Agriculture in the 21st Century.

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March 2000
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Printed in Mexico.


Abstract: This lecture reviews prospects for meeting the three major challenges confronting agriculture at the start of the 21st century: the food supply challenge, the need for agriculture to play a central role in reducing poverty; and the challenge to meet increased concerns over natural resource management. The potential for meeting these challenges is examined first through a conventional study of divergent global aggregate projections and a discussion of critical assumptions and major uncertainties to 2025. This analysis is then complemented by a more speculative review of the potential structure of production agriculture and agribusiness in the new century. Both the conventional and more speculative approach form the basis for developing two potential scenarios for world agriculture in the 21st century (a positive scenario and an alternative, less optimistic one). The shape of agriculture in the 21st century is most likely to lie somewhere between these extremes, but the extent to which either scenario becomes reality will have very different implications for meeting the challenges of ensuring food security, alleviating poverty, and protecting natural resources.

ISSN: 1405-5112
AGROVOC descriptors: Food production; Production economics; Production factors; Food supply; Poverty; Nature conservation; Resource conservation; Agricultural sector; Agroindustrial sector; Agricultural development
AGRIS category codes: E10 Agricultural Economics and Policies
Dewey decimal classification: 338.19
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ALEX F. McCALLA

Introduction
The title of this lecture suggests that I should know what the shape of agriculture will be in the 21st century. I want to begin by making it clear that I have no crystal ball. What I shall do is first engage in a bit of history, then try to identify the critical forces shaping agriculture in the 21st century, and conclude with some scenarios that might emerge.

I believe world agriculture faces many and different challenges in the 21st century. My basic proposition is that globalization, increased market orientation for agriculture the world over, radical and rapid changes in technology, and new concerns about the environment and natural resource management will heavily influence how agriculture evolves as it seeks to meet global food security challenges.

I begin by sketching out the challenges facing agriculture and the rural sector in the 21st century. The challenge has three quite different dimensions: a supply challenge; the need for agriculture to be an engine in poverty reduction; and the requirement of meeting increased concerns about natural resource management. Next, I present a stylized review of what has happened in world agriculture over the last 200 years, focusing more sharply on the period since 1960.

I then turn to the future and present two conjectures. The first is a conventional, aggregate view of the challenge of food supply, poverty reduction, and natural resource management. I look at divergent global aggregate projections and explore the critical assumptions and major uncertainties about outcomes to 2025. But this traditional approach says nothing about how agriculture will
change as it is buffeted by powerful external and internal forces. Therefore the next part of the paper discusses the possible structure of production agriculture and the agribusiness sector in the 21st century. It will be much more speculative than the conventional view and represents thinking in progress. I close by sketching two extreme scenarios for global agriculture and argue that the future lies somewhere in between.

**Challenges to World Agriculture in the 21st Century**

World agriculture in the 21st century will face three major challenges: how to feed a growing world population, how to contribute to reducing the still-high prevalence of rural poverty in the world, and how to respond to increased concerns about managing the natural resource base.

**Challenge I: Global Food Security**

The first and continuing challenge facing world agriculture is to produce enough food to feed the growing world population. World population could reach 8 billion people by 2025 or 2030 and possibly 10 billion people by 2050. Nearly all of the increase of 2 billion people in the next 25 years will be in developing countries.

The urban population in developing countries will rise by a like number. The implications of urbanization are significant for the food system. It is estimated that people living in rural areas depend on their own production for more than 60% of their food supply (only 40% is purchased in the market). People living in urban areas, however, depend on the market for close to 90% of their food supply. So every time one person moves from a rural to an urban setting, needed market supplies must increase by a factor of 2. Between now and 2025, population has been calculated to increase 40%, but marketed food needs to increase by 60% (Brown and McCalla 1998).
Furthermore, rising incomes shift the nature of demand. For example, a recent study from the International Food Policy Research Institute (IFPRI) forecasts an increase of 180% in meat demand in developing countries by 2020 (Pinstrup-Andersen, Pandya-Lorch, and Rosegrant 1997).

Where will this food come from? Is expanded trade a likely answer? The events of the past 40 years suggest that it is not. Since 1960 world grain production has more than doubled, and world grain trade also doubled from 100 to close to 200 million metric tons. The share of world grain consumption that is traded, however, has remained constant at about 10%. Looked at the other way around, what that says is that on average, 90% of the world’s food consumption takes place in the country where it is produced. If grain demand over the next 25 or 30 years increases 50-60%, and if trade increases only proportionately, to say 300 million tons, then it is clear that most of the increase in the food production must come from production systems in the countries where the additional people will live.

And where will they live? Most of the population growth between 2000 and 2030 will occur between the Tropic of Capricorn and the Tropic of Cancer—in other words, in all of Latin America except for the Southern Cone of Argentina, Chile, and Uruguay; all of Central America and most of Mexico; all of Africa except the North Africa Region and the nation of South Africa; the southern half of India and all of southeast Asia, including Indonesia. These areas are all still experiencing relatively rapid population growth. On the other hand, areas outside of the Tropics are experiencing significantly slower and even negative rates of population growth: the former Soviet Union; China; Europe; North America; Argentina, Chile, and Uruguay; the southern half of Australia; and New Zealand.
Putting these two "facts" together suggests that most of the food needed to meet increased needs in the next 25 years must be produced in tropical and subtropical farming systems. We know that these systems are complex, highly heterogeneous, fragile, generally low in productivity, and dominated by small-scale, poor farmers. And to make things more complicated, we know much less about farming systems in these regions than we do about systems in temperate regions.

A further challenge for the next 25 years will be to reduce the 840 million undernourished people who still exist on this planet despite significant increases in aggregate agricultural output (FAO 1996).

So the food production challenge ahead is not small or easy. It requires increasing the productivity of complex, low-yielding farming systems in ways that do not damage natural resources or the environment.

**Challenge II: Poverty Reduction**

Despite the rapid urbanization projected to occur in the coming decades, it will be 2015 before as many people live in urban areas as in rural areas. As of today, some 70% of the poor are still rural dwellers. Of that 70%, the majority draw some or all of their income from agricultural activities. Therefore literally billions of small and generally poor farmers live in poverty or near the poverty line.

The import-substitution, industrialization development paradigms of 1950s to the 1980s attributed a very limited role to the rural sector in terms of driving economic progress and generating economic growth. But clearly those paradigms did not work, and it is time to recognize that agriculture and the rural sector can be an engine of growth that drives improved incomes and increased employment. The second challenge facing global agriculture therefore is to develop technologies, policies, and
institutions that contribute to unleashing agriculture’s full potential as an engine of growth. Meeting this challenge will require farmers to have access to both domestic and international markets. To reiterate: the second challenge to agriculture is to be an engine of growth and poverty reduction.

**Challenge III: Sustainable Natural Resource Management**

The third challenge to agriculture in this new century is to create a set of technologies, incentives, and policies that encourage small-scale farmers to want to pay attention to the long-run stewardship of the natural resources they manage. If we are to address the question of natural resource degradation seriously, we must address it by encouraging these farmers to use their resources in a way that is sustainable over the long term. This is so because farmers use most of the world’s arable land and are involved in managing much of the world’s forest and range land. Agriculture uses more than 70% of the world’s fresh water, and much biodiversity is contained in agricultural systems. Agricultural activities influence the boundaries of forests and deserts. Therefore, the question of improving the management of our natural resources is intimately tied to improving the productivity and profitability of small-scale farmers in the developing world.

**A Triple-Win Situation**

World agriculture therefore faces these three major challenges in the years ahead. If we are successful in meeting them, we get a triple-win situation of increased food security, reduced rural and global poverty, and improved management of natural resources. The question is, how will agriculture respond in the changing global environment? Before venturing into the future, however, it is worthwhile to explore how we got to where we are now and recall how world agriculture surmounted earlier challenges.
How Did World Agriculture Meet Past Challenges?

What has been the performance of agriculture over the last 200 years? What follows is a very stylized view of the evolution of agriculture over this period, in which a bit more attention is given to the last 40 years of the 20th century.

The growth of agricultural output over the past 200 years has been phenomenal. When Robert Thomas Malthus wrote in 1798, he perceived the limits on agricultural production to be serious and imminent. Since then world population has increased six-fold, and global agricultural production has more than kept pace. Falling real grain prices for most of the 20th century are evidence of that success. The sources of increased food production, however, have been quite different over this 200-year period. For example, for most of the 19th century, increased output came from expanding the land area in production, and that expanded area was primarily located in “newly settled areas” — the Americas, Southern Africa, and Australia. Science-based agriculture is really a product of the 20th century. The new technology—mechanical, biological, and chemical—came in different forms and was adopted in different sequences in different parts of the world, a point I will return to later. It led to phenomenal increases in yields in some parts of the world.

Land area expansion as a contributor to increased output declined in importance throughout most of the 20th century. Developments to increase the intensity of land use through, for example, greatly expanded areas of irrigated agriculture, played a significant role in increasing agricultural output over much of that period, however. But in general, over the last 200 years, science and technology have played an increasingly important role in meeting world food needs. Will the same be true in the future? I return to this point later.
The results of these technological developments have been really quite substantial. The 1960s was a period in which there were dire predictions of famine, yet the world did remarkably well in providing adequate global supplies of cereals. From 1960 to 1990, global cereal production doubled, per capita food availability increased 37%, per capita calories available per day increased 35%, and real food prices declined 50%.

Even with these good indicators of overall global performance, significant regional differences remained. Average calories available per day increased significantly in the Near East and North Africa, East Asia, and Latin America to levels of 2,700 calories per day or higher. South Asia's calorie availability grew more slowly, and people in this region still experience significant undernutrition. In sub-Saharan Africa, per capita food availability decreased between 1960 and 1990.

The global gains over the 1960-90 period came from the Green Revolution and from rapidly expanding production in developed countries based on conventional genetic crop improvement and intensified monocultures using high levels of fertilizers and pesticides. The policy environment in most countries was protective and inward looking. Farmers in rich countries were subsidized, receiving high guaranteed prices that further encouraged intensification. Farmers in poor countries, on the other hand, were taxed. The international trading system under GATT was for agriculture highly protected, and growth in world grain trade slowed in the 1980s and 1990s.

But despite all these gains, more than 840 million people remain undernourished, mostly in Africa and South Asia. Worldwide, 1.3 billion people live on less than US$ 1 per day, and the majority of them are in agriculture. Rates of natural resource degradation are judged to be increasing. Thus the old model for meeting challenges to agriculture is unlikely to be viable.
The Future Directions of Agriculture: Critical Variables and Structural Evolution

So how will world agriculture evolve? It is to that question that I now turn. I want to do this in two ways. The first approach is rather conventional. I review projections of various sorts about how easy or difficult it will be to meet the three challenges described earlier. The focus is on defining what appear to be the critical assumptions and uncertainties about how easy or difficult the provision of global food security will be. About the presentation of issues in this part of the paper I am reasonably comfortable.

The second approach is more speculative, focusing on how agriculture might evolve in the 21st century as it tries to meet the challenges to food security, poverty alleviation, and natural resource management. What will agriculture look like in terms of structure, technology, and its policy environment? Will it be more of the same or something quite different? This part of the paper is very preliminary and unfinished—a work in progress. I hope it will stimulate you to think along with me as we go from global aggregates to farms and agribusinesses the world over. I do this in the context of some major global trends that I believe will help shape agriculture. I close by sketching a couple of scenarios.

The Conventional Aggregate Approach

Meeting the Supply Challenge

There are widely differing views on the difficulties of meeting food needs in the 21st century. Those using economic projection or simulation models, based significantly on history, tend to project sufficient global supplies until at least 2010 (see Agcaoili and Rosegrant 1995; Alexandratos 1995; Mitchell and Ingco 1993). IFPRI makes similar projections to 2020 (Rosegrant, Agcaoili-Sombilla, and Perez 1995). Those projecting on the basis of resource availability and environmental constraints (perhaps these should be called ecological...
modelers) are generally much more pessimistic. The most extreme view combines resource constraints with biological yield pessimism and foresees serious problems ahead, as do Brown and Kane (1994), for example. The very nature of projections using compounding growth rates of population and income compared to compounding growth rates in yield means that food gaps grow rapidly if the growth rate of demand exceeds the growth rate of supply. On the other hand, if supply growth rates exceed demand growth rates, food prices fall. The latter was the predominant outcome in the 20th century.

How can these economic optimists on the one hand and the ecological pessimists on the other hand reach such different conclusions in projecting food supply potential? Their differences come from how they deal with four critical projection variables. I call them “critical assumptions.”

1) Assumptions about the rate of increase in biological yields.
   Economic modelers point to 2-3% increases in production in 1960-90, but even projecting lower rates of 1.5-1.7% per year still results in more rapid supply growth, as population growth rates are projected to fall even more rapidly. These modelers are optimistic about the potential of biotechnology. Ecological modelers point to yield increases in the 1990s of less than 1%, yield stagnation in intensive irrigated systems—e.g., triple-cropped rice in the Philippines—and a decline in yields in rice-wheat systems in South Asia. These modelers are very skeptical about biotechnology solving all problems.

2) Assumptions about how much land will be added to or lost from agricultural production over the next 30 years. Area expansion, while not the major driving force behind production increases over the past 30 years, still contributed significantly. Modelers continue to assume some increase in land area under agricultural production but less than in the
previous period. Ecologists and Lester Brown argue that land lost to urban and industrial use, plus degradation of existing land, means that less land will be available in the future. They argue that any new land brought into production would be ecologically fragile and environmentally sensitive.

3) Assumptions about how much land can be subjected to increased intensification through irrigation and/or changed cropping patterns. Intensification had a big impact over the past 40 years as irrigated area in developing countries doubled. Cropping intensity rose as shorter duration varieties were bred to allow two crops instead of one crop per year, or three instead of two. Economic modelers project that this trend will continue, though at lower levels. Ecologists argue that there will be no more new irrigation but rather increased competition for water and significant land degradation.

4) Assumptions about the impact of environmental degradation on food production capacity. Economic modelers tend to ignore natural resource constraints. Ecologists see them as big issues. Land loss, through erosion and water pollution, will be a constraint. Water quality will decline. Rangelands are overgrazed and fisheries depleted. For ecologists, these are major constraints to future production growth.

In my judgment, the optimists are too optimistic and the pessimists are too pessimistic. Reality suggests that feeding 2-2.5 billion more people will be an enormous challenge. The bottom line is that virtually all of the increase in production globally will have to come from knowledge-based agricultural intensification, using modern science and biological technology: genetics, agronomy, pest management, resource management, and improved capacity to deal with biotic and abiotic stresses. Land expansion and intensification through capital-intensive irrigation simply will not make significant contributions to output. In fact we may have to raise output with less land and less water, and do it in a resource-friendly way.
Because of projections of urbanization and income growth, the composition of output will clearly change. Where will the feed come from to meet growing demand for meat? Will China, for example, expand feed grain production to produce its own meat or will it import meat directly? New demands for fruits and vegetables will also shift cropping patterns. Overall, the location of global production could shift significantly.

Can these challenges be met? On the production side, I believe it can be done, but there are four "big ifs" or uncertainties:

1) If we can develop sustainable production systems capable of doubling output. This is an unprecedented challenge for agriculture and biological science. It requires attacks on all fronts (e.g., ecology, soils, agronomy, breeding, farm management, pest management) in a systematic way that increases the productivity of complex farming systems. We cannot focus only on increasing the yields of single commodities grown in monoculture.

2) If we have in place domestic and international policies and institutions that do not discriminate against agriculture and that provide appropriate incentives to hundreds of millions of farmers around the world. We must do away with policies that tax agriculture, such as over-valued exchange rates, industrial protection, and low-priced food requisitions, as well as policies that distort farmers' incentives (Schiff and Valdes 1992).

3) If we continue to invest in public agricultural research—for example, through the Consultative Group on International Agricultural Research (CGIAR)—and build stronger partnerships with the private sector to tap the enormous potential of molecular biology for the small-scale, impoverished farmers around the world.
4) If we stay the course with removing distortions to freer agricultural trade. The Marrakech Agreement of 1994 put agriculture for the first time under the rules of the General Agreement on Tariffs and Trade (GATT), now the World Trade Organization (WTO). These include tariffication of all non-tariff barriers, reductions in domestic support, reduced import barriers, and lower export subsidies. They will make a more level playing field for developing countries, which is critical, because as countries move away from self sufficiency, they must be able to use world markets. Countries must be assured of access and should expect reasonably stable markets. Therefore the agricultural negotiations scheduled for 1999-2000 should focus on reducing levels of protection in member countries of the Organisation for Economic Co-operation and Development (OECD), thereby providing improved access for developing countries.

These will all help to meet the food supply challenge.

**Meeting the Poverty and Natural Resource Challenge**

Supply is only one challenge to agriculture in this new century; the others are concerned with reducing and eliminating poverty and with improved natural resource management. In the developing world, where the World Bank mainly operates, poverty remains a predominantly rural challenge (World Bank 1997). As noted, 70% of the poor people in the developing world still live in rural areas. To meet this challenge, we must improve the productivity and profitability of millions upon millions of small farmers and promote employment-intensive rural growth.

For this to occur, farmers will need new, appropriate technology. Here the role of biotechnology should be critical if it can be applied to the crops of complex farming systems in the tropics and subtropics. As we break away from the heavy focus on basic food crops (rice, wheat, maize) and move towards an emphasis on
more diversified production systems involving all crops, animals, and trees, the research needs are likely to be very large.

Profitability will come from increased market orientation as farmers produce food and fiber for domestic and international markets. Here the critical issues are appropriate policies and incentives.

If we can meet the challenge of improving farmers' well-being, we will also have the additional benefit of encouraging farmers to be more effective stewards of the world's natural resources. Farmers manage virtually all of the arable land in the world and use most of its fresh water. Therefore the issue of improving the welfare of rural communities, by improving the profitability of agriculture, is a triple-win situation. It contributes to poverty reduction, it contributes to food security, and it contributes to improved natural resource management.

Thus ends my "conventional aggregate" discussion. I now turn to the more speculative part of this lecture. What agriculture will look like in the future will clearly be a product of its past but will also be shaped by the environment within which it evolves. The next sections of this lecture explore what I see as the major external and internal trends that are likely to impact on agriculture. Later I will use the confrontation between these external forces and the internal dynamics of 20th century agriculture to speculate about two scenarios for agriculture in the new century.

**Forces Shaping the Future**

Several global political and economic mega-trends could influence the environment in which agriculture will evolve. After discussing these, I identify six more radical changes that will impact directly on agriculture. I conclude by listing three issues that will undeniably affect the environment in which agriculture develops but whose outcomes are very unpredictable.
Global Mega-trends

- **Globalization** is characterized by integrated capital and financial markets, which link domestic economies’ monetary and financial sectors ever more tightly. Continued WTO trade liberalization will reduce trade barriers and link countries’ real sectors as never before. The implication is that problems of individual countries will have global impacts, as witnessed in East Asia, Latin America, and Russia during the recent financial crisis.

- **The decline of socialism and the ascendancy of markets.** There are no longer competitive economic paradigms. As supporters of a global market economy celebrated victory, serious questions were raised about the appropriate division of roles between the public and private sectors, both in terms of owning and operating productive enterprises (privatization) and in terms of regulation of the private sector.

- **The end of bipolar global politics.** Will this continue to foster a precipitous rise in regional and national armed conflicts and in global terrorism? Will national and regional security issues replace global security issues?

- **Democratization** in Latin America, Eastern Europe, Asia, and some parts of Africa. Will the trend continue?

- **The rise of the civil society, decentralization, and community empowerment** could radically alter the balance of power between local, regional, and national governments.

- **Changed macroeconomic paradigms** minimize the role of government in driving the economy and preach monetary stability and fiscal conservatism. This, combined with the ascendancy of markets and trade liberalization, means nation-states’ capacity to control their own internal economic well-being is significantly lessened.
External Events Directly Impacting Agriculture: Six Driving Forces

- **Molecular biology.** Just as mechanical, biological, and chemical technologies shaped agriculture in the 20th century, molecular biology and its application through biotechnology could have incredible impacts in agriculture in the 21st century. But how will it play out? The potential seems unlimited, but consumer and civil society concerns about altering nature seem to be growing, especially in Europe. There is great uncertainty here.

- **Information technology** is experiencing a similar revolution to biology. The computer, the satellite, and the cellular phone have already radically changed the way we look at each other, do business, and do science.

- **Environmental concerns**—about pollution, loss of biodiversity, deforestation, health, and sustainable resource use—are still increasing. Pressure is rapidly growing to subsidize agriculture for producing "environmental services" for the rural countryside, the so-called "multi-functionality" of agriculture.

- **Resource competition:** rising population, urbanization, industrialization, and environmental demands will all increase competition for agriculture’s historic virtual monopoly on arable land and fresh water.

- **Global warming.** Evidence strengthens yearly that long-run temperatures are rising and that weather variation may be increasing. Globally cropping patterns are likely to shift, but to where and by how much is uncertain. Global production impacts are even less clear, but on balance aggregate production will change less than the production in particular regions.

- **Agricultural trade liberalization.** Bringing agricultural trade into the WTO fundamentally alters member countries’ flexibility in the choice of domestic policy instruments and their settings. Liberalization in the 1999-2000 Mini-Round could lead to a much more open international market. Who will benefit, and who will lose?
Unpredictable Issues

Here I quickly list three issues that will certainly influence the context within which agriculture will evolve but about which I cannot hazard predictions.

• The first is the evolution of intellectual property rights and its interface with biotechnology.
• The second is the policy behavior of major players in agriculture. In a more globalized, tightly linked, liberalized world economy, big players matter more. In world agriculture, six giants loom large in agricultural production, consumption, and trade. These are (in descending order of importance) China, India, the countries of the European Union (soon to get larger), the United States, Russia, and Brazil. How any or all of these countries decide to achieve food security could have significant global impacts, both positive and negative. In some sense these are the potential loose cannons in the system.
• The third issue is concentration and internationalization in agricultural supply and marketing firms. Will size, concentration, and multinationalism spread globally to developing countries, or will a more community-based structure emerge as a part of integrated rural development?

How Will These Global Trends Impact on the Structure of Agriculture?

How will the tendencies listed above affect the global food system and its ability to meet the three challenges outlined at the beginning of this lecture? Let me begin by discussing some broad generic impacts; then I will turn specifically to impacts on the structure of agriculture and on the agro-industrial complex that surrounds the production system.
Generic Impacts
The role of government in the global food system will be significantly different and possibly diminished. Markets will play a much larger role, as will citizens at the local and regional levels. This trend will lead to freer trade, internally and internationally, in both inputs and outputs. It will lead to less expenditure on input subsidies, price supports, export subsidies, and on public sector research. It is still evolving, as many governments leave the productive sector and assume a more uncertain role as makers of the economic environment.

The molecular biology revolution and its application through biotechnology, coupled with changes in intellectual property rights, have given rise to massive increases in private sector research investment and in proprietary science. So far the focus has been primarily on the developed countries. How far this revolution will spread to developing countries is unclear. I will return to this point in the concluding sections of this lecture, when I discuss two scenarios for the future.

Finally, globalization and the information revolution mean that science and technology are truly global, and therefore national agricultural strategies are less and less viable. Human capital, investment dollars, and scientific knowledge are globally fungible. This means that a country is either part of the global knowledge system or gets left behind. The implications for traditional agricultural research and extension systems are tremendous.

Structural Impacts on Agriculture and Agro-Industry
Agriculture around the world is very heterogeneous, so it is difficult to generalize about the shape of agriculture and agro-industries in the 21st century. Let me try to use some simplifications. Hayami and Ruttan (1971), in their groundbreaking book Agricultural Development, have argued that technological change drives the shape of agriculture and that technological change in turn is
induced by the relative resource endowments of a country. If a country has much land and few people, labor-saving technology is in demand, as occurred with mechanization in the United States. Countries that are short of land and have substantial labor (e.g., Japan) tend to develop land augmenting, i.e., yield increasing technology, such as biological and chemical technology. The result appears to be a quite different structure of agriculture. Mechanical technology is labor saving and generally scale expanding, leading to larger scale agricultural operations, whereas biological and chemical technology is potentially scale neutral and can be adopted in smaller scale intensive agriculture.

Let me review briefly how this hypothesis might play out in the future, building on the forces that shaped agriculture in the past. Basically I will look at two types of agricultural systems. The first consists of systems that are land rich and labor poor, found in the areas of agricultural expansion in the 18th and 19th centuries (North America, southern South America, Southern Africa, and Australia, as well as many countries of the former Soviet Union). I call these “areas of extensive agriculture.” The second group of systems is found where the ratio of labor to land is high (Europe, Japan, China, and India, as well as many of the poor developing countries in Latin America, Asia, and parts of Africa). I call these the “areas of agricultural intensification.”

My submission is that the sequence of adoption of mechanical, biological, and chemical technologies in the 20th century contributes to explaining why world agriculture looks the way it does today. Let me briefly make my case, addressing three different regional aggregations: the newly settled areas, the older settled areas of Europe and Asia, and the now developing countries.

Areas of extensive agriculture—These areas first adopted labor-saving, scale-enhancing mechanical technology. As Hayami and Ruttan’s induced innovation hypothesis suggests, farmers sought technical change to replace the scarcest and most expensive factor of
production: labor. Horses first replaced manpower, and then tractors replaced horses, the latter mainly in the first 30 years of the 20th century. This freed up millions of hectares that previously produced horse feed to produce food. The next technology adopted was biological, including improved varieties as well as improved agronomy. Chemical technology was a post-World War II phenomenon, and with its application, yields soared. Yields in the US Corn Belt have more than quadrupled since World War II. But all this chemical and biological technology was introduced in an already mechanized, relatively large-scale agriculture which was becoming more and more specialized. The result is that today in most of the newly settled areas a bimodal agriculture has developed, in which fewer and fewer larger scale farmers produce an increasing share of the output while a much greater number of small-scale and part-time farmers produce a declining share. This phenomenon is most pronounced in the United States, where less than 300,000 farmers (of a total of 1.9 million) produce more than 80% of the output. The other 1.6 million produce less than 20%. Mixed livestock-crop farming has essentially vanished. Large-scale, highly commodity-specific enterprises dominate both the crop and livestock sectors. Similar trends are occurring in Canada, Argentina, and Australia.

The question for the future is where will these agricultural systems go. First, it is clear that they will evolve from their present state, so they will continue to be bimodal, with few large farms producing most of the output. Some of the farming systems using high levels of chemical inputs may not be sustainable, given growing concerns about the environment and increased competition for water and land. However, as evidenced by the no-till revolution the United States, Canada, Argentina, Brazil, and Australia, practices will change to become more environmentally friendly when they are profitable; therefore I do not foresee continued growth in the scale of field crop production.
I see different directions in livestock and specialized fruit and vegetable production, however. The poultry industry the world over is already highly concentrated and vertically integrated. The same is happening in the pork industry and may happen in beef. Contract farming already characterizes the specialized crop industry.

These trends will continue and spread globally as so called “designer agriculture” becomes more common. By this I mean producers being paid to produce commodities to precise and consumer-specific requirements. This practice is likely also to spread in European and other higher income countries. It will be made possible and progressively easier by biotechnology.

One extreme vision of developed country agriculture is presented by the National Agricultural Biotechnology Council (NABC 1998), which sees US agriculture partially substituting for the petroleum industry by producing bio-based fuels, chemicals, and industrial products. While this is unlikely to happen fast, there are clearly immense potentials for molecular biology to let agriculture produce more than food and fiber.

**Areas of intensive agriculture**

*Europe/Northern Asia.* In Europe and Northern Asia, the long-settled areas of Europe, Japan, and China historically were characterized either by large estates and small tenant plots or small family farms. Farm size was diminishing rather than expanding because of inheritance laws. If Hayami and Ruttan are correct, in this environment, where land is the scarce resource, one would expect a focus on yield-increasing technology first. In fact it seems clear that in Europe and Asia the major biological and chemical innovations preceded mechanical technology. Given that both of these technologies are scale neutral but commodity specific, small farms tended to specialize. Mechanical technology came much later. In some cases, large-scale adoption of mechanical technology has produced an agriculture resembling US agriculture, as in the plains of Paris and central England. But in most cases small-scale
mechanical technology has been introduced to fit the scale of agriculture. The bottom line is that at the beginning of the 21st century, agriculture in these areas looks much different than it does in the United States and other areas of extensive agriculture. It is still relatively small scale, highly chemical input intensive, and tending towards more farm-level specialization. The question for the 21st century is how it will evolve. Will European, Korean, Japanese, and northern Indian agriculture become like North American agriculture, or will it take a different path? My argument is that it will not become like US agriculture, because the relative power of external versus internal forces shifted substantially in the last third of the 20th century and will continue to shift in the new century. External factors such as environmental and natural resource concerns will shape agriculture more than endogenous technologies and sector-specific policies. Further, concerns about preserving the rural landscape will slow any expansion in the scale of agriculture.

Developing countries: The now developing countries were segmented into plantation and subsistence sectors. The plantation sector evolved in the direction of the land-extensive areas, with a strong emphasis on scale and labor-saving mechanization. The subsistence sector was largely bypassed by technical change until after independence in the 1950s and 1960s. Early efforts to improve productivity involved attempts to transfer technology and knowledge then operating in the developed countries. Where appropriate conditions prevailed, new technology, such as semidwarf rice and wheat varieties, was adopted. These new varieties were fertilizer responsive and high yielding, but they required good water management, good agronomy, and sophisticated pest management. They were adopted in well-watered, agronomically favored areas and are the stuff of the Green Revolution. But much of the rest of developing country agriculture, particularly in less-favored ecological areas, has yet to experience fully any of these technical revolutions, mechanical, biological, or
chemical. Their agriculture continues to resemble agriculture of the 18th century and earlier. Where will these countries go in the 21st century? My belief is that for areas of high population density it will be crucial to foster small-scale, diversified, and employment-intensive systems. This effort should be driven by both the poverty goals and the natural resource management paradigm. But will this be the case? I return to this question in the scenarios described later. The one big question is how sub-Saharan agriculture, especially in countries with substantial land resources, will evolve.

**The agro-industrial sector**

*The agro-industrial sector.* Let me say a few words about the input supply industry—the part of the agro-industrial sector that grows as agriculture intensifies and incomes rise.

The earliest agricultural input industry was in farm machinery. Not surprisingly, it developed in the United States first. It was characterized by inventions—the plow, the reaper, the binder, the seed drill, the combine harvester, and the tractor—all of which were protected by patents, permitting investment in innovation to be recouped. The farm machinery business is subject to economies of scale in manufacturing and has gone from hundreds of small firms producing limited lines to a few multinationals producing broad lines. Note that in this industry public sector research played a much smaller role than it has played in other agro-industries. What does this say about other research areas as intellectual property rights are more widely applied?

Supplies of biological inputs, primarily seeds, were generally provided by small regional or national firms and were commodity specific. These firms used varieties produced by public research organizations and were largely replicators and distributors of proven varieties. This structure changed rapidly with technological change. Hybrid maize seed had to be purchased annually, and therefore private research and development costs could be recouped over time. Plant Variety Protection in the United States in the 1970s broadened
patent protection to production of non-hybrid seed. This legislation has led to a very rapid consolidation of firms nationally, and with the advent of biotechnology, the internationalization and concentration of seed and chemical businesses is occurring rapidly (e.g., Dupont has bought Pioneer).

As for other inputs, the production of fertilizers (especially nitrogenous fertilizers) and pesticides is frequently a byproduct of the petroleum industry, which is generally highly concentrated and global.

Thus at the end of the 20th century, input supply industries were becoming dominated by fewer and fewer very large multinational firms. I see no particular reason for this trend not to continue, but the consequences for developing countries, which could be left behind, are uncertain.

With regard to the processing and marketing industry, there is room for only a quick summary. As a society shifts from being a predominantly subsistence agrarian society to an urban, industrial/service society, dietary and food consumption habits change. Manual labor is replaced by machines, people move off the farm, cities grow, and incomes rise. Food processing and distribution industries have been driven by these variables as well as changing markets and changing technology (for example, canning, drying, frozen food, refrigerated shipment, chemical preservatives, and ripening agents). On the marketing side, the first development was of global markets for grains and oilseeds, which led to multinational traders such as Cargill that have become more concentrated over time. In other food lines, the preferred approach for many companies was direct foreign investment, as opposed to trade, which enabled them to be an insider in protected domestic markets. This process created global conglomerates with many domestic subsidiaries, such as Nestlé and Unilever.
These trends have accelerated in developed countries as affluence, urbanization, and gender equality in the workplace have significantly changed the nature and diversity of food demands in the marketplace.

Overall, the agro-industries surrounding the production agriculture sector in developed countries have grown in importance relative to the production sector, are generally concentrated (i.e., large), and are frequently multinational (if not global) in scope.

In the developing countries the input supply industry is a mix of government providers, small entrepreneurs, and domestic representatives of multinational firms. The food marketing chain in many countries is still characterized by government or parastatal marketers of basic foods and many local, small-scale vendors of fruits, vegetables, and meat. Except for poultry production in Asia, vertical integration is not yet a characteristic.

The question for the future is how the agribusiness sector will play out. The evolution of this sector will be influenced partly by what happens in the production sector and partly by what happens in the global food system.

**Two Possible Scenarios for the Future Direction of Agriculture**

I now sketch two possible scenarios, each beginning from where we are at the start of the 21st century but each making differing assumptions about the trends that will influence the shape of agriculture. One may be called a positive scenario while the other will perhaps seem ominous to some.

**A Positive Scenario**

In a positive scenario, globalization, the information revolution, and the ascendancy of markets all lead to freer capital and technology flows, which in turn allow poor countries to experience rapid, widely
shared economic growth. Real trade liberalization occurs as developed countries open their markets and reduce subsidies, and developing countries experience expanded export opportunities. Democratization, decentralization, and less distorting domestic policies equalize opportunities for poor rural people, especially farmers, resulting in sustained, employment-intensive rural growth. Biotechnology is widely applied to important crops growing between the Tropics. Public sector research investments, addressing public good issues, are sustained and significantly improve the productivity of complex tropical and subtropical farming systems. Environmental concerns and natural resource competition foster the development of technologies that reduce dependence on the old model of chemical-intensive, large-scale, monoculture agriculture. The result in developing countries is a small-scale, highly productive, multifaceted agriculture; the agriculture of the older, labor-intensive areas of Europe and Asia and the areas of extensive agriculture is modified to become more consistent with environmental concerns and long-term preservations of critical global resources, including biodiversity, land, water, and natural habitats. Finally, global warming occurs at a sufficiently slow pace that global agriculture can adapt. This scenario is possible if we do the right things starting now.

**An Alternative Scenario**

One could, I believe, equally postulate an alternative, less satisfying scenario. In this scenario, globalization leads to bigger disparities between the haves and have-nots. Financial instability increases and smaller and more vulnerable countries are buffeted by economic insecurity. Gains in poverty reduction are partially reversed, as in Indonesia. Real agricultural trade liberalization fails as developed countries succeed in continuing to subsidize and protect agriculture (multifunctionality carries the day in the WTO) and poor developed countries still lack access. Urban elites regain or maintain control in developing countries, which continue to
pursue policies biased against agriculture and rural areas. Decentralization and participation run afoul of entrenched political and bureaucratic systems and poor rural areas are left behind. The fruits of biotechnology remain primarily focused on temperate crops of global importance while public investment in agricultural research of relevance to the developing countries withers under fiscal conservatism. The result is a truly global, bimodal agriculture in which large-scale, input-intensive farms outside the Tropics become larger and more concentrated. Agribusiness keeps ahead of them on the same path they are following now. Small-scale agriculture between the Tropics languishes, increasing dependence on external food supplies.

Under an even worse scenario, significant agricultural resources are diverted to producing industrial and energy products, thereby reducing available supplies on world markets. Discussions of aspects of this particular scenario talk about “losing” countries—countries that are losers in technology, trade, and policy reform. A further dismal aspect of this scenario is that global warming increases the numbers of food-deficit, poor developing countries, which fall farther behind those in more temperate areas.

**Implications for Global Food Security**

I could continue to elaborate on these various scenarios for the future, but this brief outline has conveyed their most salient characteristics. I suspect that all of us would like the positive scenario to emerge but are concerned that recent trends may portend that at least some parts of the alternative scenario are possible. My proposition is that the outcome will lie somewhere between the two scenarios, although the outcome cannot be defined more precisely, because it depends on actions yet to be taken. But the implications for the challenges facing world agriculture and global food security are significant.
The positive scenario contributes to meeting all three challenges described earlier. Food production and rural incomes rise for countries between the Tropics. Trade liberalization and continued policy reform contribute to poverty reduction and improved incentives for the husbandry of natural resources. Disparities in income between rural and urban, rich and poor, are reduced, and greater global stability would seem to follow.

The consequences of the alternative scenario could be quite stark. Complex farming systems between the Tropics are not improved. Poverty, rural and urban, deepens. Dependence on international food supplies increases, meaning that poor, food-deficit countries are more vulnerable to international instability. The worst variant sees agricultural resources in rich countries diverted to producing energy and industrial products. This scenario leads to reduced export supplies of basic cereals, causing higher and more unstable prices. This, coupled with continued protection in rich countries, leads to limited access for tropical products and generally contracting export opportunities. Finally, if what appears now to be the likely impact of global warming occurs, i.e., reduced rainfall in the tropics and subtropics and more rainfall in the temperate zone, the consequences for the 2 billion additional people who will live in developing countries between the Tropics, plus the 1.3 billion very poor people who are already there, are not pleasant to contemplate.

How will these possibilities play out? I don’t know. The critical drivers to watch are agricultural trade liberalization (WTO 1999-2000), biotechnology and intellectual property rights (IPR), and domestic policy reforms and their impact on a level policy playing field for poor rural people. Remember the four uncertainties I mentioned in the conventional model: understanding complex farming systems, investment in research, a level policy playing field, and real trade liberalization. In reality these are the issues, no matter which approach for future “directions of agriculture” you wish to take.
References


