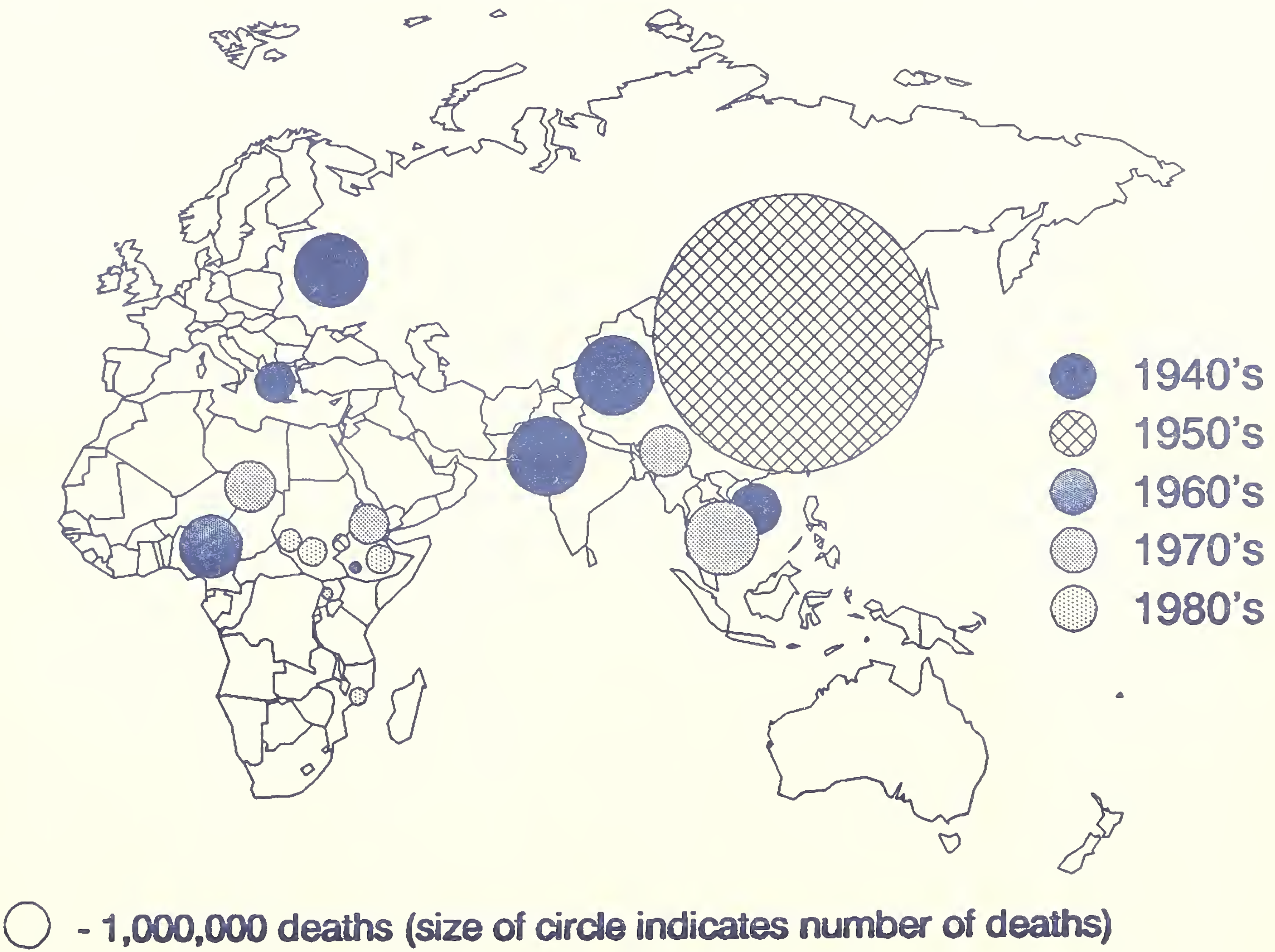
Sudan, like Cambodia, has normally been a food-exporting country. Sudan exported grain every year between 1966 and 1983 *(5, appendix table 9)*, and continues to do so. It had a bumper grain harvest in 1988 *(7, Sudan table)*. Because of the civil war in southern Sudan, about 250,000 more deaths than normal associated with malnutrition are estimated to have occurred in 1988 *(3)*. The war continues. It has interrupted local cattle and grain markets. People are afraid to travel because of land mines. Each side perceives food as a weapon in the war. Wells have been poisoned. International relief efforts have been repeatedly frustrated by military operations. The war has pushed southern Sudan into a new kind of Stone Age, in the words of one on-scene report, characterized by extreme isolation, disease, and widespread hunger. Apart from famine, the disruptions added to the 300,000 new refugees last year. The United Nations estimates 100,000 deaths will result in 1989 unless food can be stockpiled in the south.

Ethiopia and Mozambique also remain on the verge of famine due, in part, to military activity within their borders. But their immediate prospects, at least, are not catastrophic.

Conclusion

While famine is probably not strengthening its claims on the lives of the poor, it remains a threat in many parts of the world and looms constantly over the future of a few African nations. Effective strategies for control have been developed and are adequately supported internationally wherever local institutions are stable. Where they are not, however, people are still at risk. Stronger rural infrastructure in many countries and more rapid resolution of armed conflict would eliminate the fear of famine for many.

MAJOR FAMINES



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The Global Trade Environment and Agriculture

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Three changes in the past 30 years have radically altered the environment for agricultural trade:

- First, the increasing integration of trade and financial markets, spurred in part by the rapid rise in international banking, has led to increasing dependence by the United States and other countries on global markets that are susceptible to manipulation by government policies and programs. The rapid increase in international capital flows, primarily a result of a surge in world liquidity during the 1970's, coincided with increased trade in goods and services.

- Second, the shift from fixed to flexible exchange rates in the 1970's gave greater autonomy to domestic monetary and fiscal policies and transferred the effects of changes in these policies to trade-dependent sectors, such as agriculture.

- Third, multilateral negotiations under the General Agreement on Tariffs and Trade (GATT) have significantly reduced tariffs on merchandise trade, largely exempting agriculture and other primary products but allowing for substantial worldwide increases in protection in the 1980's through nontariff barriers.

Changing Circumstances

The 1980's started as a decade of increasing commodity surpluses, decreasing trade, and declining prices on broad categories of goods. This was in stark contrast to the 1970's world of recurrent food crises, expanding trade, decreasing stocks, and rising prices. Thus, the agricultural policy challenge is to provide flexibility in a changing environment.

Government intervention in agriculture restricts the ability of the system to respond. Many of the industrial countries, for example, are characterized by substantial government subsidies of agriculture, encouraging production of a wide variety of grains, livestock, and dairy products well in excess of domestic needs and independent of global competitive conditions. The developing and centrally planned economies, on the other hand, have tended to implicitly tax agriculture while subsidizing food consumption.

The debt problems of the developing and Eastern European countries have severely constrained their ability to import on commercial terms, even at real dollar prices well below those of the 1970's. Pressures to control inflation caused by the excesses of the 1970's have further impeded flows. The global trade environment is still highly constrained, directly in the Third World and indirectly in the industrialized world, by financial conditions that are partly the remnants of inflationary fears.

International Trade and the World Food System

Problems in global commodity markets are a symptom of the conflict between the growing economic integration of national economies and the independent pursuit of agricultural policies which basically reflect domestic political concerns. The outcome has been increasing government intervention, growing distortions in market signals, and consequently inefficient production; resources in the industrial world are being shifted into agriculture because of policy, not market, signals. Resources in developing countries are being similarly shifted into the nonagricultural sector. This conflict has serious implications for world food security. Its resolution requires that trade more closely reflect fundamental economic factors.

One of the features of the postwar economy has been the consistent pattern of growing world integration. Today, most national economies have large proportions of domestic output dependent on export markets for sale or import markets for inputs and retail goods. Except for a few recession years (1979-83), world trade has grown substantially faster than world gross domestic product (GDP) for 1961-87 (fig. I-1), making economies more interdependent.

Nevertheless, this growing interdependence is not constant across countries. The industrial economies have been opened to increased trade at a much faster rate than have the developing economies. This can be partially explained by the inward-looking industrialization (import substitution) policies pursued by the majority of developing countries. This occurred in spite of the general systems of tariff preferences which industrial countries have instituted for the products of developing countries. Except for the East Asian countries, most developing countries have not taken advantage of this preference.

The pattern of integration does not grow at a constant rate. The 10-year period after the first oil shock, between 1974 and 1983, was a period of reduced growth in trade relative to GDP. However, the price increases of 1973 and 1978-79 produced dramatic shifts. The oil shock of 1973 resulted in a 2-year fall in the volume of overall merchandise trade, followed by strong growth in the subsequent 4 years. But in 1978-79, the industrial countries refused to accommodate the price hike with inflationary policies, as had been the case between 1975 and 1979. That worldwide restriction on monetary growth produced a global recession that lowered the volume of trade for 4 consecutive years.

In recent years, industrial economies have continued to integrate, while the developing economies (in sharp contrast to the growth spurts in trade of the 1970's) are being largely left out of the post-1982 recovery. The debt crisis has forced many of the most heavily indebted nations to reduce imports. At the same time, the constraints on investment cut the development of potential export industries. The lower participation of these debt-constrained countries in the world trade system places their food security at risk, lowers their long-run growth potential, and reduces market opportunities for all nations.

Agriculture in World Trade

Worldwide, agriculture has dramatically declined as a percentage of total trade (fig. I-2). First, the process of economic development generally reduces resource intensity devoted to food production relative to industrial sectors. However, the exclusion of agriculture from the GATT also contributed to the decline.

The share of agricultural trade for the developing countries has declined the most rapidly, from 29 down to 12 percent of total trade over 1961-87. The share for the industrial market

Figure I-1
Trade to Gross Domestic Product Index

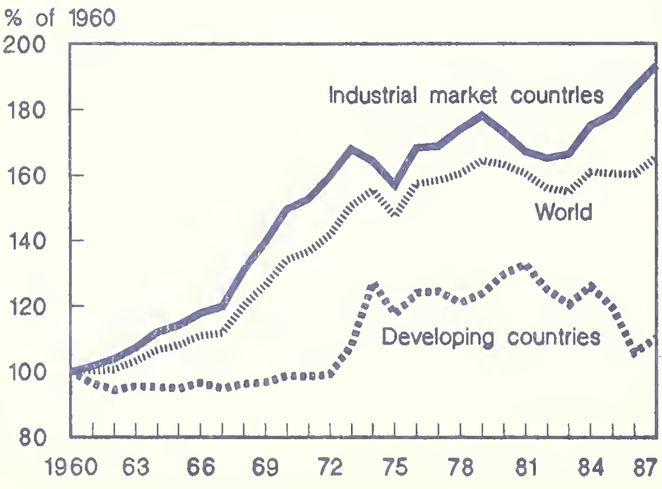
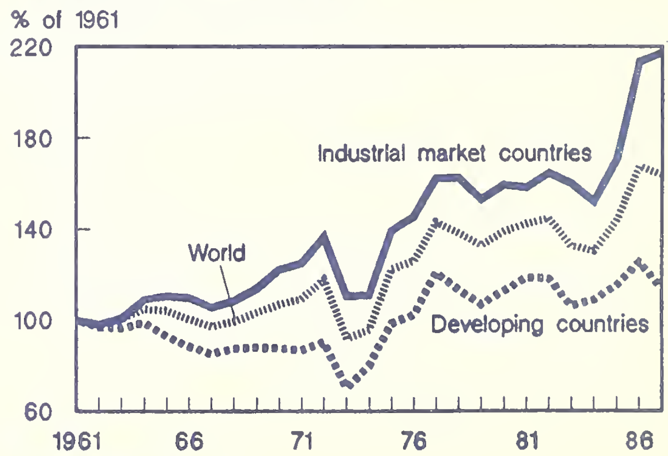


Figure I-2
Ratio of Growth in Agricultural Trade to Agricultural Production



Average exports plus imports.

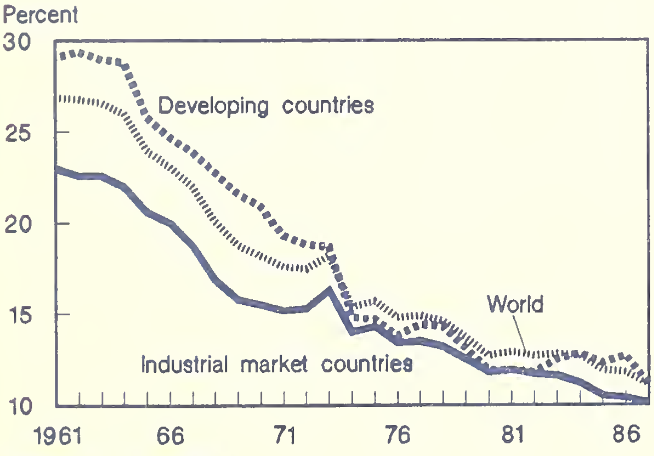
economies fell from 23 to 13 percent. The decline, mirroring the slowdown in trade growth, has stabilized in recent years at 11-14 percent of total trade. However, agricultural trade will likely continue a slower decline relative to total trade.

The pace of agricultural trade integration since 1960 has been slower than that of total trade integration, but is increasingly important to agricultural production (fig. I-3). Recently, agricultural markets of the industrial market economies have become more integrated, but developing economies have not.

Trade in grains steadily increased as a proportion of production from 1961 until the early 1980's (table I-1). After 1983, trade in grains no longer kept pace with production. Although the developing countries increased their purchases as a percent of production between 1961 and 1987, this was not enough to prevent the accumulation of huge stockpiles in the West by the end of 1987. When the developing market stagnated, surpluses grew in the industrial countries, and exports plummeted as a proportion of production. Despite the drought-induced reduction in grain stocks entering the 1989 crop year, conditions for rebuilding stocks will persist for the next few years, given normal weather and the present trade environment.

Grains as a percent of total agricultural trade has declined since 1970's. From nearly 20 percent of the proportion of all agricultural trade in 1981-85, the share taken by grains fell to almost 12 percent by 1987 (table I-2). Industrial country grain exports, as a proportion of agricultural trade, have declined by one-third since the first half of the decade. Developing countries have not only reduced overall agricultural imports, but also the proportion of grains.

Figure I-3
Share of Agriculture in Total Trade



Average exports plus imports.

A sharp contrast to grain trade is provided by fruits, vegetables, and nuts, in which trade as a proportion of production has grown through the 1980's. The key importers of these products are the industrial countries, which are unconstrained by world financial conditions. However, they also seem to benefit more by trading with each other than with the developing world. Increases in trade as a proportion of production have been matched by both imports and exports (apparently) between the industrial nations. The industrial countries have been more fully integrating their economies through increased world trade (along with selected countries in East Asia).

Fruits, vegetables, and nuts have also been rising as a proportion of all agricultural trade, in exports and imports. The developing countries have boosted their exports dramatically in the most recent 3 years shown, while the industrial countries have increased both imports and exports.

Hopeful signs for agricultural trade can be seen in a view of trade in meat and meat products. Trade has increased as a proportion of total meat production (table I-5). The developing world's imports of a higher proportion relative to production can be interpreted two ways. It may mean that incomes are rising rapidly, but it could also mean that domestic production facilities have deteriorated in some countries or can no longer produce the same quantity from existing capital. Some countries have been forced to slaughter livestock because feedstuffs could not be purchased with scarce foreign exchange, and therefore the future expansion of feedgrain exports to much of the developing world does not appear promising in the early 1990's.

Trade in meat and meat products as a proportion of total agricultural trade has generally risen (table I-6). Exceptions are recent declines in imports in the developing world and exports by the developing world excluding China.

Agricultural trade responds broadly to the forces directing total trade. The increasing integration of the industrial countries is mirrored in agricultural trade, with the developing world occupying a more precarious marginal position.

The Role of Monetary and Fiscal Policies

Monetary and fiscal policies have played an important role in short-run changes in trade flows. One of the most important aspects of the growing integration of the world economy has been the emergence of a well-integrated world financial system. Banks, investors, and governments can now shift real resources across borders with dazzling speed and efficiency. This development is closely associated with the increasing dependence on trade, periods of substantial disequilibrium in trade markets, and the desire of world bankers and financiers to escape the growing regulation of domestic financial markets.

Table I-1--Percentage of production of all cereals taken by trade

	1961-70	1971-75	1976-80	1981-85	1985	1986	1987
			Percent				
World:							
Exports	9.6	11.0	12.6	13.5	12.4	11.2	12.5
Imports	9.4	10.8	12.4	13.3	12.2	11.1	12.3
Industrial countries:							
Exports	24.0	31.2	36.5	37.0	32.8	30.0	35.8
Imports	16.3	17.5	16.9	13.8	12.8	12.3	12.7
Developing countries:							
Exports	3.4	2.8	3.3	3.7	3.5	2.9	2.4
Imports	7.6	8.3	10.2	11.9	10.9	10.6	12.2
Developing countries excluding China:							
Exports	5.3	4.5	5.4	6.3	5.9	4.9	4.1
Imports	9.5	11.2	13.8	16.6	16.1	15.4	16.8

Note: Exports do not match imports largely because of differences in timing and reporting. An export may be counted as occurring in one country in one year and by the importing country in the next year. Exports reported by crop year are assigned to a calendar year based on the year in which the harvest occurs.

Source: (1).

Table I-2--Percentage of agricultural trade taken by cereals

	1961-70	1971-75	1976-80	1981-85	1985	1986	1987
				Percent			
World:							
Imports	17.6	18.9	17.9	19.1	17.2	14.0	12.4
Exports	17.0	18.9	17.4	18.8	17.0	13.7	12.3
Industrial countries:							
Imports	11.7	12.4	10.8	10.4	9.5	8.8	8.2
Exports	23.1	24.8	23.2	24.0	22.1	17.8	15.8
Developing countries:							
Imports	38.4	37.4	32.6	32.4	30.0	26.5	23.7
Exports	8.8	8.4	7.6	9.3	8.5	6.4	5.3
Developing countries excluding China:							
Imports	35.6	35.8	31.0	30.8	29.5	26.0	22.5
Exports	7.9	7.3	7.0	9.2	7.6	5.6	4.9

Source: (1).

Table I-3--Percent of production of fruits, vegetables, and nuts taken by trade

	1961-70	1971-75	1976-80	1981-85	1985	1986	1987
			Percent				
World:							
Exports	6.8	7.7	8.4	9.0	9.1	9.4	NA
Imports	6.7	.6	8.3	9.0	9.4	9.3	NA
Industrial countries:							
Exports	9.2	10.9	12.7	15.1	16.1	16.5	NA
Imports	14.7	17.7	21.1	24.8	27.5	27.6	NA
Developing countries:							
Exports	5.4	6.1	6.7	6.9	6.7	.0	NA
Imports	1.9	1.9	2.3	2.6	2.4	2.3	NA
Developing countries excluding China:							
Exports	6.8	7.6	8.4	8.8	.8	.7	NA
Imports	2.5	2.5	3.0	3.4	3.2	3.1	NA

NA = not available.

Source: (1).

Table I-4--Percentage of agricultural trade taken by fruits, nuts, and vegetables

	1961-70	1971-75	1976-80	1981-85	1985	1986	1987
				Percent			
World:							
Imports	12.6	12.4	12.4	13.0	13.5	14.9	15.9
Exports	11.7	11.6	11.6	12.1	12.5	14.1	14.8
Industrial countries:							
Imports	14.2	14.3	14.7	16.6	17.1	17.9	19.5
Exports	12.1	10.6	10.5	10.5	11.1	12.4	13.2
Developing countries:							
Imports	7.8	7.6	8.1	8.1	8.1	8.8	8.2
Exports	10.5	11.9	12.0	14.4	14.2	16.4	17.8
Developing countries excluding China:							
Imports	8.7	8.5	9.0	8.8	8.6	9.5	9.0
Exports	9.6	11.0	11.2	13.8	13.9	15.7	17.3

Source: (1).

Table I-5--Percent of production of all meats taken by trade

	1961-70	1971-75	1976-80	1981-85	1985	1986	1987
World:							
Exports	5.6	6.2	6.9	7.3	7.1	7.4	NA
Imports	5.5	6.0	6.7	7.1	7.0	7.4	NA
Industrial Countries:							
Exports	7.1	8.7	10.2	11.5	11.5	12.4	NA
Imports	8.7	9.7	10.0	9.7	10.3	10.7	NA
Developing Countries:							
Exports	4.5	4.1	3.8	3.6	3.2	3.0	NA
Imports	1.6	2.1	3.9	5.0	4.6	5.2	NA
Developing Countries excluding China:							
Exports	5.4	4.8	4.5	4.5	4.1	3.8	NA
Imports	2.1	3.0	5.7	7.9	7.6	8.8	NA

Source: (1).

Table I-6--Percentage of agricultural trade taken by meats and meat products

	1961-70	1971-75	1976-80	1981-85	1985	1986	1987
World:							
Imports	7.7	8.9	8.5	8.6	8.3	9.3	9.9
Exports	7.9	9.3	8.8	8.9	8.5	9.4	10.1
Industrial countries:							
Imports	9.2	11.1	10.3	10.1	9.8	10.5	11.2
Exports	10.5	11.3	11.0	10.8	10.7	11.9	12.2
Developing countries:							
Imports	3.3	3.6	5.0	6.1	5.9	6.8	6.5
Exports	3.9	5.4	3.9	4.4	3.9	4.0	4.7
Developing countries less China:							
Imports	3.7	4.0	5.7	6.7	6.3	7.4	7.2
Exports	3.7	4.9	3.4	3.8	3.1	3.1	3.4

Source: (1).

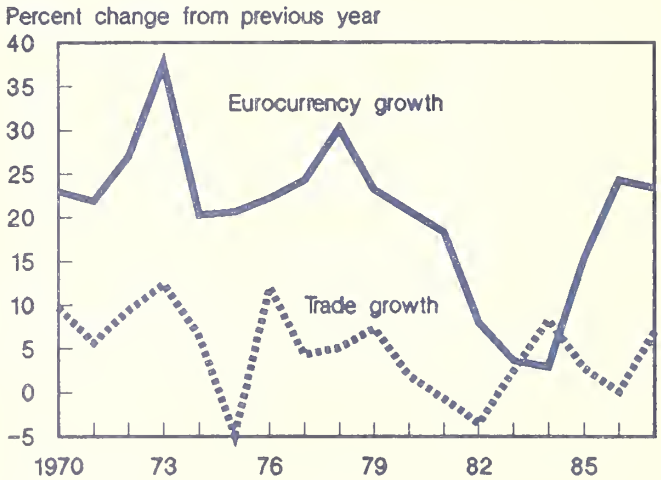
Immediately after World War II, international capital movements were almost exclusively related to trade or government-to-government transfers. The Eurocurrency market burgeoned in the 1960's, largely in response to a sustained period of U.S. balance of payment deficits.[1] The Eurodollar market broadened to include all major European currencies, and other offshore banking centers emerged around the world. There are major international capital markets operating in all regions of the world. (Besides New York and London, there are extensive Asian markets in Hong Kong and Singapore, Latin American markets, and secondary markets in small island states.) The huge dollar deposits associated with the oil shocks and the move to flexible exchange rates greatly expanded these markets.

The opening of world capital markets has permitted trade in some factors of production on a previously unheard-of scale, one indication being the expansion of multinational corporations. Providing financing to overseas investors enables them to seek the most efficient means of production immediately, rather than buy capital goods out of current production. The shift in capital can also partially offset trade restrictions in goods and labor markets.

The enormity of the stock of private assets and the flow of transactions on these markets greatly hinder the ability of any one government or set of governments from significantly altering international financial flows. In mid-1987, Eurocurrency deposits exceeded $4 trillion, compared with total world exports of approximately half that amount. International financial flows are estimated to exceed $40 trillion per year, or more than 20 times the trade of goods and services.

Changes in these overseas assets can exert a great impact on real trade flows. Figure I-4 shows the effect of abrupt changes in the rate of growth of money on real trade since 1970. The trade recessions of 1975 and 1981-82 accompanied marked declines in the growth rate of overseas bank assets. The 1986-87 surge in real trade growth has been accompanied by growth in these bank assets similar to that of the 1970's. However, as seen in figure I-4, this surge has been isolated in the industrial world and the Four Tigers (South Korea, Hong Kong, Taiwan, and Singapore) (not shown). One may conclude that the exclusion of many developing and most Soviet Bloc countries from world capital markets, a direct result of the debt crisis, has also blocked their participation in the gains in international trade.

Figure I-4
Eurocurrency Growth and Real Trade



Financial flows dominate trade flows in determining short-term currency movements. The necessity of at least limited flexibility in exchange rates is one outcome of the emergence of the international capital markets. Foreign currency reserves of all countries amounted to $500 billion in 1987, only one-eighth of private currency deposits. In 1973, when the United States unilaterally went onto a floating exchange rate, total foreign currency reserves were already only 25 percent of offshore deposits ($100 billion compared with offshore deposits of around $400 billion). In this environment, it is impossible for any one country or group of countries to counteract the expectations of the private market and fundamentally alter changes in exchange rates. When the United States went to a freely floating exchange rate, its total foreign currency reserves were down to less than $12 billion, an amount clearly insufficient to stop any concerted private market pressure for an exchange rate change.

The growing international financial system changed the way monetary and fiscal policies affect domestic economies. Under fixed exchange rates, monetary and fiscal policies are transmitted overseas via changes in interest and inflation rates. A small fixed-exchange-rate country therefore cannot avoid external shocks caused by abrupt monetary policy changes in the rest of the world.

The world debt problem, which revealed fiscal mismanagement in some of the most successful fixed-exchange-rate (or, more accurately, managed-exchange-rate) economies of the 1970's, has become a serious obstacle to expanding trade. The Third World debt problem developed out of many of the same phenomena as the integration of world capital markets. The monetary shock that precipitated the worldwide recession of 1979-82 was transmitted unabated via fixed exchange rates to those countries most in need of continued capital inflows. Overvalued currencies then produced stag-

[1] A Eurocurrency is a bank (or nonbank) account denominated in a currency other than that of the bank's location. A deposit of U.S. dollars in any bank outside the United States is thus always classified as a Eurodollar. The Eurodollar system began during the 1950's, oddly enough, as a result of actions taken by the Soviet Union. Trade by the Soviet Union was conducted in dollars, which had to be placed in a bank convenient for international transactions. Fear that the United States would seize Soviet assets (during the height of the Cold War) if placed in a domestic U.S. bank led entrepreneurial Russians to demand a place for their deposits. Thus, the Eurocurrency market came into existence.

nating exports and surging imports. These conditions prevented repayment as credit inflows to the largest debtors ceased abruptly in 1982-83 *(2)*.

The world debt burden is the most serious constraint to world trade and development in the 1980's *(3)*. It is an intractable problem that will plague the world economy for years to come. The resolution of this problem is one major precondition for the return of a world trading environment approximating the growth of the 1970's. Although current strategies will likely begin to overcome this constraint, a solution is still distant.

Under a flexible exchange rate regime, the independent pursuit of macro policies induces changes in exchange rates through capital flows—the transfer of assets denominated in one currency to those of another. Inflation and deflation are largely kept at home. The resulting changes in exchange rates, if persistent, induce transfers of resources from trade sectors—export and import competing—to nontrade sectors, or the reverse.

A flexible exchange rate is a direct function of current and expected monetary and fiscal policies in two countries. Thus, if policy changes are frequent or volatile, then exchange rates will accurately reflect this an uncertain environment. The resource shifts that result may then either speed a needed adjustment to changing fundamental economic relationships (costs, technology, tastes, and preferences), or show that a well-meaning policy has unintended consequences. Some of these unintended resource shifts as a result of exchange rate volatility may well have led to the increased protectionism of the 1980's.

Such shifts are particularly important for those countries where agriculture is an important trade sector. The exchange rate tends to decline under conditions of easy monetary policy, increasing the competitiveness of agriculture. An exchange rate appreciation under tight monetary conditions tends to reduce the appeal of agricultural exports to overseas buyers.

The important change in the way the new system operates is that shifts in competitiveness result from exchange rate realignments rather than changes in cost structures induced by the rate of technical change. They may also be relatively short-lived—only 5 years rather than the usually more prolonged product life of agricultural commodities. For countries such as the United States, West Germany, and Japan, changes in monetary policies can substantially alter world commodity markets.

Movement away from the gold standard has caused a loss of control over the U.S. relative competitive position vis-a-vis major customers and competitors. As long as all currencies were defined in terms of gold, it was possible for the United States to devalue relative to that international medium of exchange and thus, in a single act, against all other currencies. However, the U.S. dollar replaced gold as the international medium of exchange and thus became the numeraire currency. It is now impossible to uniformly devalue the U.S. dollar.

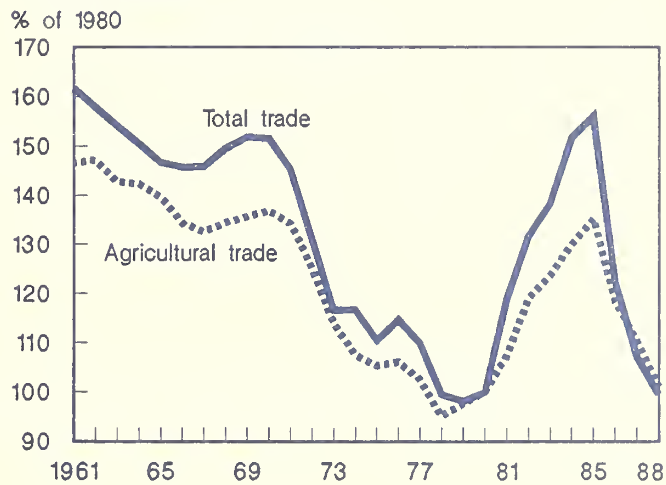
Changes in the dollar's relative value are brought about by appreciations or depreciations of other currencies against the dollar. This implies that the relative changes in the U.S. exchange rate can vary considerably among countries. Indeed, this is exactly what has happened historically. Different "baskets" of currencies change value at unequal rates. This can be seen clearly where the value of the dollar given by a total trade-weighted exchange rate (all world trade) has fluctuated more than the U.S. agricultural market exchange rate (fig. I-5).

Export share changes respond to long-run shifts in real exchange rates. Short-run changes can be hedged or returns insured via forward operations. However, short-run volatility *must* drive a wedge between potential and expected return; even the cost of hedging, which may be less than .5 percent of a given sale (the incidence of which is virtually never on the U.S. purchaser or seller) nonetheless must alter its volume. As elasticities rise, the effects become more pronounced.

Only monetary and fiscal policy stability can produce exchange rate stability. The necessity for monetary and fiscal stability has been tacitly acknowledged by the Plaza and Louvre accords of 1985 and 1987 *(4)*. But in addition, trade *must* be free and open. Cooperation within the GATT is critical.

Flexible exchange rates play an important role in the issue of protectionism and in the GATT. Discussions of any transi-

Figure I-5
Trade-weighted Exchange Rates, United States



tion between the present environment and full or partial agricultural trade liberalization must take account of the effects that exchange rates will have on frustrating or reinforcing domestic agricultural policies.

A major impact of the current world financial environment is the fact that monetary and fiscal policies now work partially through changes in exchange rates. These changes affect the relative competitiveness of trade intensive sectors, such as agriculture, much more than on nontrade-intensive sectors.

Agricultural Prices in World Trade

Real commodity prices have tended downwards in the 20th century. Figure I-6 shows how agricultural export prices have fared against all import prices for the industrial world. Since 1975, agricultural export prices have failed to either keep pace with inflation in other goods prices, or have fallen faster than other prices. Those developing countries exporting nonagricultural in exchange for agricultural goods were better off during the past decade. Food prices have fallen more sharply than nonfood agricultural prices, so developing countries have benefited as agricultural exporters and as food importers. Food price declines reflect the growing surpluses in industrial countries.

Government domestic control of prices means that excess supply (or demand adjustment) occurs through variation of international prices. Thus, if all the adjustment occurs in traded goods, agricultural prices show more volatility than other primary product prices.

Improving Trade Flows

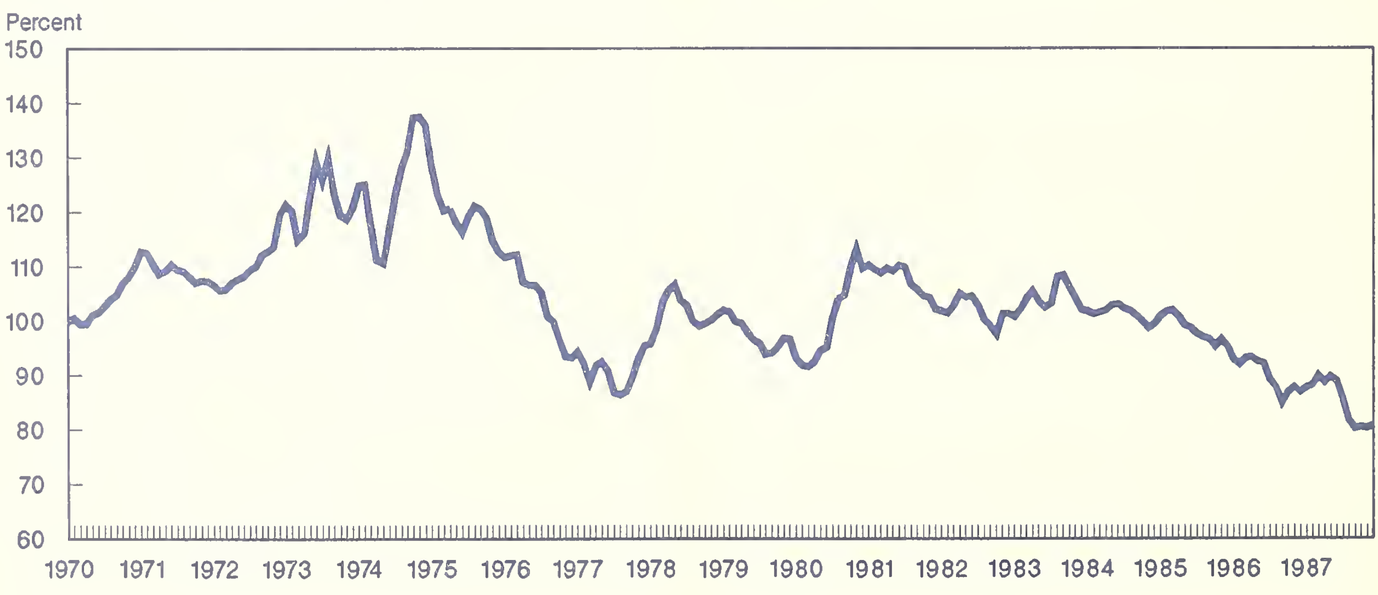
Some of the difference between total and agricultural integration can be explained by the different patterns of trade liberalization followed by the manufacturing and agricultural sectors. Most of the postwar multilateral trade negotiations have concentrated on manufacturing.

Government interventions are extensively used around the world to achieve various domestic objectives regarding agriculture. The methods used to restrict trade are voluntary quotas, administrative protection such as "unfair" trading practices, and complex regulations of health and sanitary conditions and import requirements. In some ways these constraints are more serious impediments to trade than tariff barriers, because they restrict trade movements largely independently of competitive conditions. Embargoes, sanctions, and other forms of punitive measures also interfere with trade.

These interventions prevent price signals in the international economy from being accurately reflected in domestic prices. Thus, farmers' decisions are based on price signals that will not necessarily clear markets. Where intervention is deliberately enforced on a large scale, as with the European Community's (EC's) Common Agricultural Policy (CAP), the inefficiencies take on vast proportions.

The direct effects of consumer subsidies are compounded by indirect taxes on food producers in low-income countries where agriculture employs most of the labor force. These

Figure I-6
Ratio of Raw Food Prices to All Primary Commodity Prices



countries lack the funds to meet their own food needs with imports, and their needs keep growing because the transfer of resources out of agriculture stifles effective demand. Reliance on food aid is increasing. The combined impact of all countries' agricultural policies has led to an inefficient global outcome.

The difficulties in balancing global commodity trade have led to a consensus that domestic agricultural policies have global repercussions. This consensus is behind the inclusion of agriculture in the current round of multilateral trade negotiations under the the GATT. In the Uruguay Round, all forms of explicit or implicit subsidies are being considered. A coherent plan for reducing trade-distorting policies, however, still needs to be worked out and agreed upon.

The multilateral agricultural trade negotiations can substantially improve the environment in which commodity markets operate, with competitiveness being fundamentally related to real comparative advantage in production. But if negotiations fail, an even more distorted and "unfairly" competitive environment for world agricultural trade could result.

Conclusions

World economic integration has been driven by expanding trade shares of industrial and newly industrial countries. Growth has been export-led based on expanding trade. Many of the developing countries have followed import-substitution and inward-looking growth strategies. Furthermore, the debt repayment problems of developing countries have reduced their ability to participate in international trade. The danger is that the once-industrializing heavy debtor nations will begin to resemble the low-income countries of Sub-Saharan Africa, especially if an agreement is not reached in the Uruguay Round allowing for renewed growth in world trade.

The current round of GATT negotiations can achieve a unique goal not only for agriculture, but for world trade. The confrontation of domestic interest groups could lead to the elimination of incentives for trade protection. The failure of the Uruguay Round, on the other hand, could lead to a strait-jacket of "managed trade," yet another guise for import quotas and other nonmarket interventions, which are popular ways of evading GATT principles.

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Short-Term World Food Security

by

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Food security has been defined as the ability of all people to obtain enough food in a timely manner to maintain a healthy and active life *(8, p. 1)*. That ability depends upon the translation of nutritional needs into effective economic demand. In the long run, food security depends upon a country's economy to generate and distribute purchasing power sufficient to adequately feed all its citizens. This purchasing power either encourages domestic producers to supply the food needed or, when backed by foreign exchange earned by other economic activity, allows food imports to supplement domestic production. The problem of food security, therefore, is rooted in inadequate economic development and poverty.

Food security in the short run is concerned with how nations, either individually or collectively, cope with inadequate availability of or access to food. Lack of food security may reflect chronic inability to produce, import, or distribute sufficient food. It may also result from transient shocks that threaten the supply or distribution of food. Such shocks may originate within a country from such causes as drought, pests, or diseases that devastate crops. For a country heavily dependent upon food imports, the shocks may also originate from outside, as when prices of imported food rise sharply because of events such as crop failures in major food exporting or importing countries. The shocks themselves may have nothing to do directly with food, as in the case of sharp increases in prices for other essential imports, such as petroleum, that compete for scarce foreign exchange in a country's import budget.

This article focuses upon the factors that affect world food security in the short-run in contrast to the emphasis given in the balance of this issue to those that affect the ability of the world to feed itself in the longer term. Whatever the prospects of improving long-term food security through higher productivity, strong economic growth, smoother trade flows, and other means, the problem of providing adequate food for millions of people in the present still awaits solution. Indeed, it is on what happens to those facing hunger or starvation in the immediate present that most attention focuses.

This dichotomy between the short and long term deserves emphasis because remedies designed for either term may not necessarily reinforce each other, and may even lead to potential conflict. The distinction should also be useful in analyzing and evaluating the effectiveness of markets, government policies, and individual actions in meeting human needs in response to both humanitarian concerns and economic self-interest. The measurement of world food security or insecurity and assessment of factors affecting it are questions separate from the identification of individual governments' or individuals' responsibility for dealing with food security issues. In the United States, a rough consensus seems to support a policy aimed at increasing food security around the world based both on concepts of national interest and shared humanitarian values. However, there is less agreement on the degree of responsibility, appropriate measures to be adopted, and the level of resources that should be devoted to such efforts.

Some Dimensions of Food Insecurity

Attempts to quantify the extent of food insecurity around the world commonly involve the estimation of the number of people who are undernourished, the degree of their undernutrition, the characteristics they share, and the amount of food required to bring their consumption up to some desired "normal" standard. The numbers fluctuate from year to year because they reflect not only the slowly changing hard core of the chronically hungry, but also the effects of transitory changes in food supply and distribution.

Estimating the Hungry

On a worldwide basis, national nutritional censuses which might provide a direct measure of the world's undernourished do not exist. Nearly as good information could be obtained from a compilation of broadly based national surveys of individual food consumption. Ideally, a survey would sample food intake by a group whose composition was representative of a country's population according to characteristics that affect food consumption, such as sex, age, body type, physical activity level, and also of the country's climate. The food intake of these individuals would be compared with standard estimates of the amount of caloric food energy required to support normal activity by such people. The percentage of people in the sample with inadequate intake would provide a very good estimate of the percentage of the entire population who were undernourished.

Unfortunately, such comprehensive surveys of consumption by individuals do not exist either. Furthermore, national surveys that sample total food purchases or food consumption by households are available for only a few countries and time periods. Sometimes household surveys are available for only a part of a country and their results may be extrapolated for the entire country, or perhaps even for other countries in the same region where no surveys have been undertaken.

A common extension of the above approach is to use the estimated average caloric consumption for an entire country as an approximation of the average food intake by its households. Such estimates of "dietary energy supplies" have been computed by the Food and Agriculture Organization of the United Nations (FAO) for nearly all countries based on "food balances" that attempt to account for all production, use, and movement of food commodities in and out of the country. These averages are usually adjusted based on other information such as that from limited surveys of household expenditures and income distribution, all of which requires additional difficult assumptions. Another basic approach starts with household income as the unit of analysis and attempts to correlate it with food consumption.

All of these methods have been acknowledged to have severe limitations and have resulted in widely varying estimates. The major source of variation in estimates has been the lack of agreement among experts on how to estimate the dietary energy requirements of individuals with different characteristics (for example, age, sex, weight, and activity level) and the distribution of those requirements within households.[1] For instance, a World Bank study adopted the household income approach to compare results of two different estimates of standard dietary energy requirements, both of which had expert backing. It estimated the number of undernourished in the developing countries in 1980 at 340 million (16 percent of population) using the lower standard and 730 million (34 percent) using the higher *(8, p. 3)*.

An FAO study using the household consumption approach and essentially the same population, consumption, and income data produced roughly the same estimate of the number of hungry using a standard corresponding to the World Bank's lower estimate of requirements. However, using a requirement corresponding to the Bank's higher standard, it estimated the hungry at about 495 million, 23 percent of developing country population, and 235 million less than the Bank's estimate. The difference translated into minimum average requirements of 1,840 and 2,060 calories per person a day in the World Bank's calculations, and 1,460 and 1,620 calories in FAO's *(4)*.

This all suggests that the main value of these estimates may be in indicating the broad nature, direction, and trend in undernutrition. Despite the differences in specific estimates, these studies would agree in general that in the mid-1980's:

- The percentage of the world's population that is undernourished has been declining over the last 2 decades.

- The number of hungry people continues to grow. The most recently revised FAO estimate placed the average number at about 512 million in 1983-85, compared with 475 million in 1979-81 and 460 million in 1969-71 *(2, p. 25)*.[2]

- Asia has the largest number of undernourished people, close to three-fifths of the total, although the increase in their numbers has slowed.

- Africa has the next largest pool of hunger, a little over one-quarter of the world's hungry, and that group has expanded the most rapidly.

- Poverty is the universally shared characteristic of the hungry. Among the poor, those who have the least ability to fend for themselves, such as children, lactating mothers, and the elderly, are usually the most vulnerable.

Magnitude of Food Deficits

The amount of additional food that the hungry need annually to achieve adequate diets is small. The total amount has been roughly estimated at between 15 and 20 million tons of grain, about 1 percent of global grain consumption and production annually.[3] Valued at U.S. export prices for wheat (Gulf ports, f.o.b.) in early spring 1989, this would equal $2.5-$3.5 billion.

1/ The methods used require translating different caloric requirements for diverse categories of people (e.g., adults and infants, active and inactive) into an average for the entire population without having adequate information about the distribution of such characteristics within households or the total population. The World Bank starts with an upper and lower estimate of the calories required to maintain "moderate" activity by *adults*, as estimated in a 1971 report of an FAO/WHO Ad Hoc Expert Committee. To compensate for the resulting *overstatement* of requirements for a population that also includes children and less active people, it *reduces* requirements by 20 and 10 percent, respectively. The lower requirement, 1,840 calories, merely avoids stunted growth and serious health risks, while the higher, 2,060, provides for an active working life.

FAO combines estimates of requirements for young healthy, active children to grow normally with those for adolescents and adults to maintain the body at rest (the basal metabolic rate or BMR). To compensate for the *understatement* of requirements for well nourished adolescents and adults performing physical activity needed to maintain life, the BMR was *raised* by 40 percent to 1.4 BMR as recommended by a 1981 FAO/WHO/UNU Expert Consultation. To explore the consequences of an argument that intra-individual variations in energy requirements should modify the latter figure, a cut-off based on a 1.2 BMR was also calculated. The resulting estimates of average requirements for the entire population was a lower standard of 1,460 calories and an upper standard of 1,620 calories.

For a more complete description of the World Bank and FAO methods, see *(8, pp. 1-3 and 55-57)*; *(5, pp. 4-5)*; and *(4, pp. iii-iv)*.

[2] These estimates are based on a minimum dietary energy requirement for adults of 1.4 BMR. See footnote 1.

[3] Based on International Food Policy Research Institute estimates *(9, p. 10)*.

A World Bank study suggests that the quantity needed in most countries typically represents less than 10 percent of national food supplies. In a sample of 35 countries, the aggregate food deficit averaged between 0.9 and 3.5 percent of national food supplies, depending on the estimate of caloric energy requirements used *(8, pp. 4, 19)*.

These quantities are based on the assumption that the income to purchase the food or the food itself could be targeted directly to the needy. Merely moving additional food into markets sufficient to drive the price down far enough for the poor to afford such food would require many times that amount. The World Bank study also indicates that national food supplies in many developing countries are either now sufficient, or could be easily expanded, to adequately feed the entire population if distribution problems could be solved. However, some low-income countries, particularly in Africa, face much more difficult obstacles in raising production.

National food deficits are sometimes described in terms of shortfalls from either the amount of food needed to maintain the historical, "status quo" average level of consumption, or from some (in developing countries) usually higher standard based on minimum desirable nutritional requirements. This deficit, or shortfall, is expressed as the difference between the amount of food needed to maintain the status quo or the nutritional standard and the sum of actual domestic production and commercial import capacity.

The status quo deficit in Sub-Saharan Africa averaged 3.8 million tons, while ranging between 2 and 6.7 million tons, during marketing years 1982/83-1988/89. Nutrition-based shortfalls averaged 10 million tons and ranged between 8 and 13.7 million tons. Food needs appeared lowest in 1986/87 because consumption, which had been reduced by droughts in the mid-1980's, was matched against a return to normal production. Nutrition-based needs also appeared low because deaths and fewer births from famine and civil disturbances had slowed population growth rates. The highest needs were estimated in the following year, 1987/88. As consumption levels increased, crops did not keep pace and a combination of deteriorating financial circumstance and rising world cereal prices reduced countries' commercial food import capacity.[4]

There is little evidence of either a rising or falling trend in either status quo or nutrition-based food aid needs in Sub-Saharan Africa. The 1988/89 needs are approximately at the mean of the 1982/83-1988/89 assessments. This suggests that little progress is being made on a regional basis in increasing food security or in advancing the level of nutrition. In fact, year-to-year fluctuations in food aid needs are becoming greater. However, the levels of shortfalls in food are declining as a share of total food needs.

Transitory Disruptions of Food Supplies

Temporary disruptions in a country's food supply may result from events specific to a particular country such as crop failures, civil disturbances, warfare, or refugee movements that spill across borders. They may also result from more remote events that reduce access to imported food, such as exceptionally poor harvests in major food exporting and importing countries or reductions in global grain stocks for one reason or another.

Whatever their source, these shocks are felt primarily as increases in world and domestic food prices, or as reductions in household purchasing power *(8, p. 4)*. The most important effect of a drought that sharply cuts food production in a low-income developing country, for instance, may be to drive up domestic food prices beyond what many can afford. Similarly, a serious reduction in global grain supplies may result in higher import prices for grain, thus cutting import capacity and boosting domestic food prices. The $20 rise in price reflected by the current U.S. export unit value of wheat of $150 per ton represents an increase in the import bill of $50 million for Sub-Saharan countries needing to import 300,000 tons of grain to maintain the nutritional status quo.

The most serious threats to food security have been those which occurred in the early 1970's, and could recur now, when substantial production shortfalls came close upon each other and led to a substantial drawdown in world grain stocks. Both then and now, the declines followed periods when the accumulation of excess stocks in exporting countries and weak international grain prices had encouraged measures to reduce stocks.

In addition, grain consumption by both people and animals, which had expanded under the stimulation of weakened prices, was at first slow to contract in the face of rising prices. As stocks fell and prices rose, consumers in low-income food importing countries found themselves bidding more intensely for grain against both people and livestock in more wealthy importing countries. The European Community's (EC's) decision to subsidize feed grain imports for its livestock producers in the face of supply scarcity (grain consumption actually rose in the EC during this period) in particular threw a disproportionate share of the burden of adjustment on developing countries. This forced their greater reliance on concessional sales and on food aid, an example of the potential conflict between short- and long-term food security measures.

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[4] Data on developing country food deficits are from a series of publications prepared since 1977 in response to an amendment of PL 480 requiring a global assessment of food production and needs. The most recent publication in the series was *(7)*.

Manmade Disasters

Manmade disasters, such as wars and civil disturbances that disrupt food production and distribution systems and contribute to mass movements of refugees, have become an increasing source of food insecurity. In many cases, what starts out as a serious but manageable crop failure turns into famine with the hungry trapped between warring political factions. The United Nations High Commission for Refugees (UNHCR), in consultation with the World Food Program (WFP), estimates that the total number of refugees and displaced persons in the world increased from approximately 7 million people in 1980 to over 12 million in 1988. In recent years, the largest number of refugees requiring material assistance have been in Africa, reflecting the interaction of political strife and drought *(1, p. 9)*.

The UNHCR also estimated that the food requirements of refuges would increase by about 15 percent to 1 million tons of grain and 213,200 tons of nongrain foods in 1989. The drain on food aid resources by manmade disasters is evidenced by the fact that more than 70 percent of the resources of WFP's International Emergency Food Reserve (IEFR) have been earmarked for refugees in recent years.

Economic Strains

Less dramatic but often equally serious threats to food security result from economic events that cut the household income of people with marginally adequate or already inadequate diets. For instance, the sharp rise in oil prices in the early 1970's helped exacerbate the 1972-74 food crisis by contributing directly to recession in many developing countries. The rise also produced recession in the developed countries that led to diminished demand for exports from developing countries and reduced their foreign exchange to purchase food imports whose prices had increased sharply.

In recent years, a major problem facing many developing countries is how to achieve "structural adjustment" of economies unsuccessfully coping with high debt, foreign exchange shortages, and rapid inflation that is a requirement for assistance from international lending institutions. The intent of such an adjustment is to put those economies on a better footing for achieving the longer term growth that is the foundation of long-term food security. But the austerity measures required to achieve such adjustment are very difficult to implement without producing a short-term slowdown in the economy that may reduce consumer purchasing power. This provides another example of a merging of short- and long-term problems of food security, and how measures designed to deal with them can conflict.

Coping with Supply Disruptions

In some cases the capacity to adjust to such shocks may lie within the power of the individual countries affected. In others, some sort of assistance or concerted action from outside may be the only alternative to sharply reduced consumption.

National Stock and Trade Adjustments

The effectiveness of food security policies that rely heavily on food imports to maintain consumption depends critically on the price of imported grains. Such prices are sensitive to the level of global grain stocks, particularly as they reflect the level of reserve stocks in grain-exporting countries. Approaches to adjustments to food production shortfalls in developing countries have revolved around questions of stock policy both at the global and national levels and management of food imports, including food aid. Countries experiencing a shortfall in production may absorb the effects by either drawing down stocks or reducing consumption, or by transferring the price impact to the world market through trade. Developing countries usually find it more necessary to absorb such shortfalls than developed countries because they have fewer financial resources with which to maintain food stocks and facilities needed to hold them or to pay for food imports.

Economists generally agree that the costs of maintaining national buffer stocks sufficiently large to meet most shortfalls in national food production are, on average, much higher than the cost of importing food for that purpose. In the case of infrequent but unusually large shortfalls, the costs are also probably beyond the means of most developing countries. For most of these countries, the more cost-effective solution would be to hold sufficient stocks to dampen the initial price impact of reduced supplies until imports begin arriving.

Developing countries, as a group, have made rather limited progress in building modest stocks to deal with small fluctuations in supplies or immediate emergency requirements. India, the major focus of fears of famine during the 1972-74 crisis, is a notable positive exception. Before then, India was regularly dependent upon large grain imports to make up grain production deficits. Thereafter, however, policies favoring the adoption of new technology helped production catch up with consumption during the 1970's. Stocks were generally built up when harvests were good, especially in the mid-1980's when supplies were adequate to support some exports. Thus in recent years, India has met production shortfalls largely with domestic stocks while using imports to a large extent to replenish stocks.

Countries in Sub-Saharan Africa have found it very difficult to maintain even modest reserve stocks because food production for so long has lagged, making large imports necessary in a not always successful attempt just to maintain consumption. However, even there, bumper crops in some countries following the 1983-84 drought permitted stock buildups along with some increases in interregional trade.

Some attempt has been made to supplement national stock policies with an international mechanism designed to assist developing countries in managing food imports. The International Monetary Fund (IMF) in 1981 established a Cereals Compensatory Financing Facility to provide up to 5-year loans with favorable terms to developing countries facing sharply increased costs in grain imports because of production shortfalls or other external economic shocks. In August 1988 this facility was combined with another that provides support to members of the IMF receiving financial support for IMF-supported economic adjustment programs in the event of adverse external shocks such as declines in export receipts or a rise in import prices or interest rates. It is now known as the Compensatory and Contingency Financing Facility. Very limited use has been made of the facility, probably because of the limited borrowing capacity of eligible countries and a reluctance to accept IMF conditions for economic policy reform.

Various food "insurance" schemes have also been suggested under which countries would pay "premiums" to finance the holding of stocks, especially in developed countries. So far, not much political support has been evidenced for such schemes, in part because of the difficulty of resolving how the financial burden of financing such arrangements should be distributed among exporting and importing participants.

Stocks and Food Security

In the immediate aftermath of the 1972-74 food crisis, international discussions of food security often focused on proposals to enhance the effectiveness of the world's grain reserves. At the 1974 World Food Conference in Rome, some 70 countries—including the United States, but not the USSR or China—subscribed to the International Undertaking on World Food Security. The Undertaking envisaged the establishment of an international system of nationally held grain reserves. In very loose terms, it called for adoption of national stockholding policies and establishment of national stock targets that would maintain minimum stocks for the world as a whole to ensure continuity of supplies for both domestic and foreign requirements growing out of crop failure or natural disaster. The amount and method of their holding by individual nations were to be nationally determined. The Undertaking also called for consultation and sharing of information on such matters.

Just what constitutes adequate grain stocks is controversial. An FAO study in 1974 concluded that stocks equal to at least 17 percent of total annual grain consumption are necessary for maintenance of a "minimum safe level of world food security."[5] That number assumes nearly irreducible working stocks in the "pipeline" of about 12 percent and actual usable reserve stocks of 5 percent. A very high proportion of the reserve component of stocks are held by the developed grain exporting countries.

Another study, based on more recent historical data, suggests a slightly smaller overall requirement, but a need for smaller working stocks and larger reserve stocks *(6, pp. 50-51)*. It also suggests that "pipeline" requirements may be declining because of increased efficiency in the marketing system. Although more working stocks are needed to fill the pipeline as more grain moves into international trade, better methods and facilities for handling, transporting, and storing grain should streamline the pipeline, especially in developing countries. Reduced requirements for working stocks means more available for reserve stocks. The fact, however, that interest rates are a major component of storage costs introduces considerable uncertainty into the assessment of optimum stock levels.

Any single indicator of food security is likely to be inadequate, particularly one as highly aggregated as the 17-percent figure. For instance, it takes no account of the composition of stocks and their distribution or of the distribution of consumption of grains between human consumption and livestock sector consumption. Nor does it directly reflect the interrelated trends in production, consumption, and trade. This means that a considerable variety of situations, accompanied by different food price responses, can potentially be described by the same percentage indicator.

The attempt to establish an internationally coordinated system collapsed in 1979 when participants could not agree on the overall size, distribution, and financing of internationally coordinated national grain stocks as part of a proposed new International Wheat Agreement. The issue was also intertwined with others that arose at the time of the Tokyo Round of Multilateral Trade Negotiations. The United States tended to view such an international reserve system as a means of providing a degree of world market stabilization and food security in a liberalizing world trade system in which market prices would largely determine production and consumption decisions as well as market shares. The EC appeared more interested in using a reserve system to, in effect, administratively allocate world trade shares in a manner that maintained its Common Agricultural Policy. The United States announced in 1981 that it was opposed to any

[5] The FAO secretariat defined "safe level" as "the level of total carryover stocks required to ensure in the following season continuity of supplies on national and international markets, and to maintain consumption levels and safeguard against acute shortages in the event of crop failure or natural disaster" *(3)*.

international control or coordination of grain reserves and advocated a more market-oriented approach to world food security and reserve stocks.

Without an international reserve system or a free world market in which producers make the major decisions about stock holding, domestic agricultural and trade policies have determined grain stock levels. In terms of global food security, such policies have generated usually adequate, if sometimes excessive, grain stocks since the 1972-74 crisis. However, the 1988 drought, and supply controls aimed at reducing U.S. surpluses, resulted in a sharp decline in North American grain production and stocks. World grain stocks were estimated (in June 1989) to have fallen at the end of 1988/89 to the lowest level, as a percentage of total utilization, since 1974/75, but still to exceed 17 percent of utilization. Global wheat stocks, as a percentage of utilization, were only slightly above 1972/73's 30-year low and were projected to decline further by the end of 1989/90.

Global grain stocks were not expected to be rebuilt in 1989/90 despite forecasts of a substantial recovery in grain production that were unusually dependent upon favorable weather. Thus, the current world agricultural system has not eliminated the potential for serious threats to global grain price stability and food security. Food security prospects in the near term will depend more than usual upon weather, but the evolution of agricultural and trade policies around the world will also be important.

International Food Aid

Food aid has provided an important source of adjustment to supply shocks. The most concrete international food-aid commitments are embodied in the Food Aid Convention (FAC) of the International Wheat Agreement (IWA). The current IWA has no economic provisions, but it originally aimed at maintaining world wheat prices within a set price band. The FAC was originally intended to serve both humanitarian and commercial objectives by ensuring that surpluses were channeled toward countries and consumers lacking the financial capacity to buy food, and away from commercial markets where they might depress prices. The countries belonging to the FAC in 1971 pledged to supply a minimum of 4.23 million tons of cereals (grain or financial equivalent) annually. In 1980, the minimum was raised to 7.59 million tons. The minimum pledged by the United States was increased from 1.89 to 4.46 million tons. Other current major guarantors include the EC (1.65 million tons), Canada (495,000), Australia (200,000), and Japan (225,000).

Most food aid donors also endorsed a 10-million-ton annual target for total food aid through 1977/78 at the 1974 World Food Conference, but it implies no specific commitments for individual countries. Donors have extended the target, but have been unwilling to raise it. The target was not achieved until 1984/85 when a combination of increased needs resulting partly from the African drought and a large buildup of grain stocks in the exporting countries led to shipments of food aid in cereals frequently approaching 12.5 million tons. However, such food aid was forecast to fall to about 9.8 million tons in 1988/89, and the U.S. component to about 5.6 million tons, because of a combination of generally good crops in potential recipient countries and the strong contraction of wheat stocks, accompanied by higher prices, in exporting countries.

The U.S. share of world food aid in grains has fluctuated around 60 percent in recent years. Other countries without the administrative facilities of the United States have tended to use the WFP to distribute their aid. As noted earlier, the IEFR was created to help meet emergency situations and supplement the WFP's regular resources directed to projects with both developmental and nutritional aims. The IEFR provided assistance to some 30 countries faced with natural or manmade emergencies during 1988. As of September 1988, total pledges by 56 donors to the regular resources of the WFP for the 1989-90 biennium equaled about $343 million, 25 percent of the agreed target of $1.4 billion. Pledges amounting to $1.2 billion (76 percent commodities and 24 percent cash), 87 percent of the target, had been made by 80 donors for the 1987-88 biennium. Pledges to the IEFR in 1988 equaled 328,310 tons of cereals and 62,914 tons of other foods. Contributions for all of 1987 totaled 636,293 tons of cereals, 42 percent of which was donated specifically for Afghan refugees, and 60,030 tons of other foods.

U.S. Food Aid Policy

U.S. food aid policy has its roots in Public Law (PL) 480 enacted in 1954, which reflects a blend of humanitarian and domestic agricultural policy concerns. The law specifically takes account of the objectives of alleviating hunger overseas, surplus disposal, and export promotion. The emphasis given to these individual but interrelated objectives in implementing the law has varied over time, depending on both domestic and external circumstances. The approach to attaining these objectives has also varied. The most important adaptations are concerned with guaranteeing U.S. food aid commitments and targeting the most nutritionally vulnerable countries and individuals.

The U.S. Congress's establishment of a 4-million-ton Emergency Wheat Reserve in December 1980 also reflected a melding of humanitarian and domestic agricultural policy concerns. The reserve was intended to be used "solely for emergency humanitarian food needs in developing countries" and to guarantee U.S. food aid commitments. A similar 6-million-ton reserve was proposed in 1977, intended to be consistent with the U.S. reserve proposal in the International Wheat Council, in conjunction with a proposed substantial enlargement of the U.S. Farmer Owned Grain Reserve. Congressional approval was not obtained until after the Government acquired 4 million tons of wheat, whose shipment to the Soviet Union was embargoed in January 1980, so as to isolate it from the market in order to avoid depressing prices. The first drawdown from the reserve, as a guarantee of U.S. food aid, was announced in October 1988 when the Administration ruled that 1.5 million tons of wheat could be released to meet 1988/89 PL 480 needs anticipated before arrival of the 1989 U.S. harvest. The reserve may have to be tapped again in 1989/90. No policy has been announced concerning future replenishment of the reserve.

To direct more food aid to the poorest countries, the Congress in 1975 established a requirement that at least 75 percent of all U.S. concessional credit sales under PL 480 go to countries defined by the World Bank's International Development Association as low-income countries. Title III of PL 480 established a procedure for forgiving a percentage of Title I credit obligations in exchange for the recipient government's using the local currency generated by Title I sales to help finance programs for rural and agricultural development, nutrition, health services, and population planning, with emphasis on activities to assist small farmers, sharecroppers, and landless farm laborers.

Other legislation has aimed at increasing the proportion of U.S. food aid required to be allocated under Title II which lends itself more effectively to targeting of malnourished groups, as opposed to Title I which lends itself to general market distribution. Another program (Section 416) provides donations of surplus food in U.S. Government stocks to needy people overseas. It is targeted and administered in much the same way as Title II. At its peak in FY 1985, Section 416 shipments equaled 40 percent of the value of those shipped under Title II, but the recent reduction in Government held stocks has caused Section 416 donations to dwindle. For instance, by the end of 1988, no U.S. Government held stocks of nonfat dry milk were available for allocation to food aid programs in FY 1989. A similar situation existed in the EC, the other traditional major donor of dairy products for food aid.

Information and the Efficiency of World Food Distribution

Rapid collection, interpretation, and dissemination of information about developing food shortages is important to both the efficient operation of commercial markets and the effective administration of food aid programs in alleviating conditions of food insecurity. The reduction of uncertainty can mean less need for reserve stocks because of reduced waste caused by poorly timed deliveries and a better grasp of the range of possible contingencies.

Data Collection and Analysis

Perhaps the greatest area of improvement in conditions affecting world food security has been in the collection and interpretation of food information relating to potential shocks to the world food system. FAO has played a leading coordinating role in this activity, and the U.S. contribution has also been prominent. The effective monitoring of agricultural conditions around the world still depends largely upon ground observations of harvests and the factors that affect them, such as plantings, rainfall, soil moisture and plant growth. More and more, however, such "ground truth" is being used to confirm data obtained from remote sensing such as those provided by space satellites, and to ascertain the relevance of those data in local farming systems.

The Global Information and Early Warning System (GIEWS) of the FAO is the office with the greatest capacity for this work. The country coverage of GIEWS has increased from only a dozen countries in Africa to all of Africa. The GIEWS project has received bilateral funding from European countries for improvements in remote sensing and data processing and communication. Cooperation and coordination among FAO offices and with the WFP has been much improved. Italy is currently providing assistance to GIEWS in its program of technical assistance to Africa. National agencies are being assisted to establish early warning systems that make use of locally acquired remote sensing data and country data on indicators of shortfalls in agricultural production. The GIEWS has the capacity to provide both early warning of food production shortfalls and the specific localities and communities that are affected. Limited coverage in Asia and Latin America remains a problem.

U.S. Foreign Food Information System

Since 1984, U.S. Government agencies have cooperated in preparing quarterly reports on the food deficits in countries prone to food shortages. This food needs analysis (FNA) is done under the jurisdiction of the Development Coordinating Committee (DCC). The reports, entitled *World Food Needs and Availabilities*, are published by USDA.

Cooperation among U.S. agencies facilitates the exchange of current information between U.S. trade and technical missions overseas and the commodity and economic analysis offices of USDA's Economic Research Service (ERS) and Foreign Agricultural Service (FAS), and also with the FAO in Rome. Analysts access current weather and crop information through the Joint Weather Facility operated by FAS and the National Oceanic and Atmospheric Administration. Information on financial and trade influences on food aid needs is acquired from such international agencies as the World Bank and the IMF.

The FNA examines the agricultural, food, and economic situation in each of 55 countries to ascertain the current and probable next-year food supply shortfalls. The analysis incorporates data on food production, stocks, food trade, world commodity prices, and the major factors bearing on a country's commercial food import capacity. These include financial reserves, merchandise trade balances, and debt payment obligations. The report deals with the aggregate national food supply, but does not address how evenly food supplies are distributed within countries.

The "status quo" and "nutritional" based measures of food requirements discussed earlier capture two different aspects of the food security problem. The "status quo" requirement estimates the food needed merely to maintain per capita consumption at recent levels. Because the status quo measures the failure in capacity to sustain current levels of food availability, it is a measure of the food need arising from sporadic interruptions in food supply. The status quo need is very much a measure of food security in that it signals diminution in food availability to which the population is accustomed.

The nutrition-based measure is concerned with the food needed to meet the FAO/World Health Organization standard of minimum per capita caloric requirements for a normal active life. The nutrition-based food deficits analyzed in the FNA provide a short-term view of a long-term problem. The factors, such as population growth and caloric requirements, determining the nutrition-based food requirements are stable and enduring. As in the analysis of status quo needs, the availability of food is influenced by the very short-term considerations of crop production and the financial situation of countries.

Improved National Food Policy Development

Other factors also can increase the efficiency of the marketing system and the effectiveness of stock and trade policies. In the aftermath of the 1972-74 food crisis, it was recognized that many developing countries did not have the governmental mechanisms and policies to effectively deal with threats to food security. One response was to create in 1976 within FAO the Food Security Assistance Scheme (FSAS), among whose objectives was the formulation of national food security polices and action plans. Advisory missions typically recommended a package of projects that included establishment of a unit within the host government to advise on food security policy, construction of storage facilities, establishment of strategic grain reserves with food aid donations, establishment of a management and operations system, including creation of revolving funds for stock management of such reserves, training of national staff, and improvement of domestic food information systems.

In recent years, the FSAS has broadened its aims to include projects concerned with expanding food production, improving distribution systems, and strengthening institutional mechanisms for planning and management. An important feature of the approach has been to seek out developed country donors to become intimately involved in project financing, planning, and management. At the beginning of 1988, 63 projects were operating in 30 countries (23 in Africa, 5 in Asia, and 2 in Latin America and the Caribbean) plus 5 regional projects in Africa and 1 in Asia, with a total value of $40.5 million. A total of about $89 million has been committed since the FSAS's inception. The donors tend to be countries without extensive overseas aid agencies. The United States usually prefers to carry out similar activities through its Agency for International Development.

Trade Liberalization and Food Security

Current dissatisfaction with the operation of the world agricultural trading system stems from the growth of protectionism in the 1980's, the budgetary cost of agricultural subsidies, fights for export market share, and other concerns not directly related to food security issues. Most studies suggest, however, that food security stands to benefit from a liberalized environment for agricultural trade.

The greater exposure to price movements accompanying trade liberalization would spread the required adjustments among more countries, for instance, thereby lessening the average change in consumption and stocks in each from what happens in a situation of restricted trade. The spreading of adjustments would, among other things, minimize the danger of sharp food price rises as occurred in the famous case of the EC's subsidization of feed grain imports during the 1972-74 crisis.

With substantial trade liberalization, one might expect these results:

- A lower requirement for global grain stocks relative to the level of grain utilization and trade because of greater market efficiencies.

- Smaller variations in world grain prices because of the more equal spreading of the effects of shocks through the system.

- A substantial reduction in the grain stocks held by the United States, and to a much lesser extent, by other grain-exporting countries, the major source of reserve stocks used to absorb supply shocks in the rest of the world. This would likely be true also if the United States moved to a more market-oriented or lower level of support for producers in the absence of substantial trade liberalization. The reduction in stocks would likely be much larger than the reduction in requirements in terms of food security resulting from greater market efficiencies.

- Higher world grain prices than experienced in the first half of the 1980's.

Thus, the question of how the world will adjust to reduced grain stocks in the United States and other grain-exporting countries could emerge as a central issue as trade liberalization progresses. Presumably, some countries, reacting to market signals as these become clearer, will pick up some of the former U.S. burden. Just what level of global stocks the market will call forth and how adequate such stocks will be in terms of food security will be a subject of speculation because of the absence for so many years of experience with a free global market.

Given their severely constrained financial means, developing countries, however, are not likely to increase substantially their holdings of stocks without some form of external assistance. Although they should benefit from smaller year-to-year price variations for imported food, they would appear to become more vulnerable to such occasional sharp fluctuations in global grain stocks and prices as occur. Thus, it appears likely that issues such as grain reserves or insurance schemes for aiding developing country food imports during periods of price instability are likely to receive renewed attention.

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Conclusions

by

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World food production over the past four decades has more than doubled and the production growth has exceeded the rate of population growth. Despite this very positive long-term trend of increasing food availability, the world seems to cycle between two kinds of food crises—too much and too little. During the late 1970's, the world appeared to be entering a period of food scarcity and rising real food prices. Most of the 1980's has been a time of rising stocks, depressed world agricultural prices, and concerns about excess production capacity. As we approach the close of the decade, concerns are again surfacing that the future will likely be characterized by inadequate food supplies.

Why the Cyclical Concern about Food Supply?

There are several reasons why, in spite of favorable long-term trends in per capita food production, the world always seems to be facing a crisis of either scarcity or plenty. First, agriculture by its very nature of dependence on uncontrollable weather is subject to unanticipated variations in production from year to year. The effect of weather-induced production variability is localized rather than spread evenly around the globe, and therefore its impact on the food supply of a particular population is much more dramatic than on global food supply.

As a matter of fact, as the first article showed, world grain production is quite stable around trend. Calculations by the Economic Research Service for the three decades 1950-80 show variability of world crop production around the trend of only 1.4 to 1.6 percent. In the same period, the variability range in the United States was 1.4 to 3.2 percent; in the European Community (EC), 1.8 to 3.2 percent; in the USSR, 3.7 to 5.3 percent; and in India, 2.5 to 5.5 percent. If one could aggregate food production across all commodities and countries (avoiding the difficulty of unit of measure), the degree of stability would probably be found to be even greater.

Also, the margin between too much and too little food is quite narrow. In most years, the world's population tends to consume what is produced. That is, accumulation and drawdown in global stocks from year to year are relatively minor.

Another factor contributing to cyclical concerns over food supply is the fact that most food is consumed in the country in which it is produced. That is, a relatively small percentage of the world's food production enters into international trade. Thus, in the case of grains, the most widely traded set of commodities, only 12 percent of world production was traded in 1984-86. It is also true that much of the trade in food is between net exporting countries and takes place to add variety to diet and to overcome seasonal shortages of domestic production. The number of net food exporting countries is small, and they tend to be highly developed, high-income, low-population-growth countries. The vast majority of the world's population lives in chronic food-deficit countries. Many of these countries are also poor, underdeveloped, and have very limited capacity to utilize commercial food imports to offset domestic food shortages. The concern about too little food is in reality primarily a concern about the vulnerability of the poor developing countries with high rates of population growth, often highly variable domestic agricultural production, and limited means of importing food.

The countries of the world (especially the developed countries, both net importing and net exporting) tend to employ agricultural and trade policies which insulate their producers and/or consumers from supply shocks. This insulation by policy forces adjustment to supply shocks onto a thin world market, magnifying the price effect of small global production shocks, and further reducing the ability of the poor countries to rely on world markets for food security.

Why the Current Concern about Food Supply?

One might ask why, when the world has recently experienced surplus production, rising stocks, depressed world prices, and predatory competition for market share, concern exists about the future ability of the world to provide adequate food supplies. The current concern seems to derive from a combination of short- and long-term phenomena.

During the last 2 years, world grain stocks have been drawn down to what many consider dangerously low levels. This drawdown has resulted from a combination of policy actions, primarily by the United States and the EC, to restrict production and move burdensome stocks onto world markets through efforts to maintain market competitiveness. The effect of these policy actions was reinforced by the severe drought in North America in 1988 and early 1989 in the United States and Argentina, which significantly reduced production.

Both of these factors are short-term. The policy actions were intentional and are reversible, and neither seems to indicate a long-term change in the world's ability to produce food. However, such phenomena do remind the world of the thinness of the margin between plenty and scarcity, and they focus attention on longer-term trends that could limit growth of food production over the long haul.

The phenomena that many observers feel have negative implications for the long-term ability to maintain an adequate food supply are several. Agricultural production, as a biological process, depends on the world's natural resource base, especially soil and water, and favorable climatic conditions. The world's supply of land and water is relatively fixed, although its utility for agricultural production can be modified over time through investment. Most land well adapted for agricultural production is being utilized, and the easily harnessed supplies of irrigation water have been exploited. The proportion of growth in global agricultural production derived from expansion of cultivated area and irrigation has been declining.

New lands recently brought into production tend to be fragile, their productive life under technologies being used appears quite limited, and in many cases, such as the Amazon of Brazil, their use for agricultural production is thought to have serious negative long-term effects on the world's environment and climate. There is growing concern that misuse of land and water in agricultural production is degrading the world's land and water resource base in a way that may be irreversible and which, in the long run, will reduce its long-term productive capacity.

As the supply of additional land and irrigation water to be brought under production has diminished, increases in food production have derived increasingly from the application of new technology, much of which depends heavily on intensive use of chemicals, which has led to degradation of the environment through pollution of ground and surface water and, in some cases, the atmosphere. There are also increasing concerns about the effect of chemicals on the safety of the food supply.

As agriculture has become increasingly technology-dependent, questions are raised about the ability of science to provide a sufficient future stream of new technology to keep pace with increasing demands for food. The prospect for continually increasing global food production through development and adoption of new technology is further clouded by potential constraints on the adoption of technology by concerns for environmental quality and food safety. A further concern about the ability of new technology to produce adequate food supplies well into the future is the adaptability of modern technology in the low-income, food-deficit developing countries of the world. Historically, modern technology has been dependent on a more highly educated farmer and a market and institutional infrastructure to support the inputs in which technology is embodied. In general, developing countries are poorly prepared in terms of human capital and infrastructure to support adoption of modern technology.

Another long-term trend adding to the concern about adequate food supplies in the next century is the growth in aggregate demand. This growth, which derives from increasing population and per capita income, has slowed in recent years. World population growth rates have declined, and are expected to continue to decline. However, because of the large population base in the low-income developing countries where population growth rates are still high, the absolute number of people added to global population annually is still very large—approximately 90 million. Therefore, the additional food production required just to maintain per capita consumption levels will remain high well into the 21st century. Much of the slowing in demand growth for food in recent years has been the result of debt problems and slow economic growth in much of the developing world. When the debt problem is resolved (which may take many years) and rapid economic growth returns to developing countries, added pressure on food supplies will result.

Finally, the agricultural and trade policy environment is a continuing cause for concern with respect to the world's ability to make efficient adjustment to changing supply, demand, and environmental conditions. Policies have tended to create contrived scarcity, high producer incentive prices, and excess production in the richer countries of the world, and just the opposite in the poor developing countries of the world. By insulating domestic producers and consumers from world market conditions, policies restrict the flexibility of the world to adjust to changes, lead to inefficient resource use, and in many cases contribute to degradation of the natural resource base and the environment. A policy environment that remains so distortive provides another reason for concern about the long-term future of the global food supply.

On Balance, How Does the Future Look?

Simply enumerating all the phenomena that give observers cause for concern about the longer-term global food situation does indeed point to some dangers ahead. However, as the preceding articles point out, we either have or are developing means to deal with them. Still, the current conditions which give cause for concern have evolved over the longer period of time, and changing these conditions will require time and action.

It is true that the supply of land and water for agricultural production is limited and that the resource base, in many cases, is being degraded by improper use. However, there already exist technologies which, if adopted more broadly, could increase the efficiency of water use greatly. With appropriate technology and practices, much of the land currently being lost through erosion and salinization could be preserved, and additional marginal lands brought into production in an environmentally sound way. While land and water degradation poses serious problems, it does not appear to be a cause for concern about the ability to produce an adequate food supply over the next two or three decades. Actions must be taken to correct the misuse of the natural resource base to ensure adequate productive capacity in the longer term.

It is clear that the economic activity of mankind is changing the composition of the earth's atmosphere in ways that are causing long-term climatic change. There is some concern about the consequences of global warming. Most analysis to date indicates that this will be a slow process, and probably will not have serious consequences for a number of decades. Analysis also indicates that there will be both positive and negative effects from a rise in global temperature and associated changes in rainfall pattern. Some regions of the world may become less hospitable to agricultural production, but others may become more productive. It is difficult to anticipate the net effect on global productivity. It is clear, however, that global climate change will require change and adaptation if its negative consequences are to be minimized. It is also clear that actions can be taken to slow manmade emissions into the atmosphere, but that the life cycle of these gases is so long that current trends cannot be reversed in the short run.

Technological breakthroughs are always difficult to predict. However, there is a significant stock of technology which has not been adopted, especially in the low-income developing countries. The fields of biotechnological innovations, such as genetic engineering, appear to offer great potential for increasing agricultural productivity. How soon economically feasible applications will be available is an open question, but progress seems to be occurring more rapidly in animal than in crop production. Two serious problems must be dealt with as these areas of science produce technology, if it is to have a positive impact on world food supply. One that is already being confronted is the possible negative effects of these new technologies on the world's environment and the safety of food for human consumption. The other is whether the new technology can be applied to conditions in poor developing countries and therefore can help alleviate food shortages where they are most likely to occur.

The policy environment appears to be at a crossroad. While the last decade has seen increasing levels of protectionism on the part of the developed market economies and newly industrialized economies like South Korea, Taiwan, India, and Brazil, there have also been positive signs. The current multilateral trade negotiations under the General Agreement on Tariffs and Trade are an indication of concern and a felt need to change this environment. Another positive sign has been the significant reform of policy in many developing countries as they have dealt with their development and debt problems and responded to pressures from multilateral development and lending institutions.

The drawdown in stocks and higher world market prices have closed the gap between policy prices in most countries and market prices. This should make it easier for countries to adjust to a more liberalized policy environment. At the same time, we must recognize that policy reform has often come about as a result of pressure of circumstances, and may do so in the future. Reduced stocks and higher prices mean an easing of pressure on government budgets, and thus less pressure to reform. Nevertheless, the extent of adjustments likely to face world agriculture over the next quarter century as many of the resource and environmental issues are dealt with makes it imperative that these negotiations have a positive outcome.

On balance, it appears that in the next two to three decades the longer-term phenomena that are causing concern do not pose an insurmountable obstacle to the world food system. In this time frame, food crises will likely continue to be localized and to be the consequence of policy-induced inflexibilities in the world trading system and lack of effective demand, rather than of failure of supply. In the longer term, there are threats to the productive capacity of the world. However, there is little doubt that there are means by which such dangers can be avoided, and there is time to implement these actions. It is critical to the wellbeing of future generations that the countries of the world move forward expeditiously to take the necessary actions to ensure the continued ability to provide adequate food supplies at reasonable cost.

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