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INTERNATIONAL AGRICULTURAL RESEARCH: FOUR PAPERS

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INTERNATIONAL AGRICULTURAL RESEARCH:

FOUR PAPERS

- CHALLENGES TO INTERNATIONAL AGRICULTURAL RESEARCH
- BIOTECHNOLOGY: THE RATE OF PUBLIC POLICY
- SCIENCE, TECHNOLOGY AND SURPRISE: IMPLICATIONS FOR AGRICULTURE
- MEETING THE FOOD NEEDS OF THE WORLD

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CHALLENGES TO INTERNATIONAL AGRICULTURAL RESEARCH*

Vernon W. Ruttan**

It would be hard to imagine any public or private sector investment that has generated a higher rate of return than the investment that has been made in the system of agricultural research centers and institutes sponsored by the Consultitative Group on International Agricultural Research (the CG). Yet the CG system has not, in its maturity, been granted the luxury of the comfortable old age that its distinction might seem to deserve.

The CG system is confronted by four challenges:

- Changes in the knowledge base on which its technology rests.
- Changes in the organization and capacity of public and private sector research systems that are part of the environment in which it works.
- Changes in the priorities of donor agencies on which it depends for support.
- Change in the public perception of the role of science and technology in meeting human needs.

Let me address each of these challenges in greater detail.

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* Presented 30th Anniversary Commemorative Seminar, International Center for Tropical Agriculture (CIAT), Cali, Columbia, December 12, 1997.

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Changes in the knowledge base.

It is not possible to overemphasize the changes in the knowledge base over the last 20 years on which crop improvement rests. When I was a staff economist at the International Rice Research Institute in the early 1960s I used to walk with Hank Beachel who, along with Peter Jennings, developed the first series of high yielding rice varieties to look at his plots. I recall asking Hank what, if anything, had occurred in basic biology since he began breeding rice that had influenced his breeding technology? His answer was "Nothing"!

Two years ago I had a conversation with a young plant breeder who was spending a post doctoral, on leave from one of the CG Institutes in the University of Minnesota Department of Agronomy and Plant Breeding. I asked him about the work he was doing on his leave and how it compared to his work as a graduate student. He indicated, with some bitterness, "I have been out of graduate school for only four years and I am already obsolete."

I do not know how you are dealing with this problem at CIAT. But given the speed with which the knowledge in molecular biology and the techniques of genetic engineering are progressing it is an issue that every CG institute and every national agricultural research system must confront. Although I have illustrated this point with reference to plant breeding it is an issue that confronts every area of science based technology and practice.

Changes in the Organization and Capacity of Research Systems.

A second major challenge to the CGIAR system will be how to position itself in relation to the weaker LDC national agricultural research systems, to the stronger LDC national agricultural research systems (Brazil, India, China, Korea), to the DC national systems and to the private sector agricultural research systems. Furthermore the CGIAR system must be in a position to help the weaker national systems position themselves in this changing environment.

The magnitude of this challenge is illustrate by comparing the CG system to Pioneer Hy-Bred International. Pioneer Hi-Bred International has a research budget of $130 million. It has approximately 900 researchers employed at some 140 locations in 29 countries. The CG system has a research budget of approximately $225 million. It has about 900 internationally recruited scientists and a much larger nationally recruited research staff associated with 16 centers and institutes located at about 135 sites in about 60 countries.

As private sector research continues to expand and national agricultural systems gain strength it is going to be necessary for the CG system to think very carefully about its role. What is it essential that the CG system must do if it is to be done adequately or at all? What is the source of the public goods - of the spillover effects - that originate in the CG system? Is the CG system organized to produce the public goods that are needed? Would it have been possible, for example, for the CG system to have managed the Rockefeller Foundation sponsored International Program on Rice Biotechnology? If not what does this say about the CG system?

I feel quite confident that it is in the interest of the CG system to resolve the intellectual property issue as soon as possible. The only way to assure access to what should be public goods is to register or patent. To quote your own DG, "It is not possible to give away what you do not own".

<u>Changes in the priorities of donor agencies</u>.

It has been difficult for those of us who have worked in the field of international development, to acknowledge how strongly foreign economic assistance was motivated by the Cold War. In the case of the United States the level of assistance flows rose and declined with the tension between the

US and the former USSR. The same relationship has characterized aggregate bilateral assistance and multilateral assistance.

The Cold War had less impact on the direction of assistance flows than on the aggregate level. Ethnic politics in the US have been an important factor directing the flow of assistance resources. Events such as the world food crises of the 1960s and 1970s shifted assistance flows in the direction of agricultural development, including agricultural research.

During the last five or six years I have participated in a number of conferences in which the implicit agenda seemed to be to find some thing new to be afraid of -- something that would motivate a renewal of aid flows. The search for new rubrics, such as environmental security, have not been effective.

My own sense is that in the future a higher share of CG institute and center findings will have to come from past and future CG beneficiaries. The CG system may need to seek new donors for its traditional work while drawing on its traditional donors for its new work. I know that CIAT has made some progress in this regard, particularly with its rice program. I am quite sure that substantial increases will be difficult to achieve. But it is also very important for the CG system to explore aggressively the possibility of extending the CIAT rice model to other institutes and for other commodities.

<u>Changes in the public perception of science and technology.</u>

Popular and political confidence in the capacity of advances in scientific knowledge, and of science based technology, to meet human needs has eroded. We continue to be confronted by dramatic examples such as the effort to stop the shipment of genetically altered soybeans to Germany and of genetically altered rice seed to the Philippines.

It is easy to interpret such events as the misguided efforts of ideologically committed activists. That is often a valid interpretation. But the ability of activists to attract a following is a reflection of more fundamental problems about which the popular intuition is correct. Let me illustrate with two examples.

The United States is preeminent in almost every aspect of biomedical science - in both the underlying basic science and in the clinical applications. But there is pervasive dissatisfaction in the US with the institutional arrangements for delivering health services. Many health indicators for the US, such as infant mortality rates, rank well below similar health indicators for countries with much more limited biomedical research capacity. My sense is that the biotechnology based pharmaceuticals that are on (or coming on) the market are primarily responsive to the health concerns of the rich, the old and the fat. The institutional reforms necessary to enable the poor to lead more healthy lives continue to be neglected.

There is also a pervasive concern, in spite of the growth of food production, that the institutional reforms necessary to enable the poor, in both rural and urban areas, to meet their nutritional needs have seldom been put in place. Poverty has been reduced and nutrition has been improved in the rapidly growing economies of East Asia. Reducing poverty is an effective way to reduce hunger and malnutrition. But, as Sri Lanka and Kerala (India), have shown it is not the only way. It is not necessary to wait until we are all rich to establish institutions that provide food entitlements for the poor. The CG system will be asked to demonstrate that it can contribute to this objective - particularly in the case of the rural poor.

The fox and the hedgehog.

In closing I would like to refer to the simile provided by the Chilean historian Claudio Veliz.

In his analyses of the economic history of the English speaking and Spanish speaking Americas he suggests an analogy with the fox and the hedgehog. The fox knows a little bit of everything. The hedgehog knows one big thing. The analogy, in the Veliz book, The New World of the Gothic Fox (California, 1994) is not complementary to the hedgehog. But my own judgement is that if the CG system is to prosper in the world that is emerging each CG institute must focus its efforts on knowing one or two big things.

BIOTECHNOLOGY: THE ROLE OF PUBLIC POLICY*

Vernon W. Ruttan**

As we look to the role of public policy - including support for research, the evolution of intellectual property rights; environmental, health and market regulation - it is useful to remind ourselves of the role of public policy in the development of the biotechnology industries.

RESEARCH SUPPORT

More than any other industry, the biotechnology industry owes its origin to public support.

- Prior to the mid-1970's almost all research in molecular biology and biotechnology had been conducted by universities (with foundation and federal funding) and by federal government (primarily NIH) laboratories. The initial motivation was the potential contribution to the solution of human health problems. The flow of federal funding into biomedical research associated with President Nixon's "war on cancer" focused much of the early research in the biomedical area.
- Plant molecular biology and agricultural biotechnology developed later and more slowly than biomedical. Progress was inhibited by (a) the dramatic success of plant breeders, drawing on the techniques of "classical" Mendelian genetics; (b) initial skepticism by plant breeders about the claims being made by molecular biologists; and (c) funding constraints in the field of plant molecular biology.

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* Presented at conference on Biotechnology and Biosafety, World Bank, Washington, D.C., October 10, 1997. The paper draws on a chapter "The Biotechnology Industries" in my forthcoming book, Technology Growth and Development, (in preparation).

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SAFETY

- The initiative taken by leading researchers in molecular biology and biotechnology in calling attention to potential health and environmental dangers was unprecedented in any field of science. The 1975 Asilomar Conference, organized by Paul Berg and Maxine Singer, was the landmark event. The Conference concluded "that there are certain experiments in which the potential risks are of such a serious nature that they ought not to be done with presently available containment facilities" and recommended a moratorium on such experiments until more secure facilities could be built and appropriate protecols could be developed.
- By the mid-1980's the legacy of the Asilomar Conference had largely been reversed. In the biomedical area almost the entire spectrum of living things had been opened to genetic manipulation with controls remaining for only limited classes of experiments. One observer noted "it is quite remarkable how quickly doubts about safety receded once it appeared that profits could be made in this new technology."

As this conference indicates, however, safety concerns have remained stronger in the area of agricultural than in pharmaceutical biotechnology. These include the affects of introducing transgenic crops on the genetic integrity of wild species and the emergence of new and more troublesome weeds and other pests and pathogens.

INTELLECTUAL PROPERTY RIGHTS

- Plant patent and patent like (plant variety registration) property rights had evolved slowly in the U.S. and other developed countries since 1930.
- The landmark in intellectual property rights for biotechnology was the 1980 judicial

decision by the U.S. Supreme Court (Diamond vs. Chakrabasty) that extended patent protection to new microorganisms.

- A major issue that remains unresolved is how broadly life forms can be patented. Recent decisions by the U.S. patent and trademark office seem to favor broad interpretations. Examples:
  - * The decision to grant a patent for gene therapy that encompasses virtually all gene therapy involving in vivo technique (to Kelly, Palella and Levine)
  - * The Abbott-Geneit application to patent genetic markers (of the single nucleotide polymorplusms-SWPS type).

Students of patent policy have generally concluded that broad grants of property rights are more likely to inhibit competition than more narrow rights. Researchers are concerned that the broader grants could inhibit research.

COMMERCIAL DEVELOPMENT

- Commercial development of biotechnology has been slower than anticipated two decades ago. By the mid-1990's there were still fewer than 30 biotechnology therapeutics and vaccines on the market. During the last several years, however, new product approvals by the FDA has increased rapidly. Profitability and sustainability of specialized biotechnology firms have remained problematic. It seems clear in retrospect that in addition to a potentially promising commercial product a few "delusion genes" have also been important in starting up a new biotech company.
- In the case of agriculture it is only in the last two years that biotechnology products have become commercially important (bovine somatropen, herbicide resistant soybeans, BT

corn and cotton).

* Agricultural biotechnology is, at present, "small potatoes". Pharmaceuticals account for 90 percent of total sales. However, agrochemical and agrobiological biotechnology, which accounted for only about 2 percent of sales in 1995, is now the most rapidly growing segment of the industry.

- Non medical diagnostics (to detect chemicals, pathogens, and other contaminants in the food supply and environment) is also growing rapidly.

INDUSTRIAL ORGANIZATION

- In the 1990s the market structure of the pharmaceutical industry underwent a major transformation. For much of the postwar period the industry had been composed of large research intensive vertically integrated - from laboratory to distribution- firms. The rise of specialized CBC's is dramatically altering the structure of the industry. It is now composed of a few marketing firms, many small knowledge intensive biotechnology firms, associated university research laboratories, and the foundations and government agencies that support biological, biochemical and biotechnology research. We are now, however, seeing a wave of consolidation among the major pharmaceutical companies.
- The structure of the agricultural biotechnology industry is becoming consolidated even more rapidly than the pharmaceutical industry. Four corporate (possibly five) groupings-- centered on (a) Monsanto, (b) Novartis (formed by Ciba-Geigy and Sandoz) and Dow-Elanco, (c) AgrEvo (Hoechst & Sheriny) and (d), Pioneer-DuPont-- are evolving.

DEVELOPING COUNTRIES

- The experience of Japan, which tried to develop a biotechnology industry based on its dominance in fermentation products, seems to indicate that sufficient depth in both basic science and in bioengineering are difficult to acquire for the laggards.

- A country may not need to be at the leading edge in the development of either biomedical or agricultural biotechnology to make effective use of the technology.
  - China may be the leading country in the development, testing and utilization of transgenic plants. India, Brazil, Mexico, Egypt are also making rapid progress.
  - Anther culture and genetic marker techniques are being used by plant breeders in many developing countries.
  - Biopesticides based on BT are being used in a number of development countries.
- But substantial scientific and technical capacity will be required in developing countries if they are to introduce and manage the diffusion of these technologies safely and productively.
- There will be winners and losers in both developed and developing countries (1) the health concerns of the rich, the old and the fat will continue to be served and the institutional reforms necessary to enable the poor to lead more healthy lives will be neglected. (2) Producers of agricultural products that continue to be sold as "commodities" - undiffereiteated maize, oil seeds and cotton - will loose while those who produce the higher value added fibers, grains and oilseeds will gain.

CAPACITY TO RESPOND TO SURPRISE

- Let me remind you: (a) No one in the 1950s and few in the 1960s and 1970s would have anticipated that agricultural commodity prices would continue their long term decline into the 1990s.

- Wheat prices have declined since middle of 19th century.

- Rice prices have declined since middle of 20th century.

- Almost no one, particularly the World Bank, anticipated that in the mid 1990s petroleum prices would be below the levels of the early 1970s.

- It is not possible to anticipate surprises. The future will be different than the past because it has not yet occurred!! It is not unreasonable to expect "surprises" in population, health, agricultural production and the environment. (a) The capacity to advance knowledge and technology is the only "reserve army" available to deal with surprise. (b) Most of the time our research is focused on normal science and incremental technical change. (c) When confronted by surprise the trajectory of technical change can be redirected - but only if the "reserve army" is in place.

- My sense is that the biotechnology industry stands, in it development, at about the same stage as computers in the late 1950s before the replacement of vacuum tubes by transistors. No one committed to 1950s main frame computer development anticipated the personal computer.

We are just emerging from the first generation stage - doing what we can do by working with single genes. The second generation will involve multiple genes and the modification of plants, animal and human components. The third generation will involve the modification of whole organisms.

- An excessive commitment to avoiding surprise will also mean that we avoid the benefits from biotechnology.

SCIENCE, TECHNOLOGY AND SURPRISE: IMPLICATIONS FOR AGRICULTURE*

Vernon W. Ruttan*

We are, in the closing years of the 20th century completing one of the most remarkable transitions in the history of agriculture.

- Prior to this century almost all increases in food production were obtained by bringing new land into production. By the end of the first decade of the 21st century almost all increases in world food production must come from higher yields--from increased output per hectare and increased output per animal unit.

- In the 19th century almost all differences in agricultural productivity were resource based. In the 21st century almost all differences will be knowledge based -- on science, technology and human capital.

- A few presently developed countries began this transition in the middle of the 19th century. Others began this transition in the first half of the 20th century. Most developing countries began the transition only in the second half, and some only in the last quarter, of the 20th century.

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*Paper presented at World Bank Workshop on Emerging Issues in Development Economics, Washington, D.C., July 8, 1997.

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PRODUCTIVITY DIFFERENCES ON WORLD AGRICULTURE

Let me refer to Figure 1 (due to Philip Pardey of IFPRI)

- The vertical axis - biological (and chemical) technology (output/hectare)
- The horizontal axis - mechanical (and engineering) technology (output/worker)
- The diagonal lines - hectares per worker

I can not emphasize too strongly the importance of the distinction between biological and mechanical technology in attempting to understand technical change in agriculture.

Mechanical technology is a substitute for labor

Biological technology is a substitute for land.

Nature is, at this stage in time, appears to be relatively plastic. A nation can advance either biological or mechanical technology (or both) depending on which is appropriate. But - agricultural technology is not directly transferable across agroclimatic regions. The capacity to do agricultural science and technology-experiment station capacity-must be transferred if farmers are to have access to either modern biological or mechanical technology.

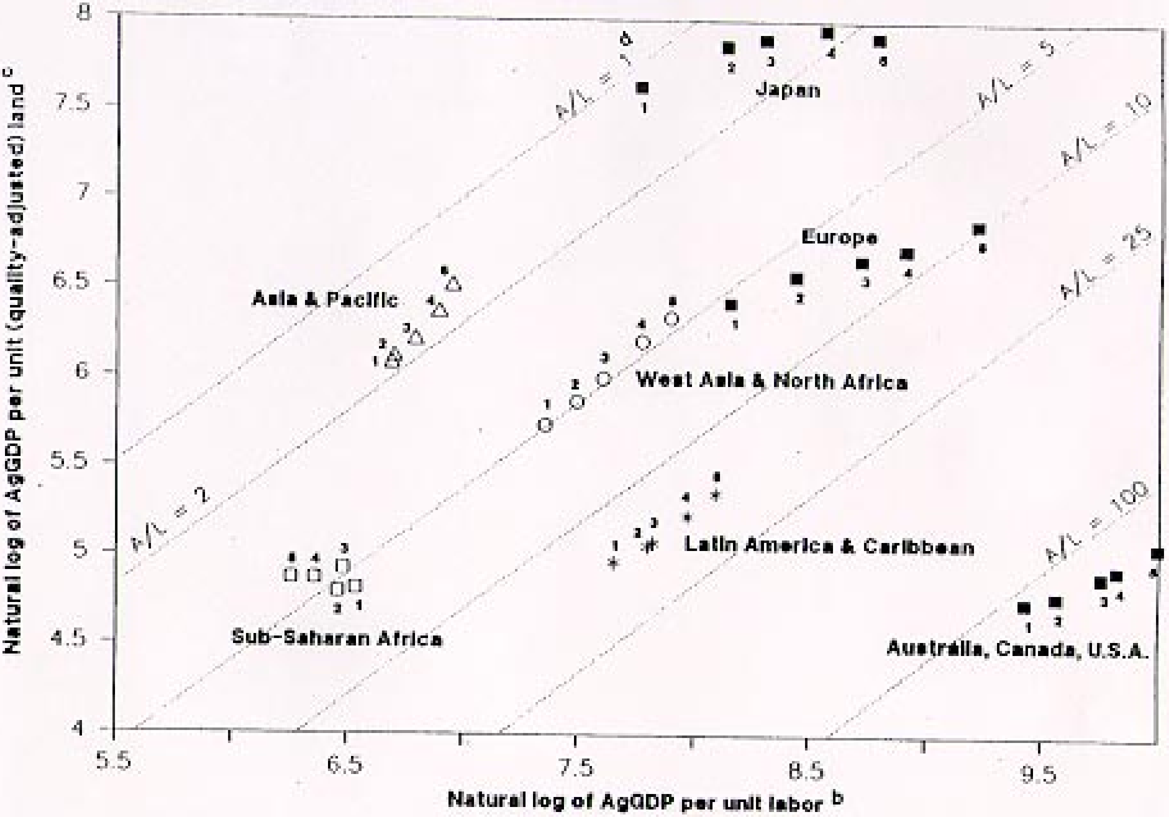
CLOSING THE PRODUCTIVITY GAP

Research reported by Hayami and Ruttan, in our book Agricultural Development: An International Perspective (Johns Hopkins, 1985) suggests (from growth accounting based on cross county regressions) that:

- With comparable investments in human capital, and
- With comparable development and use of technical inputs, (including the necessary investments in location specific agricultural R&D)

most LDC's could achieve levels of output per worker comparable to those of Western Europe.

FIGURE 1 International comparison of (quality-adjusted) agricultural land and agricultural labor productivity indices. Regional averages, 1960 - 1985. [a]



1 = 1960-64; 2 = 1965-69; 3= 1970-74; 4 = 1975-79; 5 = 1980-85

a) Sample consists of 16 Asia & Pacific countries; 20 Developed countries; 28 Latin America & Caribbean countries; 38 Sub-Saharan African countries; and 13 West Asia & North African countries
b) Labor is economically active agricultural population

c) Agricultural land is arable land and permanent crops plus permanent pasture (hectares of quality adjusted land)
d) A/L = Quality adjusted land per unit labor

Source: Authors' own calculations based on FAO and UN data

Source: Philip Pardey

Achievement of levels comparable to the United States, Canada, and Australia would, in addition, require a restructuring leading to larger farm size.

Thus technical change is necessary if output per worker in agriculture is to rise. But urban-industrial development is also necessary if income per worker in agriculture is to rise to developed country levels.

CAPACITY TO RESPOND TO SURPRISE

Those of us (or you, given my age) who will be concerned about technical change in agricultural and economic development will not escape the need to deal with uncertainty - to respond to surprise - during the next several decades.

- The capacity to advance knowledge and technology represents the "reserve army" (to coin a phrase) for dealing with surprise.

- Most of the time our research is focused on normal science and incremental technical change. Experience suggests that when confronted by surprise the trajectory of technical change can be redirected.

TWO SURPRISES OF THE LAST HALF CENTURY

Agriculture.

No one in the 1950s, and few in the 1960s, anticipated that agricultural commodity prices would continue their long term decline into the 1990s.

- Wheat prices have declined continuously since the middle of the 19th century. (Figure 2a)
- Rice prices have declined since the middle of the 20th century. (Figure 2b)

I have only to refer you to the early post WW II resource assessment studies. The President's Material Policy Commission Report estimated, in early 1950s that, in the US, would it would be necessary to add 100 million acres of agricultural land to production by 1975. In the 1960s no one, not even the most enthusiastic of green revolutionaries (of which I was one) anticipated that it would be possible to raise grain yields (under ideal conditions) from the 2-4 metric ton/hectare range to the 8-10 ton range.

Energy

The world energy (more correctly, petroleum price) increases of the 1970's is a more recent example. If the World Bank petroleum price projections of the 1970s and 1980s can be taken as an indicator World Bank energy specialists were confronted by a "surprise" every 2 years between 1978 and 1986. (Figure 3)

SURPRISES OF THE NEXT HALF CENTURY*

Surprises, by their very nature, can not be predicted. The future differs from the past in that it has not occurred. But it is not unreasonable to suggest some areas where surprises may occur.

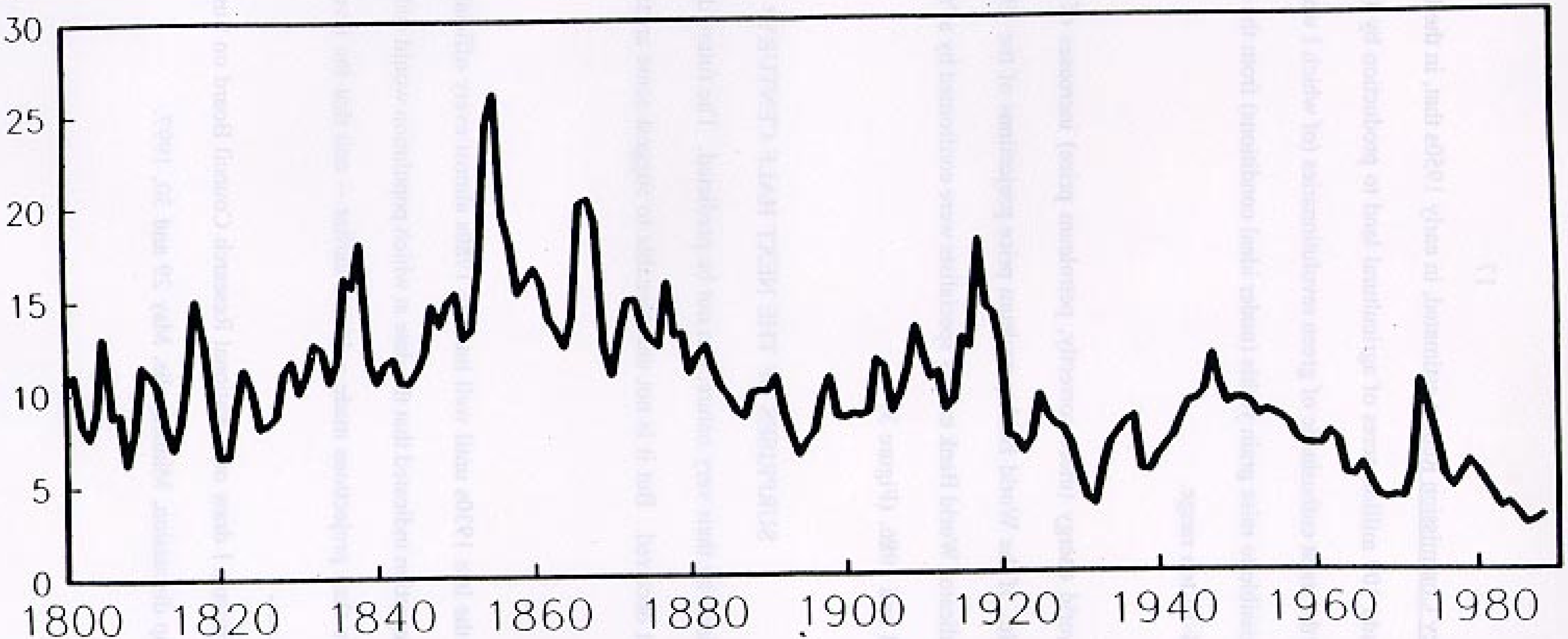
Population

From the late 1930s until well into the 1980s almost every official and unofficial global population projection indicated that the date at which population would stabilize would be further into the future than projections made a decade earlier -- and that the level at which population

*In these comments I draw on a National Research Council Board on Sustainable Development working group discussion, Minneapolis, May 29 and 30, 1997.

FIGURE 2A

REAL WHEAT PRICES SINCE 1800



Source: Edwards, Clark, "Real Prices Received by Farmers Keep Falling," Choices, Fourth Quarter 1988, pp. 22-23.

FIGURE 3

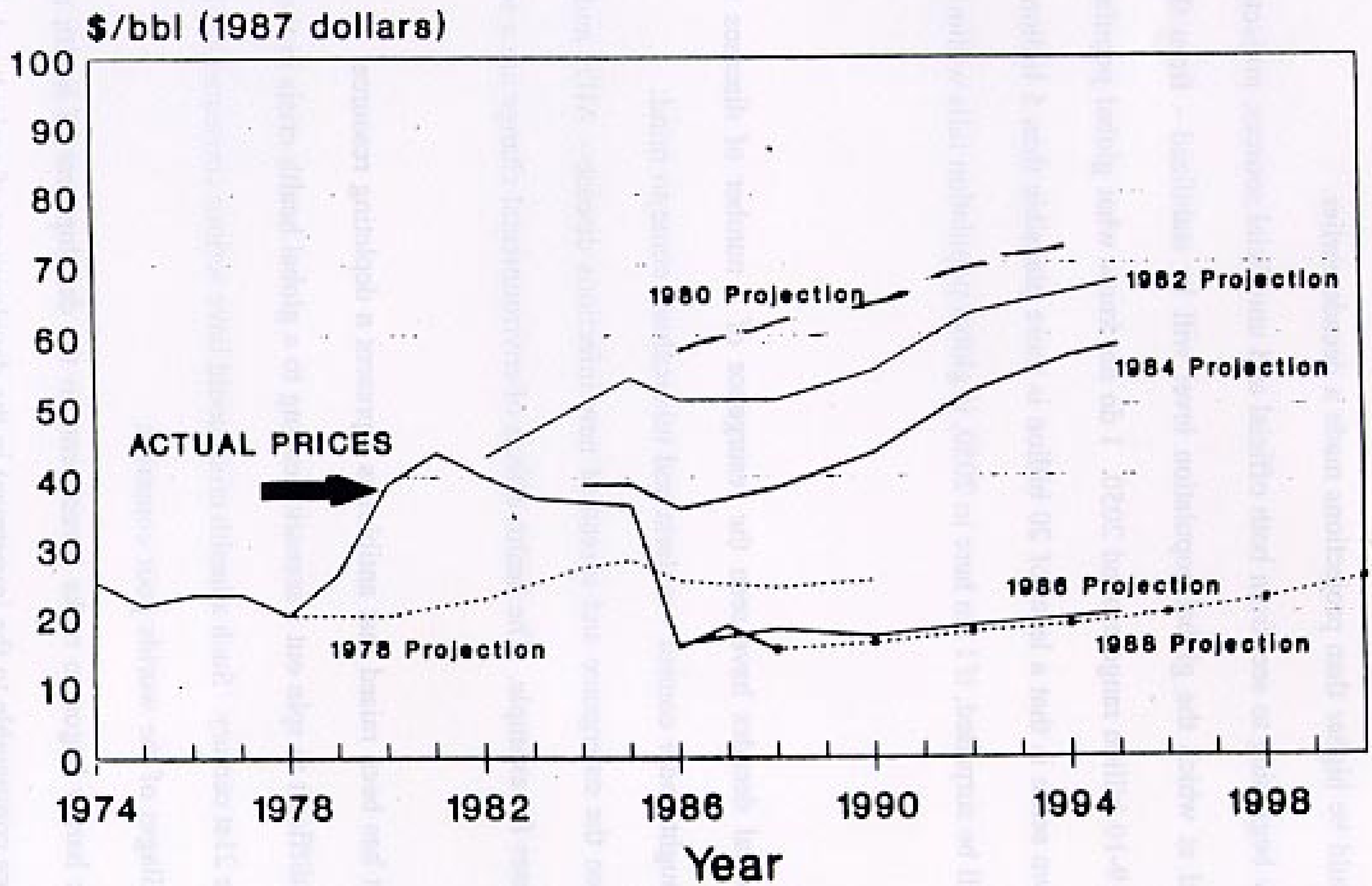


Figure 5 World bank oil price projections in constant 1987 US $ per barrel.

Source: David Jhirad, "Power Sector Innovation in Developing Countries: Implementing Multifaceted Solutions," Ann., Rev, Energy, (1990), 15:365-98.

would stabilize would be higher than projections made a decade earlier.

We are now beginning to see, from both official and unofficial sources, projections of a decline in the level at which the global population level will be stabilized - from the 10-11 billionrange to the 9-10 billion range around 2050. I do not know what global population will be in 2050. My own sense is that a level of 20 billion is more plausible than 5 billion. Either could happen. I will be surprised, if I am here in 2050, if global population falls within the 9-10 billion range.

Health

The last several decades have seen the resurgence of a number of diseases that had previously been thought under control - malaria and tuberculosis come to mind.

We have seen the emergence and spread of new infectious disease - AIDs and several other venereal diseases for example. The health effects of environmental change are a source of increased concern.

The prospect has been raised that antibiotics represent a depleting resource.

It is not too difficult to spin out a scenario leading to a global health crisis in the first or second decade of the 21st century. Such a health crisis could have serious consequences for food production in the villages of the worlds poor countries.

Yet we have hardly begun to make investments in the development of health research capacity in the tropics comparable to the investment in the development of agricultural research capacity that began in the 1960s. Instead we have dismantled much of the research capacity in tropical medicine that already existed.

The "reserve army" needs to be remobilized!

Environment*

It is unlikely, but not impossible, that in the next decade or two climate modelers might discover that rising CO_2 (and other greenhouse gas) levels are largely due to natural rather anthropogenic sources.

This would suggest that the policy focus would appropriately shift from abatement to adaptation. An adaptation strategy would imply the need to substantially strengthen agricultural, environmental and health research in the tropics.

Suppose, instead, that climate modlers confirmed that the sources of increase in greenhouse gasses are largely anthropogenic. And suppose that social science research confirms, what many of us suspect, that the national and international institutions needed to abate climate change will not be put into place until it "hurts".

Would the appropriate policy response to these two alternatives differ?

Biotechnology

Will biotechnology rescue us from the agricultural, environmental and heath surprises such as those I have suggested?

My own sense is that progress in biotechnology is today about where progress in the development of computers and other information technology stood in the late 1950s - before the development of the transistor to replace vacuum tubes.

Until a couple years ago, I frequently challenged my friends in biotechnology by suggesting that the promise of biotechnology had slipped back 8 years every decade. I am now

* I am indebted to Tom Schelling for this suggestion.

more optimistic. The promise is slipping back only 5 years every decade!

We can anticipate, drawing from the information technology analogy, that the future of biotechnology will involve surprises that biotechnologists, including those whose own genetic code contain a sequence of "illusion genes", do not imagine. But whether the surprise will realize the promise seen by some, or the curse anticipated by others, will itself be a surprise.

THE RESERVE ARMY AND THE BIG BANG

My purpose in discussing the role of surprise is to emphasize the inadequacy of development economists, and of economists generally, in assisting society to prepare for and to confront surprise. We know very little about the design of science and technology policy for an uncertain future.

We suspect that advances in knowledge and in scientific and technical practice has enabled those of us who have ordinary talent to accomplish what only those with much greater talent have been able to accomplish in the past.

But we also observe that when the time is ripe -- when the stage has been set and when the reserve army is in place - dramatic advances that go beyond normal science and incremental changes in technology have emerged.

I have in mind the advances made by the Darwins and Mendels, the Edisons and Shocklys and many others. I do not understand what calls forth such talent. But I am confident that if the "reserve army" is not in place - patiently doing normal science and making incremental advances in technology - the large advances needed to confront the surprises of the future will be called for - but the response will be weak!

MEETING THE FOOD NEEDS OF THE WORLD*

Vernon W. Ruttan**

We are in the closing years of the 20th century completing one of the most remarkable transitions in the history of agriculture. Prior to this century almost all of the increase in food production was obtained by bringing new land into production. By the end of the first decade of the 21st century almost all of the increases in world food production must come from higher yields--from increased output per hectare and increased output per animal unit.

World Food Futures

Perspectives on world food futures have cycled rapidly over the last several decades. a 1989 study at the International Institute for Applied Systems Analysis (IIASA) advanced what came to be referred to as "the 2-4-6-8 scenario" - a doubling of population, a quadrupling of agricultural production, a sextupling of energy production and an octupling of the size of the global economy by 2050. Note that it is the growth of the global economy--particularly per capita income growth in the presently poor countries--that is the source of approximately half of the growth in food demand.

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* Presented at "World Food Prize Symposium, Des Moines, Iowa, October 18, 1996. An earlier draft was presented at the "Symposium on Science and Human Goals in the 21st Century," 25th General Assembly of International Council of Scientific Unions, National Academy of Sciences, Washington, D.C.: September 24, 1996. In this note I draw on several papers in Vernon W. Ruttan (ed), Agriculture, Environment and Health: Sustainable Development in the 21st Century (Minneapolis: University of Minnesota Press, 1994).

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More recent research has criticized the IIASA projections as implying "whole nations of obese gluttons." It now seems apparent, on the basis of newer population, income growth and consumption behavior projections that global food demand growth will fall in the 2.0-3.0 percent range over the next 50 years with substantially higher growth rates at the beginning and lower growth rates toward the end. We need to be as concerned with the "income gap" as with the potential "food gap." "People who have money to buy food do not need to do so".

The recent draw down in grain stocks and run up in grain prices have, however, caused some observers to announce that the long term decline in grain prices, that had made food available to consumers on increasingly favorable terms since the middle of the 19th century, has finally come to an end. In assessing these current predictions it should be recalled that almost identical predictions, triggered by similar events, were made by some of the same observers in the early and mid-1970's. My own sense is that the recent decline in percapita production of cereals and the run-up in cereal prices was largely policy induced.

Constraints on Food Production

As the world's farmers attempt to respond to the demands that will be placed on them over the next half century they will be confronted by a number of serious constraints.

(1) <u>Scientific and technical constraints.</u> Gains in agricultural production will be achieved with much greater difficulty than in the immediate past. Biotechnology is not yet living up to its promise to provide an "encore to the green revolution." Agricultural research budgets have declined in many developed and developing countries. And "maintenance research"--the research required to prevent yields from declining, as a result of land degradation and the co-evolution of pests and disease,--is rising as a share of research effort.

(2) Resource and environmental constraints. Intensification of industrial and agricultural production is imposing increasingly severe environmental constraints on agricultural production. These range from (a) the impact of fossil fuel consumption on global climate change, (b) to the loss of soil resources due to erosion, water logging and salinization to (c) the resistance of weeds, insects and pathogens to present methods of control.

(3) Health constraints. A number of indicators suggest that health could emerge as a serious constraint on agricultural production in the early decades of the 21st century. These include the resurgence of malaria and tuberculosis, the emergence of AIDs and a number of other infectious diseases, the declining efficacy of available antibiotics and the high cost of developing new drugs for the control of infectious disease. Little progress has been made in the control of several important parasitic diseases. And we are only beginning to confront the environmental health effects of agricultural and industrial intensification.

If several of these health threats emerge simultaneously in specific geographic locations it is not difficult to visualize scenarios in which the number of sick people in rural areas become a serious constraint on agricultural production!

Institutional Innovation

I am cautiously optimistic about the possibilities of responding to the demands that will be placed on agricultural producers over the next half century. My optimism is tempered, however, by the capacity of the global community to realize a number of important institutional innovations:

- Our capacity to monitor (a) changes in the sources of productivity change in agriculture, (b) the sources (driving forces) and impact of environmental change, (c) and the sources and incidence of the emerging insults to health is inadequate. These capacities must be strengthened if we are to respond effectively.

- More effective bridges must be built, both in research and practice, among the agricultural, environmental and health communities. At present these three tribes occupy separate and mutually hostile "island empires".

Table 1 **Projection of Commodity Demand for 2050**

YEAR	CEREAL	BOVINE & OVINE MEAT	DAIRY	OTHER ANIMAL PRODUCTS	PROTEIN FEEDS	OIL AND FATS	SUGAR
2000*	2082	86	642	27	106	96	286@
Medium Population-Low Income Growth (MP-LG)							
2050	3262.4	175.5	855.9	130.5	128.3	158.6	324.7
High Population-High Income Growth (HP-HG)							
2050	4916.4	270.5	1347.3	184.5	205.3	288.6	523.8
Commodity Demand Ratios							
MP-LG RATIO 2050/2000	1.57	2.04	1.33	4.83	1.21	1.65	1.14
HP-HG RATIO 2050/2000	2.36	3.15	2.10	6.83	1.94	3.01	1.83

Units:
Cereals: Millions Tons
Dairy: Million tons wh. milk equiv.
Protein feeds: Million ton protein equiv.
Sugar: 10^6 tons refined sugar equiv.
Bovine & Ovine Meat: Million tons carcass wt.
Other Animal Products: Million ton protein equiv.
Oils: 10^6 tons oil

Source: Kirit S. Parikh, "Agricultural and Food System Scenarios for the 21st Century" in Vernon W. Ruttan (ed.) Agriculture, Environment and Health: Sustainable Development in the 21st Century. Minneapolis, MN: University of Minnesota Press, 1994), p. 34. For projections of population and income on which the demand projections are based see pp.30-31.