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Global and local implications of biotechnology and climate change for future food supplies

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ABSTRACT **The development of improved technology for agricultural production and its diffusion to farmers is a process requiring investment and time. A large number of studies of this process have been undertaken. The findings of these studies have been incorporated into a quantitative policy model projecting supplies of commodities (in terms of area and crop yields), equilibrium prices, and international trade volumes to the year 2020. These projections show that a "global food crisis," as would be manifested in high commodity prices, is unlikely to occur. The same projections show, however, that in many countries, "local food crisis," as manifested in low agricultural incomes and associated low food consumption in the presence of low food prices, will occur. Simulations show that delays in the diffusion of modern biotechnology research capabilities to developing countries will exacerbate local food crises. Similarly, global climate change will also exacerbate these crises, accentuating the importance of bringing strengthened research capabilities to developing countries.**

I. Introduction

Projections of food supply have typically been based on past experience. Economists usually emphasize the continuity and "momentum" of the development and diffusion of improved technology in making these projections. Biological scientists, on the other hand, usually place more stress on the inherent "limits" to supply growth as reflected in "carrying capacity" models. In this paper, food supply projections are based on projections of investments in productivity improvement activities and on evidence regarding the effectiveness of these activities. These projections are incorporated into a global agricultural general equilibrium model [the International Food Policy Research Institute (IFPRI)–International Model for Policy Analysis of Agricultural Commodities (IMPACT) model], which does consider limiting factors to supply growth.

These projections are first developed for a "base case," where they may be compared with other projections. The development of new techniques for developing biological inventions (biotechnology) must be incorporated into the base case, because these techniques are already producing significant inventions. Experience to date with biotechnology, however, is still too limited to be used for projections. A recently completed study of rice biotechnology elicited subjective probability estimates of research potential and of time to achievement of research potential for a large number of research problem areas for rice. This study provides a basis for both the base case projections and for an important policy simulation dealing with the diffusion of biotechnology to developing countries.

This paper also introduces a policy simulation for the effects of global climate change based on three recent studies of climate change impacts on agriculture in the United States, India, and Brazil. Although these three studies do not provide comprehensive coverage of global food production, the three studies do fit into a common global pattern showing that cooler regions of the world will benefit from global warming, whereas warmer regions will suffer losses.

Not surprisingly, the base case and policy simulations show that "local" effects can differ drastically from "global" effects. The base case computations yield relatively favorable global effects. A "global food crisis" appears not to be in the offing in the next 25 years or so. But that does not mean that "local food crisis" will not continue to exist in 2020. The base case projections show general improvement in local indexes of malnutrition, but even under the most favorable simulations, malnutrition will continue to be a real problem for much of the developing world. The policy simulations show that delays in the diffusion of biotechnology to developing countries is likely to exacerbate local effects. Global warming scenarios also show a worsening of many local effects.

The IFPRI-IMPACT model computes price projections that are essentially global. It also computes production, cropped area, and trade projections that are local (i.e., national). The cropped area effects have important implications for biodiversity because, as cropped area expands, biodiversity habitats are altered. Finally, the model also computes measures of child malnutrition based on food consumption projections.

Part II of the paper provides a brief overview of the IFPRI–IMPACT model. Part III develops the nonprice supply components of the model. Part IV develops policy scenarios to address the questions noted above. In part V, scenario calculations are reported. Part VI concludes.

II. The IFPRI–IMPACT Model

In this section, the IMPACT model is briefly described. The *Appendix* provides more detail.

The IMPACT model developed at IFPRI is a computable equilibrium market model for agricultural products (crops and livestock; 17 commodities). It is based on 35 country–region submodels[†]. Each submodel consists of equations depicting the supply for each commodity as a function of price and nonprice terms. The demand for each commodity is also

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Abbreviations: IFPRI, International Food Policy Research Institute; IMPACT, International Model for Policy Analysis of Agricultural Commodities; R&D, research and development; ITI, industrial technology infrastructure; NARs, National Agricultural Research systems; IARCs, International Agricultural Research Centers.

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[†] Agcaoili, M. C., Oga, K. & Rosegrant, M. W. (1993) *Structure and Operation of the International Food Policy and Trade Simulation (IFPTSIM) Model*. Paper presented at the Second Workshop of the Research Project on Projections and Policy Implications of Medium- and Long-Term Rice Supply and Demand [International Rice Research Institute (IRRI), Los Banos, Philippines].

described as a function of price, income, population, and nonprice terms. The submodels are linked through trade, which may be free or restricted by tariffs. The model solves for global and submodel equilibrium prices for each commodity where all markets are cleared. Linkages with other sectors are built into the model, but these are not sufficiently complex to describe the model as a global general equilibrium model. It is an agricultural general equilibrium model.

The *endogenous* variables determined by the model equilibrium are:

1. Commodity prices and quantities by country–region.
2. Trade quantities (imports and exports) by country–region.
3. Cropped area by commodity by country–region.
4. Commodities consumed; calories per capita; percent children malnourished by country–region.

The model also generates the per capita calorie availability from food consumed by using standard kilocalorie conversion values for different foods. Estimates of the relationship between the percentage of children ages 0–6 years malnourished as a function of calorie availability are made from pooled cross-section, time and series data for 61 developing countries for 1980, 1985, and 1990.[‡]

The *exogenous* variables in the model are:

1. Population by year, by country–region.
2. Nonagricultural income by year, by country–region (agricultural incomes are endogenous).
3. Total land area by country–region.
4. Nonprice (productivity) supply growth including contributions from:
    a. Farmers' schooling
    b. Agricultural extension
    c. Public-sector agricultural research
    d. Private-sector agricultural research.

Population and income projections are taken from *World Population Prospects* (1). Irrigation projections are based on IFPRI studies. Nonagricultural income projections are based on World Bank and Asian Development Bank sources.

Price and income elasticities of demand are taken from national sources where feasible. Harvested area is a function of price (price response parameters are taken from national studies),[†] total land area, and nonprice factors. Similarly, yields are a function of both price and nonprice factors. Supply is area times yield. Supply elasticities are generally low. A dynamic adjustment process is allowed, consistent with estimates of supply responses in China, India, Indonesia, and other countries.

The structure of the model allows for baseline projections to be specified for the exogenous variables. This produces baseline projections for the endogenous variables. Alternative policy scenarios can be defined and projections obtained. These can be compared with the baseline projections.

III. Specifying the Nonprice Supply (Area and Yield) Terms

The nonprice supply component for both area and yield is specified as an annual rate of change. This trend can be interpreted as a total factor productivity growth trend. Productivity growth is traceable to several sources. These include improvements in the human capital (schooling) of farmers, agricultural extension programs, and agricultural research programs (public and private), all of which produce positive productivity gains. Resource degradation produces negative productivity gains.

The IFPRI–IMPACT model is not based on trend estimates or judgements except to achieve continuity with the recent past. It relies instead on a combination of a detailed *ex ante* research contribution study for rice production and an extensive body of *ex post* productivity decomposition studies. Nonprice supply trends are developed for both yield and area for 5-yr periods: 1995–2000, 2000–2005, 2005–2010, 2010–2015, and 2015–2020.

The starting point for developing these nonprice trends was to examine past nonprice trends in yield and area growth. This was done by first removing price effects from yield and area data and estimating nonprice trends for each commodity and country for the 1962–1982 and 1983–1992 periods. In most cases, these trends were higher in the 1962–1982 "Green Revolution" period. Part of this slowdown is because of a relative exhaustion of "Green Revolution" gains, a fact that is taken into account in the component analysis. Thus, the projected future trends explicitly account for the slowdown in yield growth for most commodities in most countries (as well as accounting for strong performers, such as rice yield growth in India and pork meat and poultry production in much of Asia). For the few countries where base or end-of-year values resulted in trend estimates that were clearly outliers from trends over the 1983–1992 period, these estimates were modified to be consistent with nonoutlier trends. Phase-in rules were used to link these past trends with projected trends.

The first step in making nonprice yield projections was to break the projection into its components and subcomponents. The following component structure, based on a study of Indian crop productivity,[§][¶] was used:

1. Public [International Agricultural Research Centers (IARC)-National Agricultural Research systems (NARs)] research
    a. Management research
    b. Conventional plant breeding
    c. Widecrossing-hybridization breeding
    d. Biotechnology (transgenic) breeding
2. Private-sector agriculturally related research and development (R&D)
3. Agricultural extension—farmers' schooling
4. Markets
5. Infrastructure
6. Irrigation (interacting with technology)

The yield growth contribution of modern inputs such as fertilizers is accounted for in price effects in the yield response function and as a complementary input with irrigation and with the modern varieties generated by research. The public sector research subcomponents are based on a rice research priority setting study (2).

A. The Public Research Component of Rice. A recently completed study, *Rice Research in Asia: Progress and Priorities* (2),[‖] provided the basis for subcomponent projections for four broad rice-producing zones (South Asia, Southeast Asia, East Asia, and the rest of the world). The priorities study contributed estimates of crop losses from insect pests, plant diseases, and abiotic stresses for Eastern and Southern India, Indonesia, Bangladesh, Thailand, and China. These crop-loss estimates were treated as estimates of potential gains for specific types

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[‡] World Nutrition Database ACC-SCN, 1992.

[§] This accounting framework allows for productivity contributions from many sources. A number of studies have addressed the contribution of each source.

[¶] Rosegrant, M. W. & Evenson, R. E. (1993) *Determinants of Productivity Growth in Asian Agriculture: Past and Future*. Paper presented at the 1993 American Agricultural Economics Association International Pre-Conference on "Post-Green Revolution Agricultural Development Strategies in the Third World: What Next," Orlando, Florida.

[‖] Evenson, R. E. (1998) "Biotechnology Research Priorities for Rice," International Rice Research Institute (mimeograph).

of research. Insect reduction potentials were based on losses from 13 major insect pests. Disease reduction potentials were based on losses for 14 major rice diseases. Abiotic stress potentials were based on losses (adjusted for the proportion that can be affected by research) for nine abiotic stresses (heat, cold, drought, flooding, etc.). Management potentials were based on data for management-related pest problems (weeds, rodents, birds). Biological efficiency potential estimates were based on scientists' estimates of gains from improved plant design, improved photosynthesis efficiency, shorter growth duration, and improved grain quality.

A scientist's rating exercise was carried out with 18 senior rice scientists in 1995 and followed up in 1997 with a second rating study with an additional 60 scientists. For each of the research problem areas for which respondents had scientific qualifications, four ratings were elicited (ratings were on a scale of 1 to 5 but were calibrated to percentage achievements of economic potential) for alternative research techniques (managerial research, conventional breeding, widecrossing and hybridization, and biotechnology/transgenic rice and marker-aided selection). These ratings were:

1. A rating of achievement to date (RA);
2. A rating of potential achievement (RP);
3. An estimate of the number of years required to achieve 25% of the difference between achievement to date and potential (Y25);
4. An estimate of the number of years required to achieve 75% of the difference between achievement to date and potential (Y75).

In developing these estimates, scientists were asked to presume that both IARC and NARs programs would continue to be supported at the levels of the past decade in future periods.

The specification of two ratings, one for achievement to date and one for potential achievement, forced respondents to focus on "remaining potential." Ratings of potential minus achievements to date were summarized and converted to percent of accomplishments.

Estimates were obtained for each research problem area by research technique. For purposes of developing projections, the ratings were scaled into period estimates based on the Y75 estimates. Conventional breeding programs were considered the core genetic (improvement) programs. Widecrossing and marker-aided breeding programs were not expected to contribute to productivity gains until their actual potential achieved exceeded that of conventional breeding. Similarly, transgenic breeding was not projected to contribute to productivity until it exceeded the potential of widecrossing and marker-aided breeding.

By converting the ratings to actual percentages and multiplying them times the units affected (crop losses or yield potential), rice nonprice yield projections were created for each region for the public NARs and IARC components. Note that one can distinguish between biotechnology and conventional breeding components, thus enabling the biotechnology slowdown policy scenarios noted below.

B. Extension—Schooling Components. Several studies of agricultural extension and schooling have been undertaken (3). It is difficult to generalize as to the growth contribution of extension and schooling, however, because to produce growth, investments must be made and investments must be productive. The most comprehensive study of growth experience to date is the IFPRI study of India (4). That study indicated that the extension contribution was roughly two-thirds of the public research contribution.

The management research contribution is also related to the extension contribution. The rule for computing the extension contribution is that extension plus management research is two-thirds of conventional breeding, widecrossing, and biotechnology research.

C. The Private-Sector R&D Contribution. The private-sector R&D contribution depends on the stage of industrial technology infrastructure (ITI). The stages range from little or no ITI (stage 1A) to the Newly Industrialized Country type ITI (stage 2C) and developed country ITI (stage D). A study by Evenson and Westphal (5) defines stages for different countries (see *Appendix*). Projections of these stages are based on the expectation of the continuation of industrial reforms underway for the past decade. The *Appendix* summarizes projections of ITI by country, by period.

The India growth accounting study (4) indicated approximately a 0.1% growth contribution for India from private-sector R&D. India is a 2A country moving toward 2B status. U.S. evidence suggests a 0.2% contribution (6) for developed countries.

Based on these studies, the following private R&D growth components by ITI class were assigned:

1B = 0; 1C = .05; 2A = .1; 2B = .15; 2C = .2; D = .2.

D. Markets and Infrastructure Contributions. As with private-sector R&D, these contributions are tied to ITI class. Based on the India study (4), the following markets–infrastructure growth components by ITI class were assigned:

1B = .1; 1C = .1; 2A = .15; 2B = .15; 2C = .2; D = .1.

E. Extension to Other Commodities. Scientist ratings are not available for other crops to allow estimates similar to those for rice. However, there is a larger body of evidence from returns to research studies. From this evidence, it appears that research programs have been effective in all cereal grains. Public-sector research has also been effective in oilseed crops (soybeans). It appears that research progress has been slower in rootcrops than for cereals (the *Appendix* provides further detail on returns to research). The management and conventional breeding components for other commodities have been scaled to the rice estimates by using relative rates of return.

F. Nonprice Area Projections. Procedures for estimating nonprice area growth for 1990–1995 followed the same procedures described above for yield. In later time periods, nonprice area components depend on the availability of cultivable land, irrigation, and infrastructure investments and productivity gains as well as prices. Some of the effects operate through prices, and to the extent that they do, the price response parameters within IMPACT, the IFPRI multicommodity model, will determine changes in area. But to the extent that investments expand the effective stock of land, they are nonprice components. In practice, aggregate land expansion has slowed to very low rates in recent years as the stock of cultivable land has been exhausted. The chief component of aggregate area expansion has been investment in irrigation, which has also slowed dramatically in recent years (7). Projections of area expansion in subsequent time periods thus take estimated nonprice area growth trends estimated for 1990–1995 and in most cases dampen these to reflect the lagged effects of declining investments in irrigation. Accordingly, except for a few crops in a few regions, low rates of nonprice area expansion are projected. Nonprice growth in livestock numbers is projected based on recent historical growth and rates of change in this growth rate from previous periods.

Data on rates of return to agricultural research were used to scale the nonprice yield and area parameters for other crops to the rice cases (see *Appendix*).

IV. Policy Scenarios

The baseline case in the IFPRI–IMPACT model is based on continued support of research and extension programs at present levels. Biotechnology contributions are expected to come on line first for rice then for other commodities, according to scientists. Industrialization and trade liberalization are expected to continue.

The following alternative policy scenarios are considered:

A. Demographic gift
B. Delayed industrialization
C. Reduced IARC–NARs support
D. A 10-year biotechnology delay
E. Climate change

A. Demographic Gift. The base case population scenario is based on the U.N. "medium" population projection. The demographic gift projection reduces this to the U.N. "low" projection. This is consistent with the demographic gift (8) associated with reduced population growth. The labor force growth contributing to production will not be reduced until after the time lag between birth and labor force entry occurs. Thus, in the period from 1990 (1998) to 2020, labor force will grow at the medium projection, but the number of prelabor force consumers will decline. This is a one-time "gift" in the sense that the ratio of laborers to population will rise only for a short period before it returns to normal as labor force growth slows.

B. Delayed Industrialization. Another realistic scenario is that of delayed industrialization reforms. The past 10–15 years have seen considerable progress by a substantial number of developing economies in improving trade and industrialization policy. This has enabled many countries to move forward in the ITI classification. Indonesia, for example, has moved from a 1C technological infrastructure level to 2A and now to 2B. Continued reform to 2C status is postulated in the base case. Similarly, Thailand has moved from 2A to 2C over the past two decades, while the Philippines has remained at the 2A level. Latin American countries have generally made improvements as well.

But this move toward industrialization and the rapid growth associated with it can be reversed and delayed. This may come about because of increased local conflicts (by and large, countries with significant civil strife do not make economic progress). The recent crisis in Asia demonstrates this effectively. This scenario is one where the ITI class standings for 1995–2000 are maintained through subsequent periods. A more severe industrialization delay would call for a reversal of some of the recently attained standings (for example, political turmoil in Indonesia could cause a reversion to 2A or even IC status).

C. Reduced IARC–NARs Support. A substantial shift in international support in terms of loans or grants for NARs and IARCs over recent decades has taken place. In the 1950s, 1960s, and 1970s, bilateral aid agencies supported NARs building programs and extension programs. U.N. agencies did as well. Today these agencies support little research. For practical purposes, support for NARs and most extension programs is provided by the World Bank (and other banks and bilateral programs to a lesser extent).

It is possible that World Bank support will be reduced in the future. The Inter-American Development Bank (IDB) is proposing a regional research fund for Latin America that effectively ends IDB support for IARCs and NARs. NARs in advanced countries will be little affected, but most weaker NARs will be substantially affected. Many have reduced their nonpersonnel budgets (in the interest of saving jobs) under budget reductions in recent years. This had debilitating effects on the effectiveness of research.

D. Ten-Year Biotechnology Delay (Developing Countries). The contributions of biotechnology have been built into the nonprice terms according to the timing indicated in the scientist survey. For rice, these contributions begin early next century and become quite significant by 2015. For other crops, the timing is delayed. The biotechnology delay scenario delays the biotechnology contribution by 10 years for developing countries. We are presuming that the antibiotechnology movement will have little or no effect on developed countries, but it could easily delay access to biotechnology in most developing countries. The absence of strong intellectual property rights will also delay access to the "genes for sale" already being made available in developed countries. This scenario is supported by some nongovernmental organizations.[**]

E. Climate Change. A number of projections of climate change have been made in recent years. Agreement on the timing and extent of this change has not been reached. The estimates used here are that mean temperatures will rise by 1°Celsius by the year 2020 and that rainfall will increase by 3.5%.

Three recent studies have provided estimates of the effects of climate change on agricultural production. The first, by Mendelsohn, Nordhaus, and Shaw (11), pioneered the use of the "Ricardian" method for relating climate change to productivity through land values. This study for the United States showed that agricultural productivity in the northern counties in the U.S. would generally increase as a result of climate change, while the warmer southern counties would experience losses.

A second study for Brazil (9) found similar effects in Brazil. Municipios in the south experienced gains and those in the warmer north and central regions experienced losses. A third study for India (10) found similar effects.

The three studies were sufficiently consistent in terms of fitting into a global "surface" that we believe that extrapolations to other countries (based primarily on latitude) are justified. These are the basis for the climate change scenarios (the reader should use caution, given the limited data on which the scenarios are based).

V. Policy Simulations

Global effects are summarized in Table 1. The base case 2020/1990 ratios for production, area, trade, and prices are summarized by commodity. 2020/1990 price ratios are reported for the four policy scenarios plus a "worst-case" scenario.

The base case production scenarios show that global crop production will increase by approximately 60% by 2020. Area planted to crops will expand by roughly 10%. [This includes multiple cropping so area in crops will expand by roughly 5% (mostly in Africa—see below).] Most production gains will come from yield gains. These yield gains are roughly similar to the post-Green Revolution period gains.

Animal production will increase more than crop production and most of this increase will be caused by increased animal units. For beef, this indicates a significant increase in pasture land.

World trade will increase for all commodities and this will take the form of increased exports by developed countries and increased imports by developing countries (see Table 2).

Base case price projections indicate continued declines in world prices for all commodities. These projected declines are highest for rice and other grains. Table 1 also includes four policy scenarios for price ratios, and these can be directly compared with the base case price scenario. The first is the "Demographic Gift" scenario. This scenario has large price effects (note that the gift is temporary and would hold only for this period). Because of reduced demand (number of consumers), prices will fall further than base case prices for all commodities.

[**] Altieri, M. A. (1997) *The CGIAR and Biotechnology: Can the Renewal Keep the Promise of a Research Agenda for the Rural Poor?* Paper submitted for consideration by participants of consultation on biotechnology called by Consultation Group for International Agricultural Research (CGIAR) Chairman, April 18, 1997, Washington, DC.

Table 1. Global base case and policy scenarios by commodity

	Base case 2020/1990 ratios				Policy–price 2020/1990 ratios					
Commodity	Production	Area	Trade	Prices	Demographic gift	Delayed industrialization	IARC phaseout	Delayed biotechnology	Global warming	Worst case
Wheat	1.58	1.06	1.62	.85	.68	.90	.96	.94	.86	1.16
Maize	1.56	1.13	1.36	.77	.62	.81	.85	.90	.78	1.03
Rice	1.66	1.07	1.70	.80	.62	.86	.95	.96	.81	1.17
Other grains	1.48	1.09	1.60	.75	.63	.81	.85	.82	.75	1.04
Soybeans	1.77	1.14	2.20	.90	.84	.91	.91	.92	.91	.98
Roots/tubers	3.28	1.15	1.30	.82	.66	.86	.93	.95	.84	1.09
Beef	1.53	1.35	2.87	.94	.85	1.01	1.00	.95	.95	1.31
Pork	1.83	1.53	1.64	.90	.83	1.04	1.06	.91	.91	1.38
Mutton	1.98	1.36	1.84	.96	.89	.99	1.02	.97	.98	1.13
Poultry	1.80	1.53	3.27	.90	.83	.92	.94	.91	.90	1.01
Eggs	1.92	1.06	5.81	.75	.68	.75	.75	.76	.75	.75
Milk	1.53	1.15	3.60	.93	.83	.93	.93	.93	.93	.93

Delayed industrialization, on the other hand, will mean that prices will be higher than in the base case (by roughly 5%–6%). This is because of reduced private-sector R&D spillovers to agriculture. Reduced IARC–NARs support will have a larger impact on prices than delayed industrialization. Prices will be roughly 10%–15% higher than in the base case. Delayed biotechnology for developing countries also has significant price effects. These are similar to the reduced IARC–NARs support effects for crops but are smaller in magnitude than for livestock products. Global climate change effects are quite small (but see local effects, below). Price effects are only 1%–2% above the base case.

Table 2. Base case—all cereals

	Growth rates (%) 1993–2020					
Countries/regions	Area/no.	Yield	Production	Demand	Food	Feed
United States	0.12	0.96	1.08	0.81	0.64	0.84
Western Europe	0.04	0.42	0.46	0.39	0.10	0.53
Japan	−0.49	−0.03	−0.52	0.29	−0.05	0.62
Australia	0.12	1.75	1.88	1.01	0.84	1.07
Other developed	0.07	1.09	1.16	1.07	1.16	0.99
Eastern Europe	0.09	1.02	1.11	0.24	−0.19	0.43
Former USSR	0.04	1.18	1.22	0.49	−0.06	0.73
Latin America	0.44	1.37	1.82	1.63	1.35	1.92
Nigeria	1.20	1.35	2.56	2.85	2.92	2.11
Northern Africa	0.99	1.55	2.56	3.14	3.15	2.27
Central-West Africa	1.38	1.77	3.18	3.06	3.08	2.65
Southern Africa	1.19	2.26	3.48	2.87	2.90	2.21
Eastern Africa	1.25	1.77	3.05	2.86	2.90	2.28
Sub-Saharan Africa	1.17	1.67	2.86	2.96	3.00	2.25
West Asia–North Africa	0.11	1.85	1.96	1.97	1.94	2.12
India	0.07	1.42	1.49	1.53	1.48	3.04
Pakistan	0.19	1.54	1.73	2.92	2.92	2.96
Bangladesh	0.02	1.36	1.39	1.65	1.65	2.41
Other South Asia	0.12	1.72	1.84	2.73	2.74	2.61
Indonesia	0.09	0.98	1.07	1.44	1.18	3.34
Thailand	−0.07	1.00	0.93	1.39	0.45	2.77
Malaysia	−0.04	1.00	0.95	2.22	1.96	2.48
Philippines	0.10	2.06	2.17	2.26	1.88	3.00
Vietnam	0.00	1.41	1.41	1.43	1.41	2.29
Myanmar	0.35	1.58	1.93	1.39	1.37	2.62
Other Southeast Asia	0.14	2.22	2.37	2.14	2.14	2.07
China	0.02	0.98	1.00	1.32	0.58	3.22
Other East Asia	−0.47	0.84	0.36	1.57	0.67	2.49
South Asia	0.08	1.43	1.51	1.76	1.72	2.99
South Asia (excluding India)	0.11	1.50	1.61	2.42	2.42	2.88
Southeast Asia	0.08	1.30	1.38	1.61	1.34	2.94
East Asia	0.00	0.98	0.98	1.34	0.59	3.13
Asia	0.05	1.16	1.22	1.51	1.14	3.09
Developed	0.06	0.94	1.00	0.57	0.19	0.71
Developing	0.29	1.20	1.49	1.71	1.43	2.63
World	0.20	1.06	1.27	1.27	1.21	1.40

The "worst-case" calculation is the sum of the delayed industrialization, reduced IARC–NARs, delayed biotechnology, and climate change effects. In this worst case, prices of most crops will rise over the 1990 levels but not sufficiently to qualify as a "world food crisis." Global effects, however, are really quite misleading for policy analysis as Tables 2, 3, and 4 show. In Table 2, base case growth rates for the 1993–2020 period for cereal crop area, yield, production demand, and food and feed demand are projected by country/region. Trade effects are the difference between demand and production. We first note that area expansion is projected to be low in most developing countries (negative in some). Area expansion will be high in most Sub-Saharan African countries because these countries have land on which to expand. This will have biodiversity habitat effects.

Yield projections are actually higher for developing countries than for developed countries, reflecting the fact that they have more "catch-up" potential. Production growth rates exceed demand growth rates for most developed countries (excluding Japan). This means that exports will grow at substantial rates. For most developing countries, demand growth exceeds production growth. Because of large area expansion rates, Sub-Saharan Africa countries will not have large import growth, however.

Table 3 reports the area, yield, and trade 2020/1990 ratios relative to the base case for cereals by country/region for the climate change and biotechnology delay scenarios. Here we note that the local effects of climate change are important even though global effects were not. In particular, climate change has minor area effects for developed countries, but significantly increased cereals area in a number of South–Southeast Asian regions. Cereal yields will be higher in developed countries (by 1.63%) and lower in developing countries (by 1.38% including China, where they will rise). This means that climate change will produce more exports by developed countries and imports by developed countries.

The biotechnology delay local effects are roughly similar to the climate change effects (recall that the base case effects were also important). Delayed biotechnology diffusion will lead to increased area cropped in all regions except the U.S.

Table 3. Cereals: Area, yield, and trade simulations by region relative to the base case

	% change climate change scenario			% change delayed biotechnology		
	Area	Yield	Trade	Area	Yield	Trade
United States	.0000	.0134	.0442 (X)	−.0018	.0006	.0532 (X)
Western Europe	.0000	.0147	.0801 (X)	−.0003	.0012	−.0088 (X)
Eastern Europe	.0004	.0005	.0082 (X)	.0072	.0097	.2553 (X)
Former USSR	.0004	.0279	.3955 (X)	.0098	.0103	.5187 (X)
Japan	.0000	.0275	.0076 (−I)	.0014	.0011	.0070 (I)
Developed	.0003	.0163	.0816	.0059	.0024	.0846 (X)
Latin America	.0007	−.0203	−.2217 (I)	.0131	−.0258	−.0939 (I)
Sub-Saharan Africa	−.0004	−.0558	−.1112 (I)	.0074	−.0206	−.0282 (I)
West Asia–North Africa	.0011	−.0370	−.0947 (I)	.0180	−.0216	−.0183 (I)
India	−.0002	−.0354	−.1132 (I)	.0012	−.0238	−.0500 (I)
Pakistan	.0006	−.0367	−.0807 (I)	.0027	−.0221	−.0202 (I)
Bangladesh	.0042	−.0299	−.1494 (I)	.0159	−.0193	−.0406 (I)
Indonesia	.0028	.0063	.0571 (I)	.0097	−.0255	−.0353 (I)
Thailand	.0071	−.0341	−.1374 (X)	.0236	−.0266	−.0092 (I)
Philippines	.0014	−.0337	−.1062 (I)	.0080	−.0206	−.0164 (I)
Vietnam	.0038	−.0303	−.2521 (X)	.0147	−.0191	−.0122 (X)
China	.0002	.0154	.0831 (I)	.0023	−.0292	−.3196 (I)
Developing	.0007	−.0138	−.0816 (I)	.0080	−.0259	−.0846 (I)

and Western Europe. This will have deleterious habitat consequences. Yields will be higher in developed countries and lower in developing countries. Developed country exporters will export more. Developing country importers (including China) will import more.

Table 4 reports effects of an important local welfare index in developing countries, the proportion of children 0–6 years of age who exhibit some degree of malnourishment (see *Appendix* for more details). First, note that this measure shows great variability in 1990 by region. The base case projections show that the percentage malnourished children will decline from 34% in 1990 to 25% in 2020 (from 1960 to 1990 it fell from 45% to 34%). This is a favorable projection, although it does vary by region (falling least in East Africa). Clearly, however, in 2020 serious local problems will remain, and they form the basis for "local food crises" even if a global food crisis is unlikely to occur.

The policy scenarios show that reduced research support, delayed industrialization, delayed biotechnology, and climate change will delay progress in reducing malnutrition. The "global" effects are small, but local effects for some countries, e.g., Bangladesh and Nigeria, are significant.

VI. Policy Implications

Global effects of alternative policies are very poor guides to policy regarding investments and regulations affecting population and food supply. Local effects are more relevant.

The simulations reported here do show that population policy can be very effective in increasing income and reducing

Table 4. Malnourished children simulation [percentage childlren (0–6) malnourished]

				Reduced research support			
Countries/ regions	1990	Base case 2010	2020	IARC NARs 2020	Biotech delay 2020	Delayed industrialization 2020	Global warming 2020
Latin America	20.40	16.91	14.05	14.47	14.09	14.3	14.05
Nigeria	35.4	30.79	29.52	30.21	29.86	29.89	30.90
North Africa	31.40	29.08	27.93	28.92	28.23	28.48	31.09
Central and West Africa	22.70	22.44	21.10	21.62	21.42	21.37	21.23
South Africa	24.80	22.43	21.24	21.83	21.56	21.54	21.21
East Africa	25.50	25.47	24.77	25.35	25.03	25.08	24.81
West Asia–North Africa	13.40	11.56	9.70	10.05	9.68	9.88	9.67
India	63.00	51.25	45.49	46.91	45.70	46.22	45.49
Pakistan	41.60	36.62	32.40	33.35	32.64	32.91	32.38
Bangladesh	65.80	59.20	52.85	58.12	53.86	55.55	53.14
Other South Asia	37.00	31.62	26.59	27.83	26.90	27.22	26.80
Indonesia	14.00	10.05	7.74	8.01	7.85	7.90	7.78
Thailand	13.00	7.32	5.23	5.33	5.26	5.35	5.25
Malaysia	17.60	12.41	9.88	10.05	10.00	10.06	9.91
Philippines	33.60	25.81	21.29	22.66	21.72	22.24	21.43
Other Southeast Asia	40.00	35.69	32.78	35.21	32.98	34.15	33.11
China	21.80	15.30	13.78	14.26	13.79	14.24	13.78
South Asia	58.50	47.68	41.37	43.03	41.60	42.22	41.40
Developing	34.30	28.01	25.40	26.33	25.83	26.00	25.50

Appendix Table A1. Industrialization ITI projections

Country	95–00	00–05	05–10	10–15	15–20
United States	D				
EC12	D				
Japan	D				
Other Western Europe	D				
Canada	D				
Australia	D				
New Zealand	D				
Other Developed	D				
Eastern Europe	2B	2C	D		
Russia	2B	2C	D		
Mexico	2B	2C	2C	D	
Brazil	2B	2C	2C	D	
Argentina	2B	2C	2C	2C	2C
Other Latin America	2A	2B	2B	2C	2C
Nigeria	1C	1C	2A	2B	2C
Other Africa	1B	1B	1C	2A	2B
Egypt	2A	2B	2C	2C	D
Other Near East	1C	2A	2B	2B	2B
India	2A	2B	2C	2C	2C
Pakistan	1C	1C	2A	2B	2C
Indonesia	2B	2C	2C	2C	2C
Thailand	2C	2C	2C	D	
Malaysia	2C	2C	2C	D	
Philippines	2A	2B	2C	2C	2C
China and Taiwan	2C	2C	2C	D	
Singapore	2C	D			

poverty, provided the demographic gift is accompanied by effective food supply policy and investment and more generally by effective technology policy. Although it is probably the case that the coercion-based demographic gift in China is now yielding high dividends, it is not at all clear that coercion is justified in other countries. Certainly it is not justified in countries unprepared to support the gift with effective economic policy.

In the past 40 years, an effective system of agricultural research centers has been built. This system has enabled the very favorable global effects realized over these years. Most local effects have also been positive, although given the starting points, indexes of poverty and malnutrition remain high in many countries in spite of local progress. The simulations reported here indicate that it is vital for local progress to continue. Shifts in the objectives of research systems and delays in bringing research technology to developing countries have high prices in terms of delayed progress on poverty reduction and land use. Without continued research to improve crop productivity, cropped area will expand, with biodiversity habitat implications.

Appendix: The IFPRI–IMPACT Model Base Case

IMPACT, developed at the IFPRI, is a partial equilibrium model covering 17 commodities and 35 countries/regions. It computes global equilibriums in real prices and is synthetic, in that it uses price elasticities and nonprice parameters from other studies. The model incorporates nonagricultural sector linkages but does not compute equilibriums for markets other than the 17 commodities.

Each country/region submodel has a set of equations for supply, demand, and prices for each commodity and for intersectoral linkages with the nonagricultural sector. Crop

Appendix Table A2. Internal rate of return estimates summary

	Number of IRRs reported	Percent distribution						Approx. median IRR
		0–20	21–40	41–60	61–80	81–100	100+	
Extension								
Farm observations	16	.56	0	.06	.06	.25	.06	.18
Aggregate observations	29	.24	.14	.07	0	.27	.27	.80
Combined research and extension	36	.14	.42	.28	.03	.08	.06	.37
By region								
Developed countries	19	.11	.31	.16	0	.11	.16	.50
Asia	21	.24	.19	.19	.14	.09	.14	.47
Latin America	23	.13	.26	.34	.08	.08	.09	.46
Africa	10	.40	.30	.20	.10	0	0	.27
All extension	81	.26	.23	.16	.03	.19	.13	.41
Applied research								
Project evaluation	121	.25	.31	.14	.18	.06	.07	.40
Statistical	254	.14	.20	.23	.12	.10	.20	.50
Aggregate programs	126	.16	.27	.29	.10	.09	.09	.45
Commodity programs								
Wheat	30	.30	.13	.17	.10	.13	.17	.51
Rice	48	.08	.23	.19	.27	.08	.14	.60
Maize	25	.12	.28	.12	.16	.08	.24	.56
Other cereals	27	.26	.15	.30	.11	.07	.11	.47
Fruits and vegetables	34	.18	.18	.09	.15	.09	.32	.67
All crops	207	.19	.19	.14	.16	.10	.21	.58
Forest products	13	.23	.31	.68	.16	0	.23	.37
Livestock	32	.21	.31	.25	.09	.03	.09	.36
By region								
Developed countries	146	.15	.35	.21	.10	.07	.11	.40
Asia	120	.08	.18	.21	.15	.11	.26	.67
Latin America	80	.15	.29	.29	.15	.07	.06	.47
Africa	44	.27	.27	.18	.11	.11	.05	.37
All applied research	375	.18	.23	.20	.14	.08	.16	.49
Pretechnology science	12	0	.17	.33	.17	.17	.17	.60
Private sector R&D	11	.18	.09	.45	.09	.18	0	.50
Ex ante research	83	.11	.36	.16	.07	.01	.05	.44

production is determined by area and yield response functions. Area functions include price responses and a nonprice trend reflecting remaining land availability and technology. Yield is a function of the price of commodity and prices of inputs, and a total factor productivity change term. Livestock commodities are similarly modeled.

Domestic demand is the sum of food, feed, and industrial use demand. Food demand is a function of prices (of all commodities), per capita income, and population. Country-specific population in growth rates are based on U.N. projections (1) Income growth is partially endogenous to the model and agriculture–nonagriculture links are specified. Feed and industrial use demands are derived from final demands.

Prices are endogenously determined. Domestic prices are linked to global equilibrium prices via exchange rates, and producer–consumer subsidies and trade restrictions are allowed. Other policy instruments (acreage restrictions) are considered. Trade is determined by net supply–demand equilibrium conditions.

Malnourished children projections for children (ages 0–6 years) are based on weight-for-age standards set by the U.S. National Center for Health Statistics. Data for 61 developing countries for 1980, 1985, and 1990‡ were used to link malnourished children proportions to per capita calorie consumption (determined in the model).

The nonprice total factor productivity terms are based on a study of Indian productivity (2), a classification of industrial technological infrastructure (5), and a study of rates of return to agricultural research and extension (R.E.E., unpublished data).

The ITI classification of Evenson and Westphal (5) included the following classes:

Class 1A: Traditional ITI. Economics lack basic infrastructure. Government influence limited.

Class 1B: First emergence. Some direct foreign investment.

Class 1C: Partial modernization. Agricultural sector well developed. No R&D in producing firms.

Class 2A: Mastery of conventional technology. Market skills well developed. R&D in firms.

Class 2B: Transition to modern capacity. Reverse engineering capacity, sciences developed.

Class 2C: Export competitiveness, adaptive invention, intellectual property rights developed.

Class D: Developed country capabilities. *Appendix* Table A1 reports the ITI projections used in the base case. Evenson (R.E.E., unpublished data) reviews the rates of return studies used in constructing the base case. These rates of return are summarized in *Appendix* Table A2. The relative median rate of return ratios for commodities and regions were used to scale nonprice terms to the rice base case terms.

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