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Final report

project	**Exploring alternative futures for agricultural knowledge, science and technology (AKST)**
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1 Background and scope of the study

The current levels of impoverishment in many agriculturally-dependent economies can often be related to stagnating productivity in the cropping, livestock husbandry, and fishery sectors. At the same time, the pathways through which agricultural knowledge, science and technology (AKST) have acted in the past to reduce hunger and poverty remain highly uncertain, due to the high complexity and confluence of factors involved. Even more importantly, policymakers lack clear guidance on the relative merits and potential future role, contribution, and impacts of alternative AKST policies to enhance the food and nutrition security of the rural poor.

Although experts agree that agricultural knowledge, science, and technology has played a crucial role in reducing hunger and poverty in the past, future pathways are highly uncertain, as are the relative impacts of alternative pathways on food and nutrition security of the rural poor. Uncertainties relate to many factors, including the key drivers for future well-being, such as population and economic growth, but also to changes in the socio-political environment, in ecosystem health, and to agricultural technologies, including technological advances, technology transfer, and adoption; to the role of and changes in institutions affecting agricultural science and technology policy; and to the level of investments available for the sector.

The topic is of primary importance to the agricultural research community and policymakers in the agriculture sector as it will examine how agricultural technologies and underlying policies can impact positively upon hunger and poverty in the long term.

The overall goal of this project was to provide policymakers with options of alternative policies and investments for agricultural knowledge, science and technology based on the analysis of alternative development paths and their implications for food security, rural development, and environmental sustainability. A range of recent global assessments provide information on plausible future developments regarding agricultural production systems and their driving forces; however, no assessment has explicitly focused on the future role of AKST.

The objectives of the project were: 1) to develop 4-5 alternative development paths or scenarios for agriculture and related KST policies out to 2050; 2) to develop quantitative scenario results using the models proposed for this project; 3) to analyse the results of both quantitative and qualitative scenario outcomes and to develop implications for investment based on these outcomes; 4) to analyse the economy-wide implications of trade and subsidy policies within these scenarios; and 5) to disseminate research results.

Specific outputs from this project included:

- An accounting of the major shifters that influence the enhancement of AKST and productivity growth, together with the International Assessment of Agricultural Science and Technology for Development (IAASTD) initiative

- Descriptive narratives that lay out alternative types of agriculture and associated growth pathways through which KST acts to influence productivity, together with IAASTD[1]
- Quantified scenario results for the alternative scenarios based on the suite of national-and regional/global level models used in this project
- Analysis of implications for investment from scenario results
- Analysis of the economy-wide implications of trade and subsidy policies within the scenarios
- A series of scholarly publications and policy briefs describing our research methodology, results and policy conclusions
- Policy workshops in China, India, and Australia to discuss the results and implications
- Outreach impacts, including policy briefs and dissemination through the 2020 IFPRI, network, through CCAP, and through NCAER, as well as through IAAE and the ABARE outlook conferences in Australia, etc. and tangible synergies and further outreach through our collaboration with IAASTD.

The project was implemented in close collaboration with the International Assessment of Agricultural Science and Technology for Development (IAASTD) (www.agassessment.org), which attempted to assess the effects of agricultural KST policies and to identify important information gaps to target research more effectively and to further the capacity of developing country nationals and institutions to generate, access, and use agricultural KST for sustainable development. The relationship with IAASTD allowed the project to tap into the expertise of several hundred scientists and policymakers who participated in the assessment, and will also help research results to be widely distributed. Objectives 1-3 directly supported both ACIAR and IAASTD, while objectives 4-5 focused on ACIAR specific topics (see also Figure 1).

A significant change in project implementation was required at the end of 2006 when the Costa Rica IAASTD Bureau meeting decided to abandon the approach of using 4-5 separate storylines that would be modelled separately. As a result, the storylines and modelling results for these storylines were replaced with the development of a reference run/baseline together with accompanying policy experiments. This approach was also maintained for this project.

The results presented here are related to and based on the IAASTD analysis, but the regional aggregation chosen is different from the IAASTD regions and therefore regional and developing-country values might differ from the results presented in Chapter 5 of the IAASTD assessment. An accounting of the major shifters that influence the enhancement of AKST and productivity growth (Objective 1 of this project) was developed together with the International Assessment of Agricultural Science and Technology for Development (IAASTD) initiative (Chapter 4 of the assessment).

The following sections include results for these analyses. The IAASTD Chapter 5 includes a wider range of analyses and incorporates a combined analysis of these objectives.

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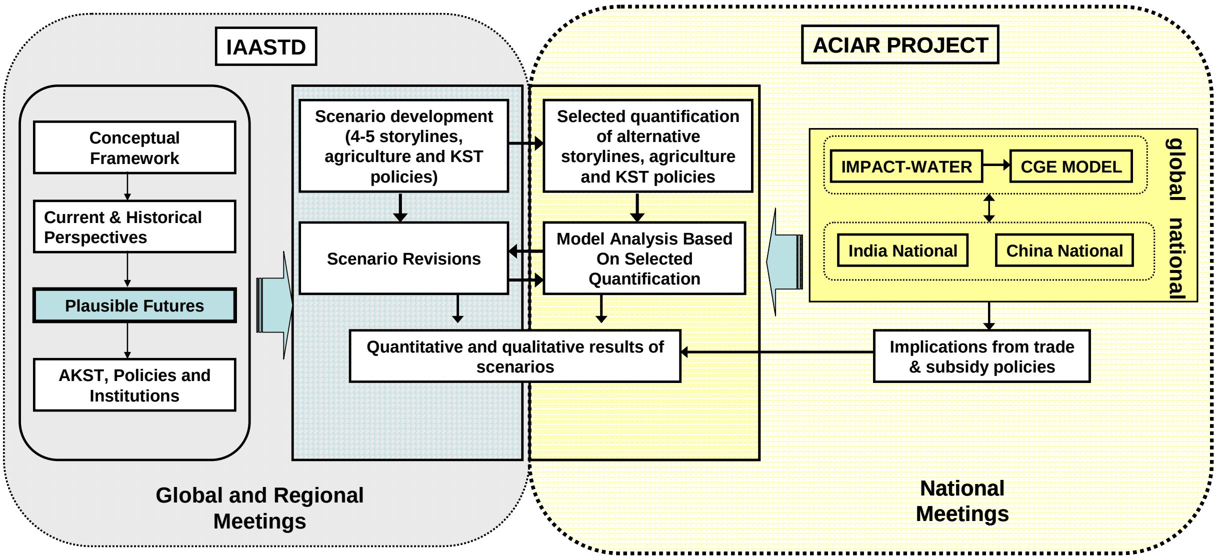
[1] *Separate storylines were developed in 2005/2006. They were subsequently abandoned in November 2006 as a result of an IAASTD Bureau decision.*

Figure 1: Synergy between KST Project and IAASTD Assessment Activities



2 Drivers that influence the future of AKST

Drivers that influence the future of AKST were developed together with the authors of Chapter 4 of the IAASTD assessment. A driver is any natural or human-induced factor that directly or indirectly influences the future of agriculture. Categories of indirect drivers include changes in demographic, economic, socio-political, scientific and technological, cultural and religious and biogeophysical change. Important direct drivers include changes in food consumption patterns, natural resource management, land use change, climate change, energy and labor. Changes in these drivers affect both public and private spending on AKST and the role that community and local actors have in AKST. Based on an assessment of how these drivers are handled in the literature, the following was found: Population is expected to increase over the next 50 years by about 2-3 billion people. Moreover, ongoing urbanization, and changing life patterns are also expected to lead to a strongly increasing demand for food and pressure on the agricultural system. In most scenario exercises, international trade in agricultural commodities is expected to increase with developing countries increasing net imports, on aggregate. While difficult if not impossible to capture in quantitative scenario exercises, democratization, decentralization and other sociopolitical developments are crucial in shaping agricultural policy choices. Existing assessments project a combination of intensification of agricultural production and expansion of cultivated land to meet increasing demands for food, feed, fiber and fuel. A major uncertainty in the scenarios presented in these assessments results from the degree of extensification versus intensification in agricultural production. New developments in AKST are expected to focus on increases in efficiency in the entire food production chain. Recent scenario exercises indicate a major increase in bioenergy production; in the medium term this might lead to a tradeoff between energy security and food security, especially for the poor. Several scenarios, in particular those that emphasize climate policy and energy security, indicate that agriculture may become an important producer of bioenergy with potential adverse impacts on land availability for food production, possibly increasing, even in the long-term, food prices and decreasing biodiversity. Most assessments also expect higher energy prices. These higher prices (and possible changes in energy subsidies) are likely to encourage the use of more energy-efficient technologies in agricultural production as well as in processing and distributing food. Existing assessments indicate that while agriculture is a major contributor to global environmental change - such as land degradation, nutrient pollution, biodiversity loss, decreasing surface and groundwater availability and climate change - it will also have to adapt to these changes. Existing assessments expect agriculture to increasingly be affected by global warming and changes in climate variability. For agriculture, changes in seasonal variability and extreme events are even more important than changes in mean temperature and precipitation. Recent studies, such as presented in IPCC's Fourth Assessment Report, indicate that negative impacts on agriculture tend to concentrate in low-income regions. In temperate regions impacts could result in net positive yields. Developments in AKST will determine the capacity of food systems to respond to the likely climate changes. Agriculture is also a source of greenhouse gas emissions and therefore agriculture can play a significant role in mitigation policies. In order to play this role, new AKST options for reducing net emissions of carbon dioxide, methane and nitrous oxide need to be developed. Trends observed over the last decade, as described in existing scenario exercises, show that the share of employment in agriculture is declining and this trend is expected to continue. Agricultural labor productivity is expected to increase as a result of improved mechanization and developments in AKST that are responsive to emerging agricultural and food systems. In developed countries, investment in traditional agricultural disciplines has often declined in favor of emerging research areas such as plant and microbial molecular biology, information technology and nanotechnology. However, recent food price increases will likely help fuel investment in direct agricultural productivity enhancements.

3 Models used in the study and quantitative modelling assumptions

3.1 Models used in the Study

Two types of models were used for the study: Partial agricultural equilibrium models and computable general equilibrium (CGE) models. Both types of models were used for analyses at the national (India and China) and regional/global levels. The partial equilibrium agricultural sector model International Model for Policy Analysis of Agricultural Commodities and Trade, or IMPACT (Rosegrant et al., 2002) was used for insights into long-term changes in food demand and supply at a regional level, taking into account changes in trade patterns using macroeconomic assumptions as an exogenous input. The CGE model GTEM of ABARE (Ahammad and Mi, 2005) was used to validate the GDP and population input data to achieve cross-sectoral consistency and to implement trade analysis. Moreover, GEN-CGE was used for India, (Sinha et al., 2003) and the Chinese Agricultural Policy Simulation Model (CAPSiM) (Huang and Li, 2003) was used for China. India and China were chosen since future policy change in these two countries will affect global food supply, demand, prices, and food security. Moreover, China- and India-specific modeling tools are used to provide deeper insights about specific development goals such as the distributional aspects of equity and poverty which cannot be addressed by global models.

In addition, the IAASTD analyses used the integrated assessment model IMAGE 2.4 (Eickhout et al., 2006), as well as the EcoOcean model for marine biodiversity and the GLOBIO3 model (Alkemade et al., 2006) for terrestrial biodiversity, the livestock spatial location-allocation model, SLAM, (Thornton et al., 2002, 2006) for a more detailed livestock assessment and WATERSIM (de Fraiture et al., 2006) for a more specific water focus.

3.2 Baseline Quantitative Modeling Assumptions

The reference case imagines a world developing over the next decades as it does today, without anticipating deliberate interventions requiring new or intensified policies in response to the projected developments. Current policy pathways are expected to continue out to 2050. The key assumptions of the reference case involve the following:

- Population: The baseline (as well as alternative policy experiments) uses the UN medium variant projections (United Nations, 2005) with global populations increasing from slightly more than 6.1 billion in 2000 to over 8.2 billion in 2050. [2] Most of the growth is concentrated in middle-income and low-income countries like Brazil, India, China and Russia while population growth continues to slow in high-income countries. Population growth drives changes in food demand and is an indirect driver for AKST.

[2] *To model exogenously determined population growth, the GTEM demographic module that determines the evolution of a region's population and, hence, the labor supply, has been turned off.*

- Overall economic growth: Economic growth assumptions are loosely based on the TechnoGarden scenario of the Millennium Ecosystem Assessment (MEA, 2005). Incomes are expressed as MER-based values. The economic growth assumptions of the TechnoGarden scenario are near the mid-range growth scenarios in the literature for the world as a whole and most regions. In some regions the scenario is a relatively optimistic scenario (e.g., sub-Saharan Africa).
- Agricultural productivity: Agricultural productivity values are based on the Millennium Ecosystem Assessment (MEA) (TechnoGarden scenario) and the recent FAO interim report projections to 2030/2050 (FAO, 2006). MEA assumptions have been adjusted from the TechnoGarden scenario assumptions to allow for conformity to FAO projections of total production and per-capita consumption in meats and cereals, and to our own expert assessment. The main recent developments regarding technological change with continued slowing of growth overall have been taken into account. Growth in numbers and slaughtered carcass weight of livestock has been adjusted in a similar fashion.
- Non-agricultural productivity: In the reference case, in general, productivity growth is projected to be lower in non-agricultural sectors than in agricultural sectors. The non-agricultural GDP growth rates are likewise based on the MEA TechnoGarden scenario but with adjustments to align with World Bank medium-term projections. While the relatively higher productivity in agriculture reflects largely the declining trends in the agricultural terms of trade, this is not translated into higher output growth in agricultural sectors relative to non-agricultural sectors. This broadly conforms Engel's law which states that the budget share of food falls with increasing income.

Disparities in growth rates among countries in the developing world are projected to continue to remain high while more developed regions will see more stable growth. Developed regions will see relatively low and stable to declining growth rates between 1 and 4 percent per year out to 2050. The Latin America region is also expected to experience stable growth rates through the projection period, though slightly higher than for developed regions between 3.5 and 4.5 percent per year out to 2050. GPD growth in East and Southeast Asia is expected to be stable, with relatively high rates of 4 to 7 percent per year. In particular, China's economy is projected to slow from the 10 percent growth in recent years to a more stable rate of 5.6 percent per year on average out to 2050. On the other hand, growth in South Asia following the strong reforms and initiatives focusing on macroeconomic stabilization and market reforms is expected to lead to projected improved income growth in that sub-region of 6.5 percent per year out to 2050. The MENA (Middle East and North Africa) region is expected to see GDP growth rates averaging 4 percent per year out to 2050.

Growth in sub-Saharan Africa (SSA) has been low in the recent past, but there is much room for recovery, which is projected to lead to modest to strong growth averaging just under 4 percent per year. Growth in Central and Western SSA is expected to fall within the 5-6 percent range. Growth in East and Southern SSA is expected at less than 4 percent out to 2025, followed by more rapid growth of 6 to 9 percent by 2050.

- Trade policies: Trade conditions seen today are presumed to continue out to 2050. No trade liberalization or reduction in sectoral protection is assumed for the reference world.

- Climate change: Climate change is both driving different outcomes of key variables of the baseline (like crop productivity and water availability) and is an outcome of the agricultural projections of the reference run, through land-use changes and agricultural emissions, mainly from the livestock sector. Medium energy outcomes are assumed in the baseline. Therefore, the B2 scenario was used for the analysis. From the available B2 scenario, the ensemble mean of the results of the HadCM3 model for the B2 scenario was used. The pattern scaling method applied was that of the Climate Research Unit, University of East Anglia. The "SRES B2 HadCM3" climate scenario is a transient scenario depicting gradually evolving global climate from 2000 through 2100.
- Biofuels: Regarding assumptions for biofuels expansion, the baseline, based on actual national biofuel plans, assumes continued biofuel expansion through 2020, although the rate of expansion declines after 2010 for the early rapid growth countries such as United States and Brazil. Under this scenario, significant increases of biofuel feedstock demand occur in many countries for commodities such as maize, wheat, cassava, sugar and oil seeds. By 2020, the United States is projected to put 130 million metric tons of maize into biofuel production; European countries will use 10.7 million mt of wheat and 14.5 million mt of oil seeds for biofuel production; and Brazil will use 9.0 million mt of sugar equivalent for biofuel production. We hold the volume of biofuel feedstock demand constant starting in 2025, in order to represent the relaxation in the demand for food-based feedstock crops created by the rise of the new technologies that convert nonfood grasses and forest products.

4 Baseline results

4.1 Food supply and demand

In the baseline, global cereal production increases 0.9 percent per year during 2000-2050[3]. This growth is a result of rapid economic growth, slowing population growth, and increased diversification of diets. Production Growth of demand for cereals slows during 2000-2025 and again from 2025-2050, from 1.4 percent per year to 0.4 percent per year. Demand for meat products (beef, sheep and goat, pork, and poultry) grows more rapidly, but also slows somewhat after 2025, from 1.8 percent per year to 1.0 percent annually.

Changes in cereal and meat consumption per capita vary significantly among regions. Results are presented in Figures 4.1 and 4.2. Over the projections period, per capita demand of cereals as food is expected to decline by 27 kg in the East Asia and Pacific (EAP) region and by 11 kg in the Latin America and Caribbean (LAC) region. On the other hand, demand is projected to considerably increase in the sub-Saharan Africa region, at 21 kg. Per capita meat demand is projected to more than double in the South Asia and sub-Saharan Africa region; to almost double in the EAP region; and to increase by 50 percent in the MENA region. In the group of developed countries, only a minor increase—at 4 percent—is projected over the projections horizon, on the other hand, given that demand is already very higher.

Total cereal demand is projected to grow by 1,048 million metric tons, or by 56 percent; 45 percent of the increase is expected for maize; 26 percent for wheat; 8 percent for rice; and the reminder, for millet, sorghum and other coarse grains (see Figure 4.3). Rapid growth in meat and milk demand in most of the developing world will put strong demand pressure on maize and other coarse grains as feed. Globally, cereal demand as feed increases by 430 million metric tons during 2000-2050, a staggering 41 percent of total cereal demand increase. Slightly more than 60 percent of total demand for maize will be used as animal feed; and a further 16 percent for biofuels.

[3] *The year 2000 reflects a three-year moving average for 1999-2001 and 2050 reflects a three-year moving average of 2048-2050 unless noted otherwise.*

Figure 4.1: Per capita availability of cereals as food, 2000 and change 2000-2050, by region, baseline

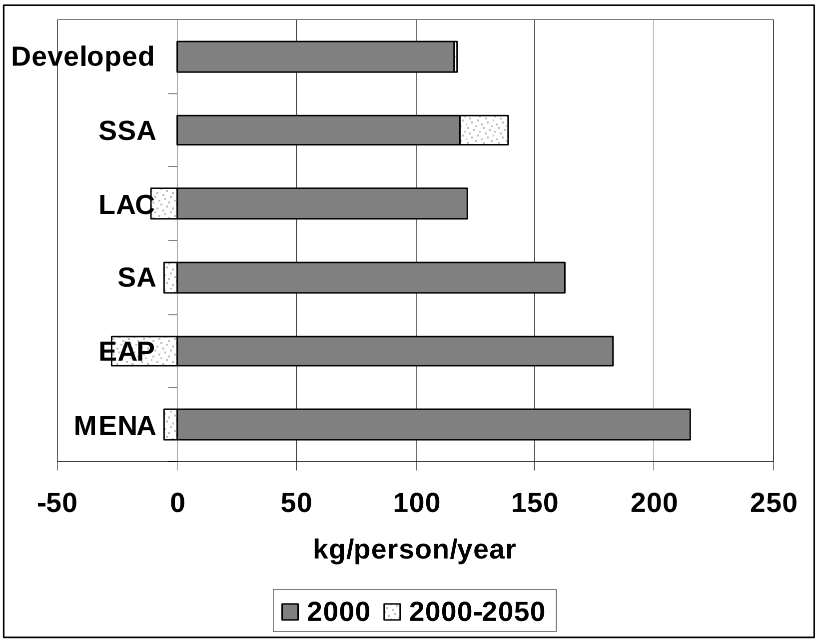


Figure 4.2: Per capita availability of meats, 2000 and change 2000-2050, by region, baseline

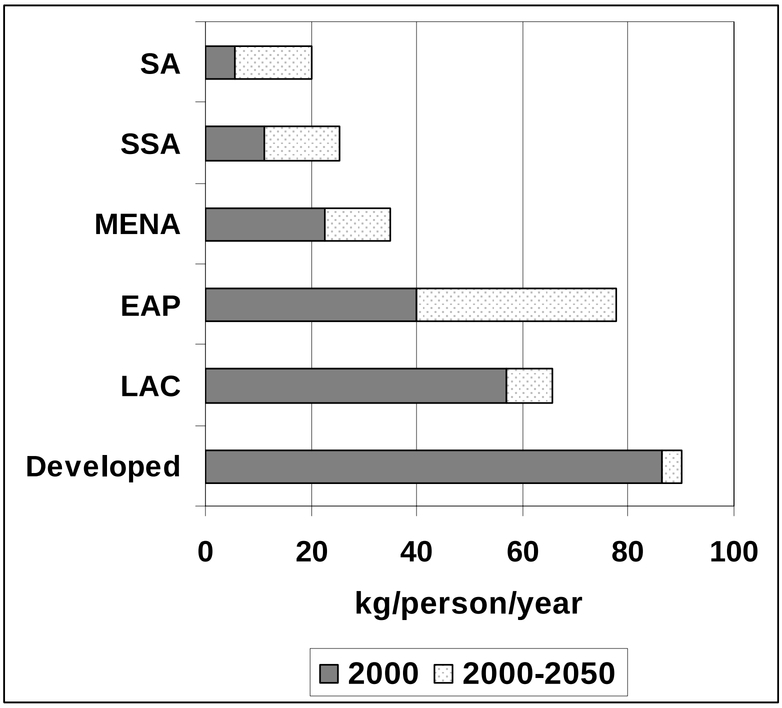
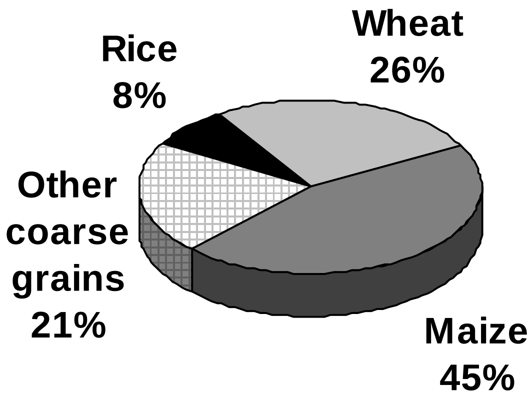


Figure 4.3: Contribution to increased cereal demand growth, 2000-2050, baseline

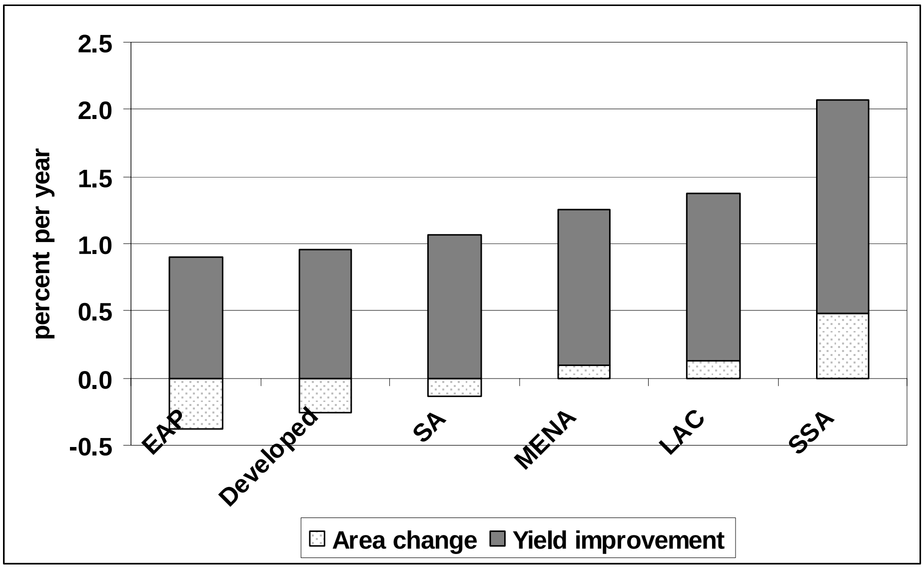


How will the expanding food demand be met? For meat in developing countries, increases in the number of animals slaughtered have accounted for 80-90% of production growth during the past decade. Although there will be significant improvement in animal yields, growth in numbers will continue to be the main source of production growth. In developed countries, the contribution of yield to production growth has been greater than the contribution of numbers growth for beef and pig meat; while for poultry, numbers growth has accounted for about two-thirds of production growth. In the future, carcass weight growth will contribute an increasing share of livestock production growth in developed countries as expansion of numbers is expected to slow.

For the crops sector, water scarcity is expected to increasingly constrain production with little additional water available for agriculture due to slow increase in supply and rapid shifts of water from agriculture in key water-scarce agricultural regions in China, India, and MENA. Climate change will increase heat and drought stress in many of the current breadbaskets in China, India, and the United States and even more so in the already stressed areas of sub-Saharan Africa. Once plants are weakened from abiotic stresses, biotic stresses tend to set in and the incidence of pest and diseases tends to increase.

With declining availability of water and land that can be profitably brought under cultivation, expansion in area is not expected to contribute significantly to future production growth. In the baseline, cereal harvested area expands from 660 million ha in 2000 to 694 million ha in 2020 before contracting to 632 million ha by 2050. The projected slow growth in crop area places the burden to meet future cereal demand on crop yield growth.

Figure 4.4: Sources of cereal production growth, 2000-2050, by region, baseline



Note: 2050 values are not three-year moving averages.

Although yield growth will vary considerably by commodity and country, in the aggregate and in most countries it will continue to slow down. The global yield growth rate for all cereals is expected to decline from 1.96 percent per year in 1980-2000 to 1.01 percent per year in 2000-2050. In developed countries, annual average cereal yield growth is estimated at 0.96 percent per year during 2000-2050; in the EAP region, at 0.90 percent per year; in the South Asia region, 1.07 percent per year. Slightly higher yield growth is expected in the MENA, LAC, and SSA regions at 1.16, 1.25, and 1.59 percent per year, respectively. As can be seen in Figure 4.4, area expansion is significant to projected food production growth only in sub-Saharan Africa (23 percent), in the LAC region (9 percent), and in MENA (7 percent).

4.2 Food trade, prices, and food security

In the last few years, real prices of food have increased dramatically as a result of changes in biofuel/climate policies, rising energy prices, declining food stocks, and market speculation. Projections reported here show that higher food price trends are likely to stay as a result of increased pressures on land and water resources, adverse impacts from climate variability and change, and rapidly rising incomes in most of Asia. Given the long-term underinvestment in agriculture, and poor government policies in response to rising food prices in many countries, it is unlikely that the supply response will be strong enough in the short- to medium-term.

Maize, soybean, rice, and wheat prices are projected to increase by 60-97 percent in the baseline, and prices for beef, pork, and poultry by 31-39 percent (Figures 4.5-4.6). Impacts of higher food prices on the net food purchasers will be substantial, depressing food demand in the longer term, increasing childhood malnutrition rates, and reversing progress made in several low-income countries in terms of nutrition and food security.

Figure 4.5: International food prices, selected cereals, 2000, and projected 2025 and 2050, baseline

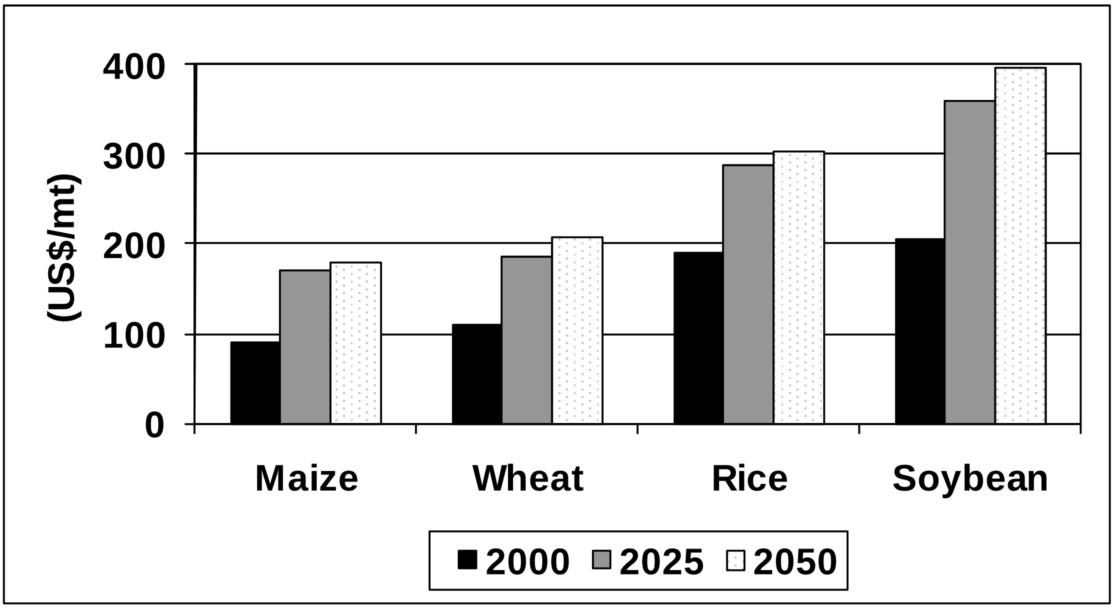
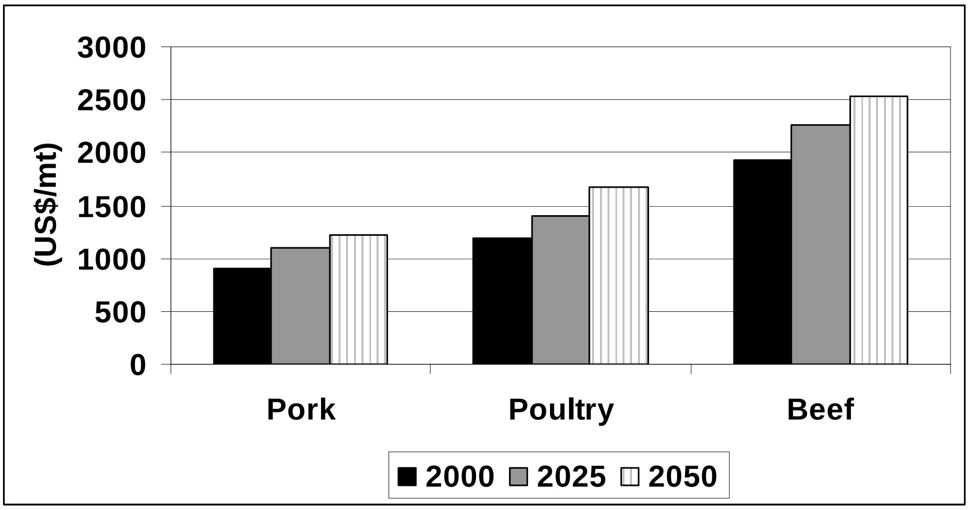
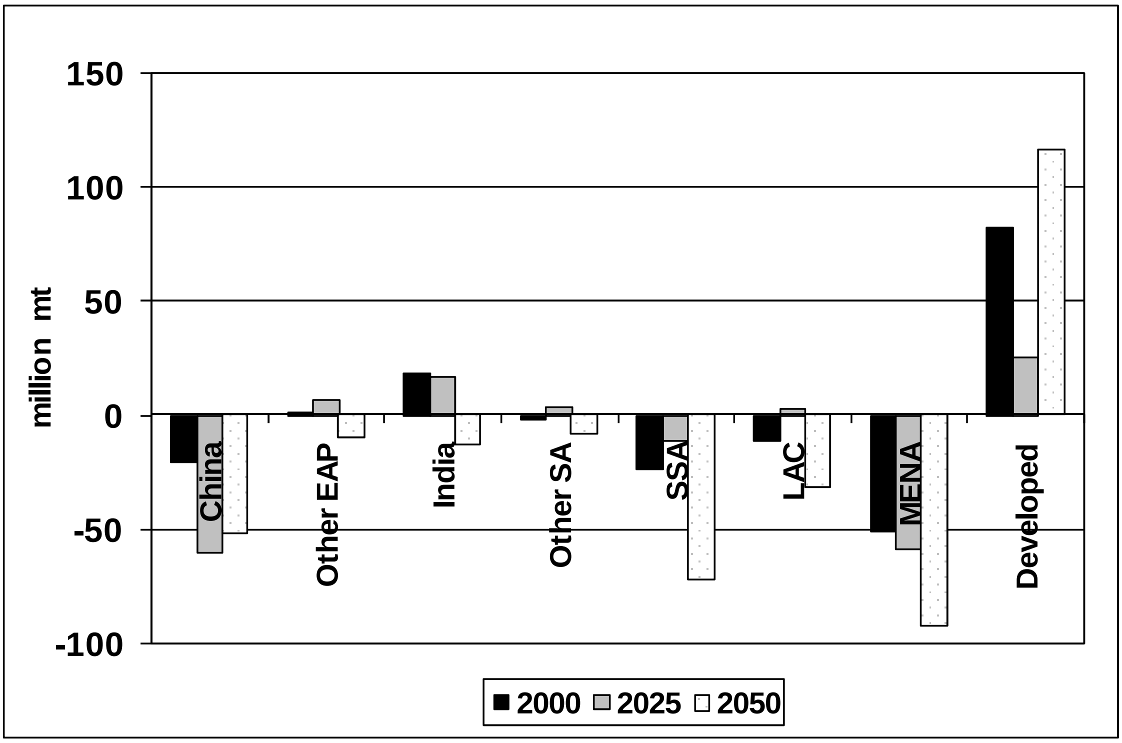


Figure 4.6: International food prices, selected livestock products, 2000, and projected 2025 and 2050, baseline



World trade in food is expected to continue to increase, with trade in cereals projected to increase from 257 million mt in 2000 to 584 million mt by 2050 with, and trade in meat products rising from 16 million mt to 64 million mt. Expanding trade will be driven by the increasing import demand from the developing world, particularly SSA, EAP, and SA, where net cereal imports will grow by more than 200 percent (Figure 4.7). Sub-Saharan Africa will face the largest increase in food import bills despite significant area and yield growth expected during the next 50 years in the baseline. By 2050, the MENA region is expected to account for 33 percent of net cereal imports; SSA for 25 percent; and China alone for 19 percent.

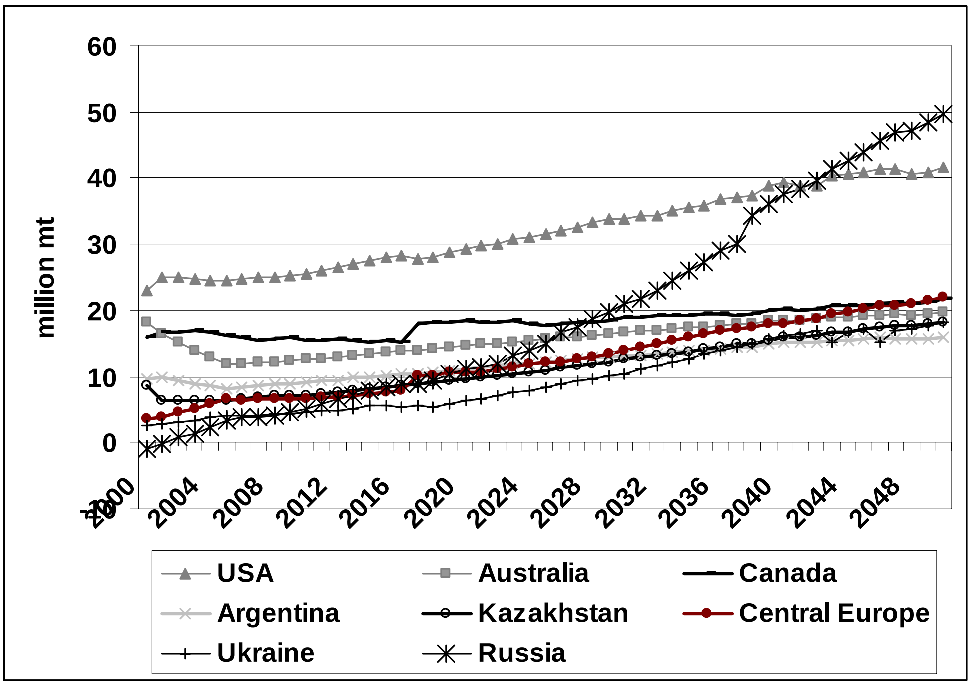
Figure 4.7: Net trade in cereals, 2000, and projected 2025 and 2050, baseline



With much of the developing countries unable to increase food production rapidly enough to meet growing demand, the major exporting countries—mostly in high-income countries and the Eastern Europe and Central Asia regions—will play an increasingly critical role in meeting global food consumption needs (Figure 4.7).

The USA and Europe provide a critical safety valve in providing relatively affordable food to developing countries. However, given the strong demand for food crops as feedstock for biofuels in the short-to-medium term, net cereal exports in these countries are projected to decline over the next decade before rebounding after food crop use for biofuel feedstock is expected to decline. For example, net maize export from the USA are expected to decline from 40 million mt in 2000 to 17 million mt in 2015 before rebounding and increasing to 62 million mt by 2025. Net wheat exports are projected to grow to 48 million mt in Russia, 41 million mt in the United States, and to around 20 million mt in Australia, Canada, Central Europe, and Kazakhstan (Figure 4.8).

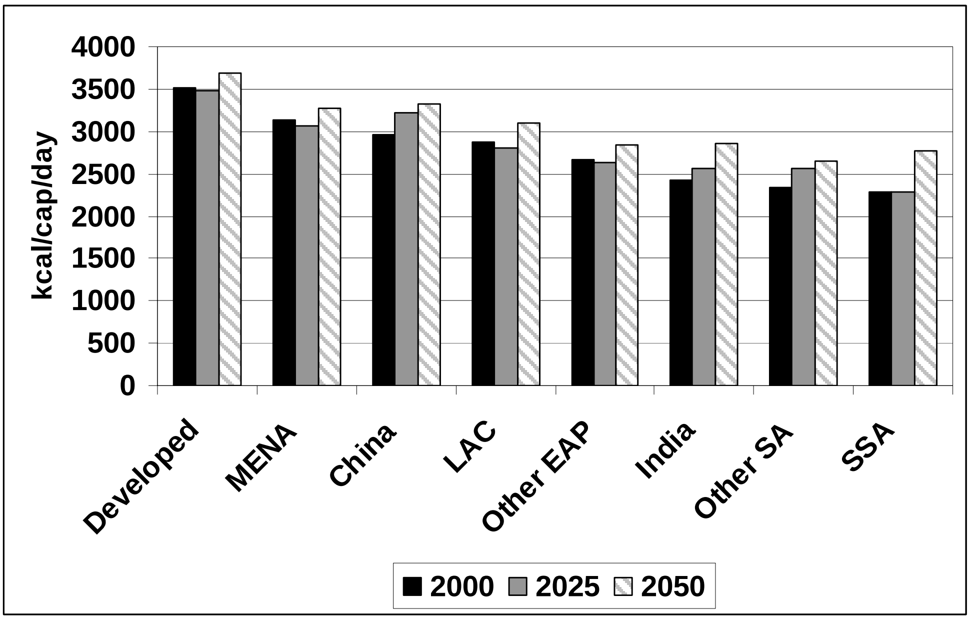
Figure 4.8: Net wheat exports, selected countries, projected 2000-2050, baseline



Net meat exports are expected to double in developed countries; and to sharply increase in the Latin American region. Net meat exports of Brazil are expected to increase by a factor of 10 over the 50-year time horizon.

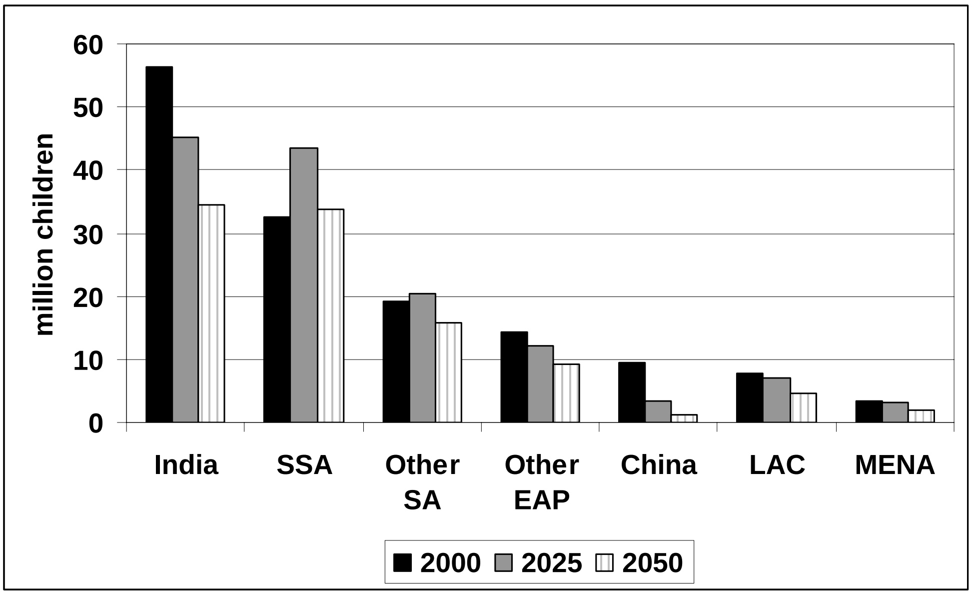
The substantial increase in food prices will slow growth in calorie consumption, with both direct price impacts and reductions in real incomes for poor consumers who spend a large share of their income on food. As a result, there will be little improvement in food security for the poor in many regions. In sub-Saharan Africa, daily calorie availability is expected to stagnate up to 2025 before slowly increasing to 2,762 kilocalories by 2050, compared to 3,000 or more calories available, on average, in most other regions. Only the Other South Asia region (excluding India) fears worse with only 2,654 kilocalories available, on average by 2050. Several regions are projected to experience declining calorie availability between 2000 and 2025. The South Asia sub-region has similar low gains in calorie availability – at 2,746 calories per capita per day by 2050. Calorie availability is expected to grow fastest in the ESAP region at 630 kilocalories over the 2000-2050 period (Figure 4.9).

Figure 4.9: Calorie availability 2000 and projected 2025 and 2050, baseline



In the reference run, childhood malnutrition (children of up to 60 months) will continue to decline, but cannot be eradicated by 2050 (Figure 5.9). Childhood malnutrition is projected to decline from 149 million children in 2000 to 130 million children by 2025 and 99 million children by 2050. The decline will be fastest in Latin America at 51%, followed by the CWANA and ESAP regions at 46% and 44%, respectively. Progress is slowest in sub-Saharan Africa—despite significant income growth and rapid area and yield gains as well as substantial progress in supporting services that influence well-being outcomes, such as female secondary education, and access to clean drinking water—by 2050, an increase of 11 percent is expected to 33 million children in the region.

Figure 4.10: Number of malnourished children, 2000 and projected 2025 and 2050, baseline



5 Alternative investments in agricultural knowledge, science and technology (AKST)

Three alternative AKST scenarios out to 2050 were analyzed to examine their implications on food supply, demand, trade, and food security. The first two scenarios examine the outcome of different levels of investments in crop yield and livestock numbers growth (AKST_high and AKST_low). A third scenario analyzes the implications of even more aggressive growth in agricultural R&D together with advances in other, complementary sectors (AKST_high_plus). These include investments in irrigation infrastructure represented by accelerated growth in irrigated area and efficiency of irrigation water use, by accelerated growth in access to drinking water, and greater investments in secondary education for females, an important indicator for human well-being (Table 5.1).

Table 5.1: Assumptions for Baseline and Alternative Agricultural Research and Technology (AKST), and Infrastructure (AKST_high_plus) Scenarios

Parameter changes for growth rates	2050 BASE	2050 AKST_high	2050 AKST_low	2050 AKST_high_plus
GDP growth	3.06 % per year	3.31 % per year	2.86 % per year	3.31 % per year
Livestock numbers growth	Base numbers growth of animals slaughtered 2000-2050 Livestock: 0.74%/yr Milk: 0.29%/yr	Increase in numbers growth by 20% Increase in animal yield by 20%	Reduction in numbers growth by 20% Reduction in animal yield by 20%	Increase in numbers growth by 30% Increase in animal yield by 30%
Food crop yield growth	Base yield growth rates 2000-2050: Cereals: %/yr: 1.02 Roots and Tubers: %/yr: 0.35 Soybean: %/yr 0.36 Vegetables: %/yr 0.80 Fruits: 0.82%/yr	Increase growth by 40%	Reduce growth by 40%	Increase growth by 60%
Irrigated Area Growth	0.06			Increase by 25%
Rainfed Area growth	0.18			Decrease by 15%
Basin efficiency				Increase by 0.15 by 2050
Access to water				Increase annual rate of improvement by 50% relative to baseline level
Female secondary education				Increase overall improvement by 50% relative to 2050 baseline level

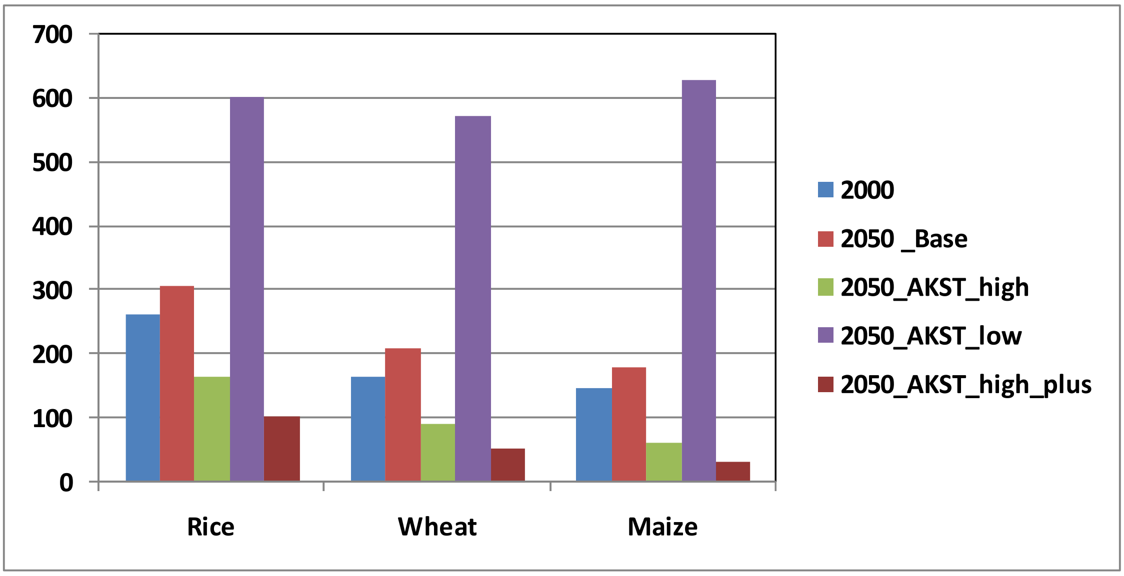
Source: Authors.

The AKST_high variant, which presumes increased investment in AKST, results in higher food production growth which, in turn, reduces food prices and makes food more affordable to the poor when compared to the reference world.

Under AKST_high, cereal production increases by 7 percent and by an even stronger 17 percent under the AKST_high_plus variant.

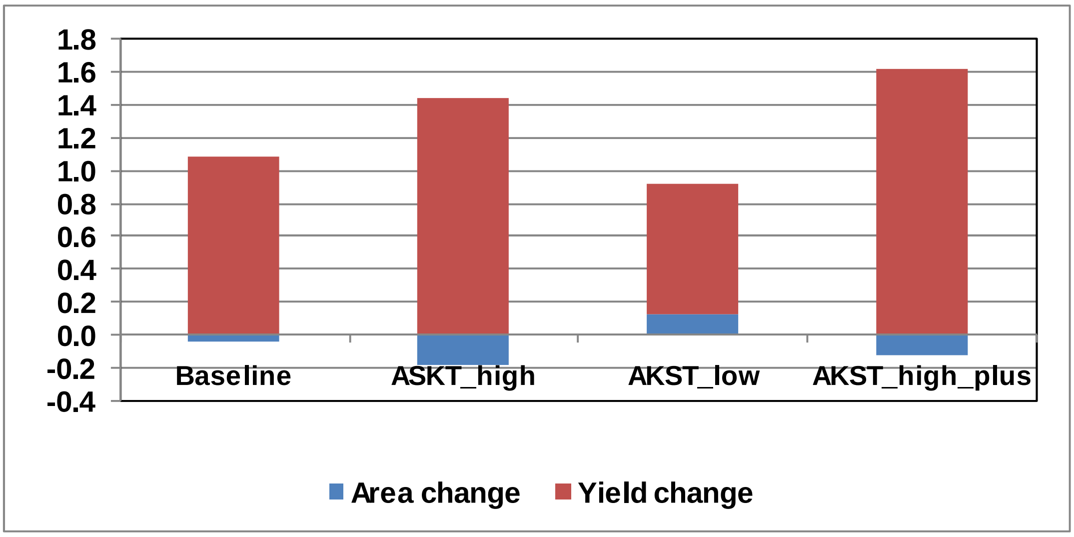
Under AKST_high, rice prices decline by 46 percent, wheat prices by 57 percent, and maize prices by 65 percent, compared to the 2050 baseline value. On the other hand, if investments slow down faster than in the recent past, prices would rapidly increase, by 96 percent for rice, by 174 percent for wheat, and by 250 percent for maize compared to the 2050 baseline value (Figure 5.1).

Figure 5.1: Cereal prices, 2050, alternative AKST scenarios (US$/mt)



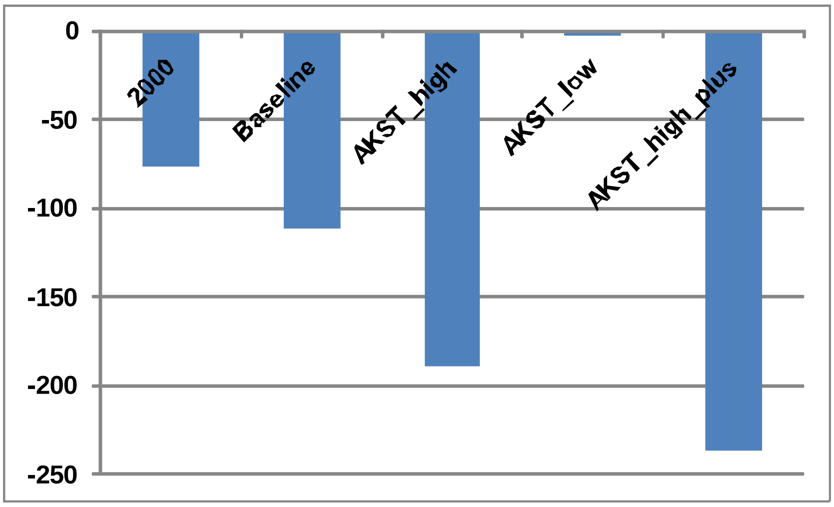
Despite these strong changes in AKST behavior, yield growth will continue to contribute most to future cereal production growth under both the AKST_low and AKST_high variants (Figure 5.2). Under AKST_low, however, the contribution of area growth to overall production growth is projected to increases compared to the baseline: from 23 percent to 35 percent for sub-Saharan Africa, and from 11 percent to 29 percent in the LAC region. For the group of developing countries as a whole, area change would contribute 13 percent to overall production growth up from a negative 4 percent (contraction of area) under the baseline. This could lead to further forest conversion into agricultural use. On the other hand, rapid expansion of the livestock population under AKST_high requires expansion of grazing areas in SSA and elsewhere, which could also contribute to accelerated deforestation.

Figure 5.2: Contribution of area and yield change to cereal production growth, 2000-2050, alternative AKST scenarios



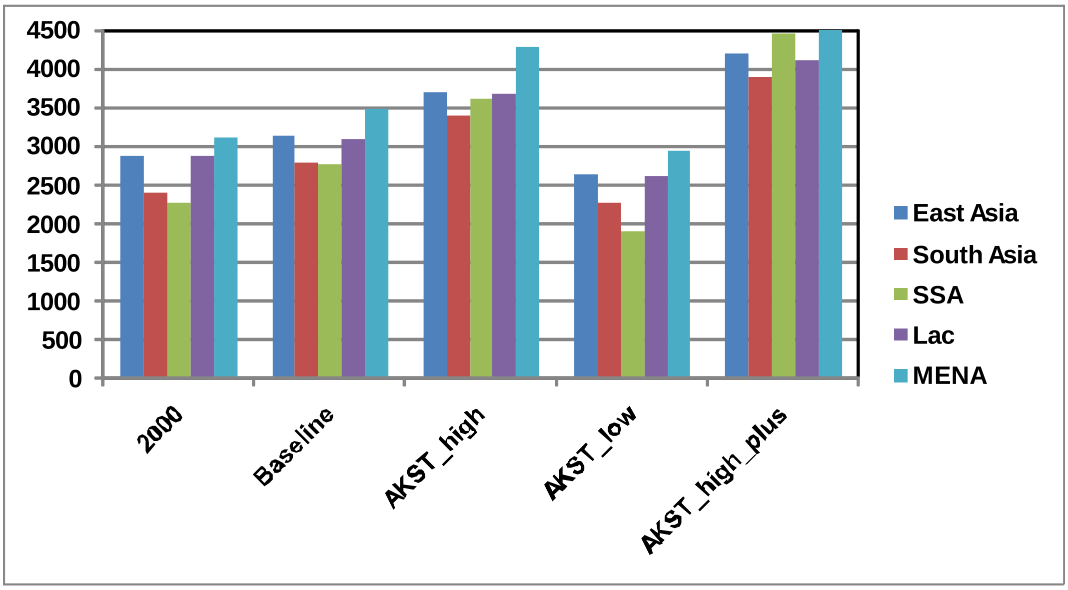
What are the implications of more aggressive production growth on food trade and food security? Under AKST_high, the group of developing countries cannot meet the rapid increases in food demand through domestic production alone. As a result, net cereal imports from the group of developed countries would increase by 70 percent compared to the reference run (Figure 5.3). Net cereal imports are projected to increase from 72 million metric tons to 125 million metric tons in the SSA region and from 93 to 100 million metric tons in the MENA region but drop by almost half in China. Under AKST_low, on the other hand, high food prices lead to depressed global food markets and reduced global trade in agricultural commodities.

Figure 5.3: Net cereal trade, developing countries, 2000 and projected 2050 for alternative AKST scenarios



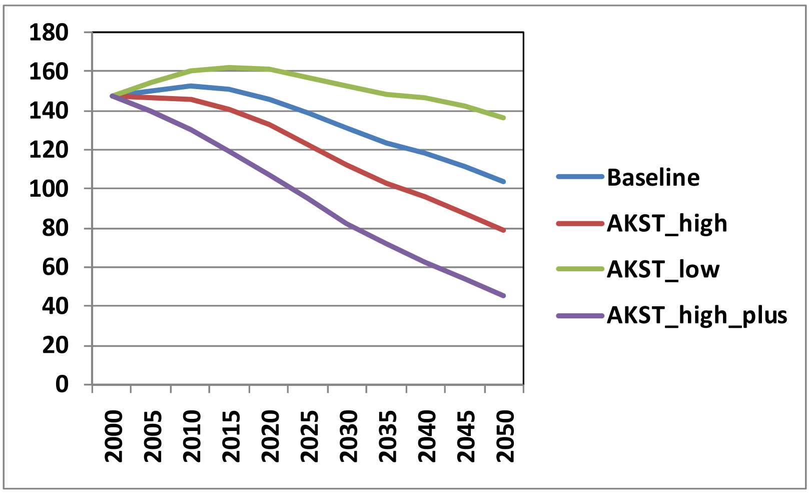
Sharp increases in international food prices as a result of the AKST_low variant as shown in Figure 5.1 depress demand for food and reduce availability of calories as shown in Figure 5.4. Average daily kilocalorie availability per capita declines by 850 calories in sub-Saharan Africa, pushing the region below the generally accepted minimum level of 2,000 calories and thus also below the levels of the base year 2000. On the other hand, under the AKST_high and AKST_high_plus scenarios, calorie availability increases in all regions compared to 2000 and baseline levels.

Figure 5.4: Calorie availability, developing country regions, 2000 and projected 2050 for alternative AKST scenarios



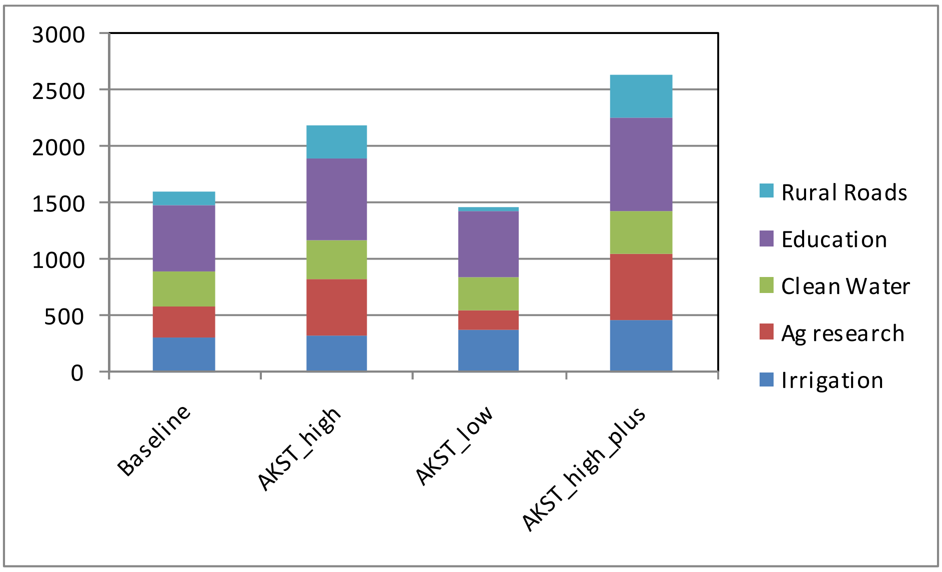
Calorie availability together with changes in complementary service sectors, including female secondary education, female-to-male life expectancy at birth and access to clean drinking water, can help explain changes in childhood malnutrition levels (see also Rosegrant et al., 2001). Under the AKST_high and AKST_high_pos variants, the number of malnourished children in developing countries is projected to decline by 24 percent and 56 percent, respectively, from 104 million children under the baseline (Figure 5.5). On the other hand, if investments slow down more rapidly, and supporting services degrade rapidly then absolute childhood malnutrition levels could return to close to 2000 malnutrition levels at 137 million children in 2050 under the AKST_low variation.

Figure 5.5: Number of malnourished children, developing countries, projected 2000-2050 for alternative AKST scenarios



What are the implications for investment under these alternative policy variants? Investment requirements for the reference run for key investment sectors, including public agricultural research, irrigation, rural roads, education and access to clean water are calculated at US$1,606 billion at 2008 prices4. As Figure 5.6 shows, the much better outcomes in developing-country food security obtained under the AKST_high and AKST_high_plus variants can be achieved at estimated investment increases in the five key investment sectors of only US$579 billion and US$1,030 billion, respectively, and are therefore within reach if the political will and resources are made available.

Figure 5.6: Investment requirements, 2000-2050, agriculture and complementary service sectors, alternative AKST scenarios ($ Billion in 2008 USD)



[4] *The list of developing countries is based on the list used in the 2008 World Development Report. Only countries and regions with baseline data are included in the analysis; Central Asia was excluded due to sparse data.*

6 Trade policies and international market constraints[5]

6.1 Introduction

Gains from trade have been extensively researched and are widely known. The objective of this section is not to add to the already overwhelming body of research on gains from trade. Rather, the key objective is to highlight the nexus between the potential gains from further trade liberalization and the perceived needs for significant investment in, and implementation of, agricultural knowledge, science and technology (AKST).

The critical needs for increased agriculture productivity growth are often underscored. This is more so particularly in the current context of heightened global concern for food prices and food security as well as of the increasing awareness of the likely implications for agriculture of future climate change and climate change response policies. The section draws on the analysis of certain trade policy and AKST scenarios developed for the International Assessment of Agricultural Science and Technology for Development (IAASTD, 2008) to suggest that the gains from trade would be sufficient to make necessary AKST investment and implementation in order to enhance much needed agricultural productivity in the future.

6.2 Trade policy scenarios

Two hypothetical scenarios representing two alternative global trade policy regimes are modeled for the International Assessment of Agricultural Science and Technology for Development (IAASTD, 2008). Scenario 1 represents a global economy in which import tariffs (and tariff equivalents) on all goods are removed incrementally between 2010 and 2020 across the globe. Scenario 2, on the contrary, represents a world in which trade barriers will escalate gradually between 2010 and 2020 such that by 2020 these barriers will be equivalent to twice the size of the existing tariff (and tariff equivalent) barriers across the board.

These scenarios are modeled using a version of ABARE's global trade and environment model, GTEM, developed by Ahammad and Mi (2005).

6.3 Gains from trade: Once again

This section presents and analyses the key impacts of the two IAASTD alternative trade policy scenarios. As discussed earlier, the two alternative scenarios are designed for illustration purposes and only representing two hypothetical but alternative global trade policy regimes. These scenarios are modeled using the most suitable version of ABARE's GTEM model, described earlier. Modeling results are presented and analyzed

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[5] *This section was prepared by Helal Ahammad, Australian Bureau of Agricultural and Resource Economics, Canberra, Australia. It is based on a longer report prepared for this project.*

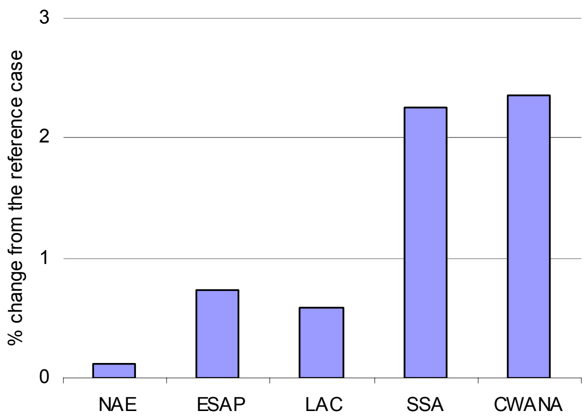
for the year 2025, five years after the assumed trade policy changes would be implemented.

Unless otherwise stated, the impacts are expressed as deviations from the reference case which represents no trade liberalization or no reduced sectoral protection throughout the projection period. It should be noted that the impacts of trade policy changes only represent 'static' gains/losses associated with resource reallocation and do not encapsulate any potential 'dynamic' gains/losses associated with any long-run productivity changes. Furthermore, except for the trade policies in question, all other policies remain unchanged as in the reference case.

6.4 Global results

Figure 6.1 shows the overall impacts of trade liberalization under scenario 1 in terms of changes in gross regional product (a GTEM regional equivalent to gross domestic product or GDP). As one would expect, the world economy is projected to benefit from multilateral trade liberalization. In particular, gross regional products (GRPs) in CWANA and SSA regions are projected to grow the most, by more than 2 per cent relative to the reference case at 2025. However, about two fifths of the global benefits (in today's dollars) are projected to accrue to the ESAP region, to which Australia belongs.

Figure 6.1: Projected impacts on gross regional product of trade liberalization under scenario 1 at 2025



The overall impact on global gross product under scenario 1 is comparable with that of a number of recent studies (see, for example, Martin and Anderson, 2005). However, the estimated CGE impacts could potentially underestimate the actual gains from trade due to, among other things, the so-called 'Armington trade structure' popularly used in CGE models, not accounting for potential dynamic gains from trade liberalization, and the poor representation in CGEs of the high border protection allegedly accorded to international trade in services.

While the removal of trade barriers under scenario 1 is projected to increase income and food consumption, the global structure of food production appears to undergo significant changes. Compared with the reference case, a significant increase in meat production is projected to occur in LAC and SSA regions with a substantial decline projected for the NAE region (Figure 6.2). The proximity of LAC and SSA regions to their key export markets in NAE regions is expected to play an important role in the projected growth in meat production in, and exports from, LAC and SSA regions. The structural change in global production of non-meat food is not as striking as in the case of meat. In non-meat production, nonetheless, LAC and SSA regions are projected to register most growth relative to the reference case at 2025 (Figure 6.3).

Figure 6.2: Projected impacts on meat production under scenario 1 at 2025

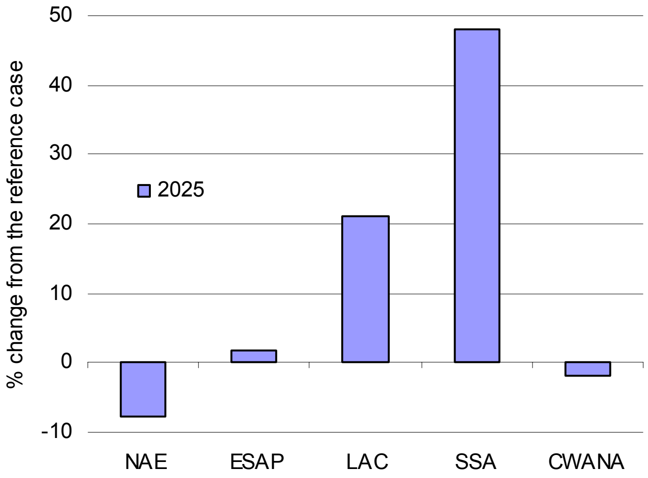
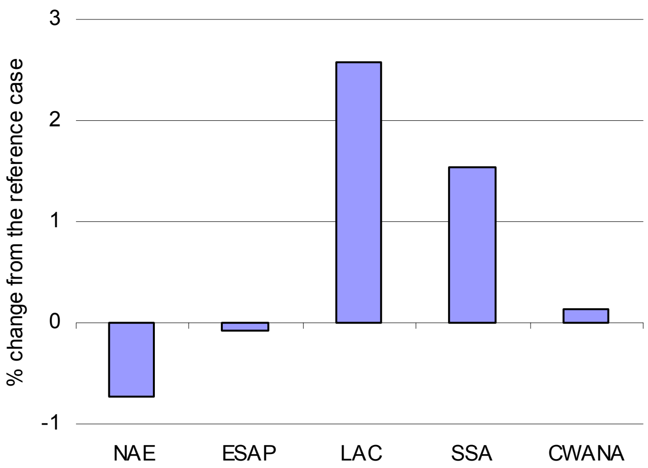
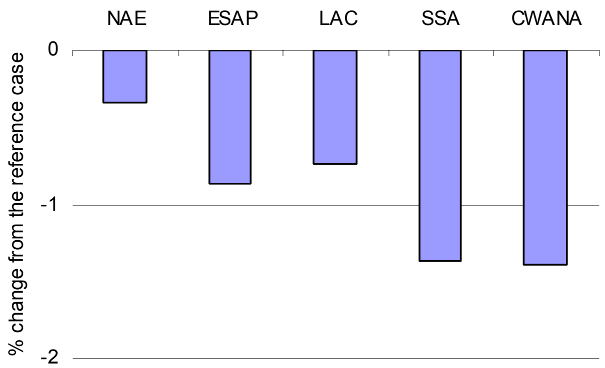


Figure 6.3: Projected impacts on non-meat food production under scenario 1 at 2025



Under scenario 2 in which trade protection will be doubled between 2010 and 2020, all broad regional economies are projected to decline relative to the reference case (Figure 6.4). Again, CWANA and SSA regions are projected to be affected the most, declining by about 1.5 per cent relative to the reference case at 2025.

Figure 6.4: Projected impacts on gross regional product of increased trade protection under scenario 2 at 2025



6.5 Implications for Australia

Compared with the corresponding regional average for ESAP, the projected (static) gains for Australia at 2025 from global trade liberalization under scenario 1 is rather modest (see Table 6.1 and Figure 6.1). Australia's overall modest gains could be attributed to its particular economic structure including its trade structure and patterns as well as Australia's relatively low trade barriers in terms of tariffs – largely due to significant past trade reforms. These aspects of the Australian economy are reinforced by various modeling issues, discussed earlier, that tend to underestimate gains from trade reforms within a CGE framework.

Table 6.1

Macro impacts of trade liberalisation on Australia, 2025

	Deviation from the reference case
Real consumption (%)	0.2
Real GNP (%)	0.3
GNP gains decomposition (cents in a $ gain)	
Real GDP	76
Net foreign transfers	18
ToT	6
GNP	100

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6.6 Implications for AKST

With increasing resource constraints and other environmental challenges, there is a growing pressure on food supply systems and natural resource management (NRM). The ongoing tightening of food markets seems to indicate that a 'business as usual' approach to funding and innovating agricultural knowledge, science and technology (AKST) will not be able to meet the growing demands for food, fiber and various NRM services. According to IAASTD, innovative AKST investment and policies are essential in building natural, human and physical capital for socially and environmentally sustainable economic growth into the future (IAASTD, 2008).

Investment requirements estimated for key investment sectors including public agricultural research, irrigation, rural roads, education and access to clean water, were estimated at US$1,310 billion in the IAASTD assessment (IAASTD, 2008) and at US$1,071 billion using the country aggregation based on the World Development Report. Between US$143 billion to US$636 billion of additional investment in the above five key sectors is estimated to achieve much better food security outcomes under two alternative scenarios modeled for the IAASTD policy analysis (IAASTD, 2008) and using the World Development Report aggregation of countries.

A conservative estimate of the potential 'static' gains from global trade liberalization, discussed earlier, far exceeds the needs for AKST investment as identified by IAASTD. Trade liberalization while in itself welfare enhancing, can generate enough resources to fund the necessary AKST investment which, in turn, will help grow agriculture production for a growing world population. As such, such 'dynamic' gains would well exceed the so-called 'static' gains from trade liberalization reported in this paper.

7 Results for China[6]

7.1 Introduction

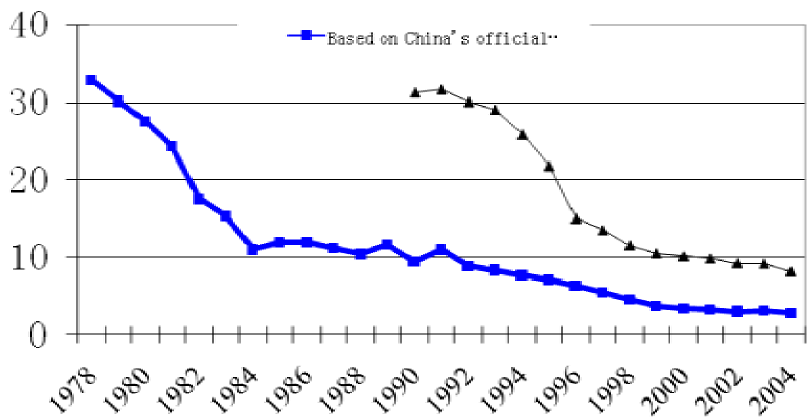
China's economy has experienced remarkable growth since economic reforms were initiated in 1979. Although there is a cyclical growth pattern, China's economy outperformed almost all other countries in Asia and has been one of the fastest growing countries in the world since 1980. Annual average growth rate of GDP reached nearly 10 percent in the past three decades (Table 7.1). The real GDP in 2006 was about 12 times that in 1978 (NSBC, 2007).

China's rapid economic growth has been associated with unprecedented progress in poverty alleviation and material well-being. In the past two and half decades, based on China's official poverty line, more than 230 million Chinese rural residents have escaped poverty, and the absolute level of poverty fell from 260 million in 1978 to less than 30 million in 2003 (Figure 7.1). The incidence of rural poverty has fallen equally fast, plunging from 32.9 percent in 1978 to less than 3 percent after 2003.

Food security, one of the central issues of concern to policy makers in China, has also improved significantly since the late 1970s. At the national level, in contrast to many earlier analysts who expected that China would starve the world in the course of the rapid industrialization and liberalization of its economy, net food import growth did not happen. In fact, even after 30 years of reform and rapid growth, China has continued to be a net exporter of food and meantime availability of food has increased significantly over time (NSBC, 1985-2007). At the micro level, China also has made remarkable progress in improving household food security and reducing the incidence of malnutrition during the past two decades. According to a publication by FAO (2002), the number of people who suffered from any sort of malnutrition in China declined from 193 million in 1990/92 to 116 million in 1997/99, or from 16 percent to 9 percent in total population.

[6] *This section was prepared by Jikun Huang, Center for Chinese Agricultural Policy, Chinese Academy of Sciences together with Scott Rozelle, Freeman Spogli Institute for International Studies, Stanford University*

Figure 7.1. Poverty incidence (%) in rural China, 1978-2004



Source: Poverty data for 1978-1988 are from World Bank (China: Strategies for Reducing Poverty in the 1990s, 1992); 1989-2004 data on official poverty are from Rural Social and Economic Survey Service of NBSC (2006). Poverty based on $1/day in PPP in recent years are computed by the authors based on NBSC's rural household income and expenditure surveys.

Table 7.1 Annual growth rates (%) of China's economy, 1970-2005.

	Pre-reform 1970-78	Reform period			
		1979-84	1985-95	1996-00	2001-05
GDP	4.9	8.8	9.7	8.2	9.6
Agriculture	2.7	7.1	4.0	3.4	3.9
Industry	6.8	8.2	12.8	9.6	10.7
Service	Na	11.6	9.7	8.3	10.2
Foreign trade	20.5	14.3	15.2	9.8	25.3
Import	--	12.7	13.4	9.5	24.9
Export	--	15.9	17.2	10.1	25.7
Population	1.80	1.40	1.37	0.91	0.63
Per capita GDP	3.1	7.4	8.3	7.2	9.0

Note: Figure for GDP (in real term) in 1970-78 is the growth rate of national income in real term. Growth rates are computed using regression method. Trade growth is based on current value in US donor.

Source: NSBC, Statistical Yearbook of China.

While the past changes in China have been wrenching for both China and the rest of world, the changes may just be starting. According to the baseline projections of almost every major economic modeling team in the world, economic growth is projected to continue into China at a minimum of more than 8 percent up until the mid-2010s and between a range of 6 to 7 percent annually between 2010 and 2020. Estimates of future growth rates vary and some are even higher. If such growth would continue through 2030 (even at 5 percent between 2020 and 2030), the economy of China will almost grow by 5 times or more over the coming 20 or so years. With the size of China's economy (it is projected that at least by 2020, China will become the third largest economy in the world), such rapid growth is likely to have profound impacts on China's own population and on the rest of the world—even when thinking about what will happen in the more modest scenarios.

While the impact of World Trade Organization (WTO) on China's agriculture in the past 7 years (2001-2007) has been very moderate, debates on the implications of rising China's economy under a more liberalized global economy in the future is growing. Both at domestic and global aspects, there are growing concern on the rise of China's economy and national food security. Many perceive that China's economic growth and its transformation will have profound effects, not just for its own people but also for many others further afield. Such effects could be a combination of new market opportunities arising from enhanced purchasing power, and greater competitiveness of China's economy as producers of selected products.

In exploring what the growth of China's economy might mean for China and the rest of the world, we focus our analyses on agriculture and the role of technologies in facilitating agricultural productivity growth for several reasons. We pay particular attention to food security as it has been and will continue to be one of central goals of China's agricultural policy. Given the size of the country, the national leaders believe that China has to produce most of its food to meet the increasing demand in the domestic market. Agriculture has played a significant role in poverty reduction in the past 30 years of reform. China also realizes that further reduction of poverty will still need to continue to boost agricultural productivity or AKST. In the future, many have predicted that major driving forces of agricultural growth will have to come from new technologies that could significantly improve agricultural productivity (Fan and Pardey, 1997; Huang et al., 2002a and 2002b).

The overall goals of this study are to analyze the performance of agricultural economy in the past, project the lively trends of agricultural demand, supply, and food security, and make implications for agricultural R&D policies toward 2050. In order to achieve the above goals, after this introduction section, the rest of this section is organized as follows. The overall trend of China's economy and agricultural development and major driving forces of food and agricultural growth in the past and challenges ahead are described as well as major challenges and policy responses in recent years and the future. This is followed by methodologies and scenarios used and projection results of both baseline and alternative scenarios with a particular focused on the implications of technological changes on demand and supply of major agricultural products, food security and poverty in the future. The final section concludes the study.

7.2 China's Economy and Agricultural Development in the Past Three Decades

7.2.1 Overall Economic Performance

China's economy has been growing rapidly since the economic reforms initiated in the late 1970s and has been pushed forward by a number of complementary policies. Since the mid-1980s, rural township and village-owned enterprises (TVEs) development, measures to provide a better market environment through domestic market reform, fiscal and financial expansions, the devaluation of the exchange rate, trade liberalization, the expansion of special economic zones to attract foreign direct investment (FDI), the state-owned enterprise (SOE) reform, agricultural market liberalization, and many other developments all have contributed to China's economic growth. In response, the annual growth rate of gross domestic product (GDP) was about nearly 10 percent in 1979-2006 (Table 7.1). The international trade grew even at mush faster than the growth of GDP (Table 7.1). Although the growth in agriculture has been generally lower than the overall economic growth, its growth is also impressive. After 1978, decollectivization, price increases and the relaxation of trade restrictions on most agricultural products accompanied the take off of China's food economy. The average annual growth of agricultural GDP in real term reached nearly 5 percent in the past 3 decades (Table 7.1).

Rapid economic growth has been accompanied with significant structural changes in China's economy. Whereas agriculture accounted for more than 40 percent of gross domestic product (GDP) in 1970, it fell to 30 percent in 1980, 20 percent in 1995 and only 12 percent in 2005 (Table 7.2). After a period of rise and fall of industrial share in the national GDP in 1970-1985, the share has gradually started to increase after the late 1980s, rising from 41 percent in 1990 to 48 percent in 2005. In contrast to agriculture, service sector expanded rapidly. The share of service sector in the national GDP increased from 13 percent in 1970 to 21 percent in 1980 and 40 percent in 2005 (Table 7.2). This trend is expected to persist in the coming years as China will continue to promote its structural adjustment policies and economic reforms in response to domestic demand and external trade pattern changes in the coming years.

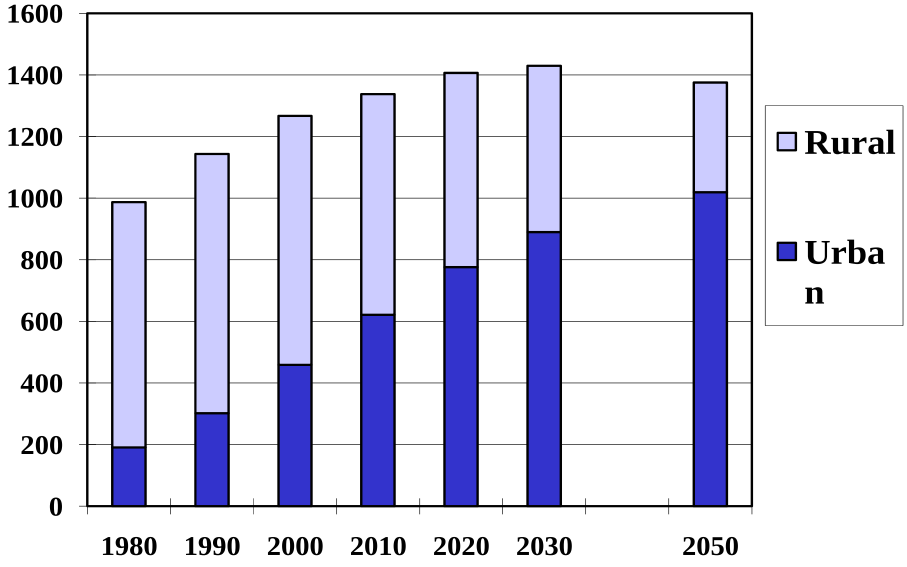
Table 7.2 Changes in the structure (%) of China's economy, 1970-2005.

	1970	1980	1985	1990	1995	2000	2005
Share in GDP							
Agriculture	40	30	28	27	20	15	12
Industry	46	49	43	41	47	46	48
Services	13	21	29	32	33	39	40
Share in employment							
Agriculture	81	69	62	60	52	50	45
Industry	10	18	21	21	23	22	24
Services	9	13	17	19	25	28	31
Trade to GDP ratio	Na	12	23	30	40	44	64
Export/GDP	Na	6	9	16	21	23	34
Import/GDP	Na	6	14	14	19	21	30
Share of rural population—see also Figure 7.2	83	81	76	74	71	64	57

Source: National Statistical Bureau, China Statistical Yearbook, various issues; and China Rural Statistical Yearbook, various issues.

Structural changes in economy have also been substantial in employment patterns. Agriculture employed more than 80 percent of the nation's total labor forces in 1970, which has declined significantly to 60 percent in 1990 and 45 percent (including part-time agricultural labor) in 2005 (4th row, Table 7.2). The share of employment accounted for by the industrial sector doubled in 1970-1985 and has remained at about 20 to 24 percent thereafter (5th row, Table 7.2). Employment share in the service sector had risen even more rapidly from 9 percent in 1970 to 19 percent in 1990 and 31 percent in 2005.

Figure 7.2. Population in 1980-2050 (million)



Source: UN Population Projection (2005)

7.2.2 Agricultural Production Growth

The growth of agricultural production in China since the 1950s has been one of the main accomplishments of the country's development and national food security policies. Except during the famine years of the late 1950s and early 1960s, the country has enjoyed rates of production growth that have significantly outpaced the rise in population.

After 1978, decollectivization, price increases and the relaxation of trade restrictions on most agricultural products accompanied the take off of China's food economy. Between 1978 and 1984, grain production increased by 4.7 percent per year; the output of fruit rose by 7.2 percent (Table 7.3). The highest annual growth rates came in cotton, the oilseed, livestock and aquatic product sectors, sectors that expanded in real value terms by 19.3 percent, 14.9 percent, 9.1 percent and 7.9 percent, respectively, in 1979-84.

Table 7.3. The annual growth rates (%) of China's agricultural economy, 1970-2005.

	Pre-reform 1970-78	Reform period			
		1979-84	1985-95	1996-00	2001-05
Agricultural GDP	2.7	7.1	4.0	3.4	3.9
Grain production	2.8	4.7	1.7	-0.7	1.1
Rice:					
Production	2.5	4.5	0.6	0.4	-0.8
Area	0.7	-0.6	-0.6	-0.5	-0.8
Yield	1.8	5.1	1.2	0.8	0.0
Wheat:					
Production	7.0	8.3	1.9	-0.6	-0.4

Area	1.7	-0.0	0.1	-1.6	-3.1
Yield	5.2	8.3	1.8	1.0	2.7
Maize:					
Production	7.4	3.7	4.7	-1.3	5.6
Area	3.1	-1.6	1.7	0.8	2.7
Yield	4.2	5.4	2.9	-0.9	2.9
Other production					
Cotton	-0.4	19.3	-0.3	-1.9	5.3
Soybean	-2.3	5.2	2.8	2.6	1.4
Oil crops	2.1	14.9	4.4	5.6	0.8
Fruits	6.6	7.2	12.7	10.2	21.0
Meats (pork/beef/poultry)	4.4	9.1	8.8	6.5	4.9
Fishery	5.0	7.9	13.7	10.2	3.6
Planted area:					
Vegetables	2.4	5.4	6.8	9.8	3.1
Orchards (fruits)	8.1	4.5	10.4	2.0	2.4

Note: Growth rates of individual and groups of commodities are based on production data.

Sources: NSBC, 1985-2006 and MOA, 1985-2006.

Agricultural growth remained remarkable for all agricultural products except for grain and cotton in 1985-2000. Fishery production experienced the fastest growth in 1985-95 (13.7 percent annual growth, Table 7.3). Although its annual growth rate fell in the following period, it still recorded 10.2 percent in 1996-2000. Over the same period, meat production and vegetable sown areas expanded at 7-9 percent annually. Other cash crops such as oil crops, soybean and fruits also grew at rates much higher than population growth.

Overall growth of agriculture sector kept at an average of nearly 4 percent of annual growth rate in 2001-2005 (row 1, Table 7.3). Comparing growth rates of individual commodities between early and late reform periods, it appears that production (measured in quantity) growth of some individual agricultural commodities fell, which may indicate that China's agricultural production has been shifting from aggregate production to value-added and quality food production. In 2005-2006, China's agricultural GDP in real term grew at annual rate of more than 5 percent.

7.2.3 Structural Changes in Agricultural Production

China's agricultural structure has undergone significant changes since the early 1980s. Rapid economic growth, urbanization and market development are key factors underlining the changes. Rising income and urban expansion have boosted the demand for meats, fruits and other non-staple foods, which have stimulated sharp shifts in the structure of agriculture (Huang and Bouis, 1996). For example, the share of livestock output value rose 2.5 times from 14 percent to 35 percent between 1970 and 2005 (Table 7.4). Aquatic products increased at an even more rapid rate. One of the most significant signs of structural changes in the agricultural sector is that the share of crops in total agricultural output fell from 82 percent in 1970 to 51 percent in 2005.

Table 7.4 Changes in structure (%) of China's agricultural economy, 1970-2005.

	1970	1980	1985	1990	1995	2000	2005
Share in agricultural output							
Crop	82	76	69	65	58	56	51
Livestock	14	18	22	26	30	30	35
Fishery	2	2	3	5	8	11	10
Forestry	2	4	5	4	3	4	4

Source: NSBC, Chinas' Statistical Yearbook, various issues and China Rural Statistical Yearbook, various issues.

Table 7.5. Shares (%) of crop sown areas, 1970-2005.

	1970	1980	1985	1990	1995	2000	2005
Rice	22.1	23.1	21.9	22.3	20.5	19.2	18.5
Wheat	17.4	19.7	20.0	20.7	19.3	17.1	14.1
Maize	10.8	13.7	12.1	14.4	15.2	14.8	16.6
Soybean	5.5	4.9	5.3	5.1	5.4	6.0	6.2
Sweet potato	5.9	5.1	4.2	4.2	4.1	3.7	3.2
Cotton	3.4	3.4	3.5	3.8	3.6	2.6	3.7
Rapeseed	1.0	1.9	3.1	3.7	4.6	4.8	4.7
Peanut	1.2	1.6	2.3	2.0	2.5	3.1	3.1
Sugarcrops	0.4	0.6	1.0	1.2	1.3	1.0	1.0
Tobacco	0.2	0.3	0.9	0.9	0.9	0.8	0.8
Vegetable	2.0	2.2	3.2	4.3	6.3	9.7	11.4
Others	30.1	23.5	22.5	17.4	16.3	17.2	16.7
Total	100	100	100	100	100	100	100

Source: NSBC, China's Statistical Yearbook, various issues; China Rural Statistical Yearbook, various issues.

Within the crop sector, the importance of the three major crops, rice, wheat and maize, have waxed and waned. The share of the major cereal grains increased from 50 percent in 1970 to a peak level of 57 percent in 1990 and then gradually declined to less than 50 percent in 2005 (Table 7.5). Most of the fall has been due to falling rice and wheat sown areas. In contrast, the shares of maize areas grew by more than 50 percent between 1970 and 2000 (Table 7.5). The rise in maize area, China's main feed grain, is correlated in no small way with the rapid expansion of the nation's livestock production during the same period.

In addition to maize other cash crops such as vegetables, edible oil crops, sugar crops and tobacco have expanded in area. In the 1970s, vegetables accounted for only about 2 percent of total crop area; by 2004, the share had increased by nearly six times (Table 7.5). The area devoted to edible oil also grew by two to three times. Field interviews reveal that the livelihood of the poor relies more on crops than livestock and fishery (when compared to richer farmers). Within the crop sector, poorer farmers produce more grains (particular maize) than cash crops. These together with figures in Table 7.5 might imply that the poor have gained somewhat less than better off farmers from the diversification of agricultural production during the reform period.

7.2.4 Food Security

To ensure national food security is one of central goals of China's agricultural policies. China's effort and success of increasing food and fiber supply to meet its growing population in the past 50 years has been well recognized. Per capita food availability reached 3040 kcal per day in 2000, a level that is 14% higher than the average of developing countries and 8% higher than the world average (FAO, 2002). China feeds more than 20% of the world's population with less than 10% of global cultivated area. Moreover, China has shifted from a food net importer to net exporter since the early 1980s (Table 7.6) and became one of the developing countries with the highest food self-sufficiency levels, which contributes significantly to the world food security. Given China's status as a net food exporter, when examining the rise in domestic food availability, it is clear that the increase was almost achieved exclusively through increases in domestic production.

Table 7.6: China's food, feed, fiber and non-agriculture trade in 1985-2005 (million US$).

	SITC	1985	1990	1995	2000	2005
Exports						
Food and feed		3183	7515	10900	12804	23420
Live animals and meat	00-01	429	1221	1822	1619	2234
Dairy products	02	34	79	75	104	180
Fish	03	154	1370	2875	3661	7527
Grains	04	917	614	281	1812	1836
Fruit and vegetable	05	433	1760	3401	3362	7431
Sugar	06	65	318	321	257	502
Coffee and tea	07	312	534	512	545	1061
Animal feeds	08	225	758	351	303	497
Other foods	09	62	82	286	608	1182
Oilseeds and vegetable oils	22, 04	552	780	975	533	971
Fiber	26	892	1096	753	1085	1186
Non-agriculture		21557	53481	137126	235314	737347
Imports						
Food and feed		1437	4460	8825	8648	20747
Live animals and meat	00-01	24	68	115	667	691
Dairy products	02	29	81	63	217	461
Fish	03	41	102	609	1217	2904
Grains	04	829	2353	3631	662	1640
Fruit and vegetable	05	16	83	185	516	1349
Sugar	06	262	389	935	177	451
Coffee and tea	07	18	30	73	94	222
Animal feeds	08	79	305	423	909	1307
Other foods	09	21	46	88	283	354
Oilseeds and vegetable oils	22, 04	118	1003	2702	3906	11368
Fiber	26	1023	1975	4108	2846	6854
Non-agriculture		37335	46911	119150	213599	632352
Net export						

Food and feed		1746	3055	2075	4156	2673
Live animals and meat	00-01	405	1153	1707	952	1543
Dairy products	02	5	-2	12	-113	-281
Fish	03	113	1268	2266	2444	4623
Grains	04	88	-1739	-3350	1150	196
Fruit and vegetable	05	417	1677	3216	2846	6082
Sugar	06	-197	-71	-614	80	51
Coffee and tea	07	294	504	439	451	839
Animal feeds	08	146	453	-72	-606	-810
Other foods	09	41	36	198	325	828
Oilseeds and vegetable oils	22, 04	434	-223	-1727	-3373	-10397
Fiber	26	-131	-879	-3355	-1761	-5668
Non-agriculture		-15778	6570	17976	21714	104996

Source: UNCOMTRADE.

At the macro or national level, grain security has received the highest attention among food security by the national leaders. China had targeted full self-sufficiency in total grain consumption before 1990s and has set the target of grain self-sufficiency rate at a level of higher than 95 percent since the late 1990s. To achieve these targets, China has invested heavily in irrigation and other agricultural infrastructure (Wang, 2000), research and extension (Huang et al., 2003), and domestic production and marketing of chemical fertilizer and pesticides (Nyberg and Rozelle, 1999). In fact, China has been a net export of grain. Although China imports high quality indica rice, China also export japonica rice and has been a net exporter of rice since the early 1980s. Import of wheat has declined from more than 10 million metric tons (mmt) annually in 1980s to nearly zero in recent years (NBSC, 1986-2007). Although in the coming decade, China will have to import maize to partially meet growing demand for feed resulted from expansion of livestock sector, China has become one of major maize exporters in the world markets since the late 1990s. Annual maize export reached more than 12 mmt 2002 and 16.4 mmt in 2003. Despite maize export declined significantly in recent years, China has not shifted from a maize net exporter to net importer.

At the micro level, household or individual food security depends on a number of factors. Access to food in rural China has changed over time. In the early years of the reform, decollectivization policies gave all farm households in China a piece of land. During this time, however, markets did not function well. As a result, most farmers produced mostly for their own subsistence. Access to food was primarily through the land that was allocated to farmers by the state. As China has changed, so has the food economy and nowhere has the change been more noticeable than in access to food. From an economy that was mostly subsistence, in recent years China has one of the most commercialized rural economies when compared to other developing economies. On the average, the shares of marketed products in total production ranged from 54 percent for grain to more than 90 percent for fish (NSBC, 2006). Even the poorest of the poor also marketed nearly all products they produced, though the rate of commercialization is less than those of the richer Chinese farmers have also increasingly purchased their food from the rural market. Stability of food supplies and access of food by the poor are the other dimensions of food security. In this regard, the government has developed its own disaster relief program. The nation’s capacity to deal with emergencies has been demonstrated repeatedly during the reform period. Transportation and market infrastructure have also improved remarkable since the early 1990s. Huang and Rozelle (2006) showed that China's domestic food markets have been highly integrated since the late 1990s. The percentage change in price for every 1000 kilometers of distance from the port was only about 5 percent, which is very comparable with the USA.

7.2.5 Driving Forces of Agricultural Growth

Past studies have already demonstrated that there are a number of factors that have simultaneously contributed to agricultural production growth during the reform period. The earliest empirical efforts focused on measuring the contribution of the implementation of the household responsibility system (HRS), a policy that gave individual farmers control and income rights in agriculture. These studies concluded that most of the rise in productivity in the early reform years was a result of institutional innovations, particularly the HRS (McMillan et al. 1989; Fan 1991; Lin 1992).

More recent studies show that since the HRS was completed in 1984, technological change has been the primary engine of the agricultural growth (Huang and Rozelle 1996; Fan 1997; Fan and Pardey 1997; Huang et al. 1999 and Jin et al. 2002). Improvements in technology have by far contributed the largest share of crop production growth even during the early reform period. The results of these studies show that further reforms outside of decollectivization also have high potential for affecting agricultural growth. Price policy has been shown to have a sharp influence on the growth (and deceleration) of both grain and cash crops during the post-reform period. Favorable output to input price ratios contributed to the rapid growth in the early 1980s. However, this new market force is a two-edged sword. A deteriorating price ratio caused by slowly increasing output prices in the face of sharply rising input prices was an important factor behind the slowdown in agricultural production in late 1980s and early 1990s. The higher opportunity cost of land has also held back the growth of grain output throughout the period, and that of cash crops since 1985.

Irrigation has played a critical role in establishing the highly productive agronomic systems in China (Wang 2000). The proportion of cultivated area under irrigation increased from 18 per cent in 1952 to a level at which about half of all cultivated land had been irrigated after the early 1990s (NSBC 2001). However, rising demand for domestic and industrial water uses poses a serious constraint to irrigated agriculture and increasing water scarcity has come to be seen as a major challenge to the future food security and well-being of people especially in the northern region. Wang et al. (2005) shows that the water management reform has been helping increase the efficiency of water use in north China, although the scope for such reform in the long run is somewhat limited.

7.2.6 Agricultural Trade

While agricultural production was growing fast, agricultural trade was growing faster. Export of food and feed increased about 4 times from about 3.2 billion US$ in 1985 to 12.8 billion US$ in 2000, and almost doubled in 2000-2005 (Table 7.6). On the other hand, Food, feed and fiber import also rose rapidly. However, in the past 2 decades, exports of food and feed have risen faster than imports. Since the early 1980s, China has been a net food and feed exporter. Significant rising fiber import and large deficit of fiber, mainly cotton, has been largely due to rapid expansion of export oriented textile industry in China.

In the same way that trade liberalization has affected growth in the domestic economy (Lardy 2001), changes in the external economy have affected the nature of China's agricultural trade patterns (Rosen et al., 2004). As trade expanded, despite the overall positive growth of the agricultural trade, share of agriculture in total trade fell sharply because the growth of non-agricultural trade was much higher than that of agricultural trade.

Disaggregated, product-specific trade trends in agriculture show equally sharp shifts (Table 7.6). The data presented in Table 7.6 suggest that exports and imports are moving increasingly in a direction that is consistent with China's comparative advantages. In general, the net exports of land-intensive bulk commodities, such as grains, fiber crop, oilseeds and sugar crops, have fallen reflecting the increase in imports. At the same time, exports of higher-valued, more labor-intensive products, such as horticultural and animal (including aquaculture) products have risen. Grain exports, accounted for nearly one third of food exports in the mid-1980s, after the late 1990s, horticultural, animal and aquatic products accounted for about 70 to 80 percent of food exports (Table 7.6).

7.3 Challenges Ahead and Major Policy Responses

7.3.1 Major Challenges

Equity and Income Distribution. While the progress in agriculture has been notable, there are also many lessons and great challenges ahead. With the transition from a planned to a market-oriented rural economy mostly complete, China's main challenge has shifted to broader development issues. In the coming years, the development process will have to be fundamentally different from the efforts in previous times when meeting the nation's food needs, poverty reduction and economic growth were the main goals.

China's rapid economic growth and the rise in the nation's overall wealth have accompanied with widening income inequality. Regional income disparity has been enlarging since 1980s (Cai et al. 2002, World Bank 2002). Eastern China grew faster than Central and Western China. The rural reforms increased rural incomes at a faster pace than urban incomes during the early 1980s. This led to a decline of the urban to rural income ratio from 2.57 in 1978 to 1.86 in 1985. However, after the one time impact of the rural institutional reforms was exhausted, urban income growth has been consistently higher than that of the rural sector. By 2004, per capita income in the urban areas was 3.21 times that in the rural areas (NSBC 2005). The rising income disparity within the rural areas has also emerged. For example, the Gini coefficients in rural areas increased from 0.24 in 1980 to 0.31 in 1990 and to 0.37 in 2003 (NSBC-Rural Survey Department 2004).

Nature Resource and Environment. While the successful technology innovation will help China to increase its agricultural productivity, China may face great challenge in coming to grips with water scarcity. Water shortages and increasing competition from industry and domestic use do not provide much hope for large gains in the areas under irrigation and the total output from irrigation expansion (Lohmar et al. 2003). This is particularly important in the North China Plain where most of China's wheat and also to some extent of maize are produced.

While the land policy helped China to increase agricultural productivity in the early reform period and contributed significantly to reduction of China's rural poverty, land holdings are so small that farming activities alone cannot continue to raise the incomes of most rural households. The challenge is how China can effectively establish linkages between rural and urban areas and encourage the large labor shift out of agriculture.

Trends in environmental degradation suggest that there may be considerable stress being put on the agricultural land base. While judicious use of modern technologies is essential to efficient food production in globally, inappropriate uses, such as excessive application rates or imbalances in input combinations, result in serious environmental problems and food safety concerns. In the past 30 years, while world total nitrogen fertilizer application increased by 7 times, China's nitrogen use in crop production increased by 45 times (Sonntag et al. 2005). On average, nitrogen use per hectare is about three times higher the world average. Environmental stresses have also been occurring in soil erosion, salinization, the loss of cultivated land, and decline in land quality (Huang and Rozelle 1995). Deng et al. (2006) show that although China did not record a decline in total cultivated land from the late 1980s to the late 1990s, average potential productivity of cultivated land, or bioproductivity, declined by 2.2 percent over the same period. Meantime, a large decline in cultivated land was recorded after the late 1990s due to industrial development and urban expansion.

Food Security or Grain Security. Falling cultivate land in recent year and rising water scarcity have led to increasing concern of national food, particular grain, security by China's leaders. Despite China now is still a net food exporter, there is also growing concern on the implications of rising Chinese income on demand for food, food prices and global food and agricultural trade in the coming decades.

7.3.2 Major Policy Responses

The leaders of China have recognized the constraints and challenges of sustainable agricultural and rural development. Recently, China has prepared its national long term development plan and a number of the proposed strategies. In the Eleventh Five Year Plan, 2006-2010 and the strategies for long-term economic development, China set its ambitious goals to move the nation to a "Harmonious Society", a smooth transformation of the economy from transition to development and from agriculture to industry and services, sustainable management of the environment, and other social and political targets.

In agricultural and rural development, China has initiated the Socialist New Rural Development Plan. Major measures to promote agriculture and rural development include public investment, land policy, market reform, agricultural research and development, water management, and off-farm employment.

Public Investment. China has taken several reforms to strengthen its fiscal revenue and public investment in agriculture. The nation has significantly increased its investment in agriculture and rural development since late 1990s. In recent years the investment into the community in terms of roads, irrigation, schools and drinking water has improved. According to a national representative survey of China's villages undertaken by the National Bureau of Statistics of China, during the past several years there has been more than one investment project per village per year. China also initiated its rural tax and fee reform aimed at reducing the rate of agricultural tax and eliminating various local fees imposed on farmers. By 2006, agricultural tax that had been implemented for 2600 years in China was completed eliminated. The pace of investment accelerated in recent years. Government investment in agriculture and rural development has also been targeted at the rate not lower than overall growth of the governments' revenue.

Land Policy. China initiated the Household Responsibility System (HRS) in 1979, which dismantled the communes and contracted agricultural land to households, mostly on the basis of family size and number of people in the household's labor force. By 1984, about 99 percent of agricultural land was contracted to all individual households for 15 years. At its conclusion, on average, average farm size was about 0.6 hectare. Although most policy makers currently seem to favor more secure rights, they still are searching for complementary measures that will not forego all of the pro-equity benefits of the current land management regime. One of the most important changes in recent years has been that the duration of the use contract was renewed for additional 30 years after the first term of 15 years contracted was expired. By 2000, about 98% of villages had amended their contract with farmers to reflect the longer set of use rights (MOA, 2001).

With the issue of use rights, resolved, the government is now searching for a mechanism that permits the remaining full-time farmers to gain access additional cultivated land and increase their income and competitiveness. One of the main efforts is a decree of new Rural Land Contract Law. The Standing Committee of the National People's Congress approved the Law in 2006. According to this law, although the property rights over the ownership of the land remains with the collective, the Law conveys almost all other rights to the contract holder that they would have under a private property system. In particular, the Law clarifies the rights for transfer and exchange of the contracted land, an element that may already be taking effect as researchers are finding increasing more land in China is rented in and out. We expect that land use rights will be gradually moved to a permanent use rights status and farm size will be also smoothly expanded in the coming decades.

Market Reform. After 30 years of reform, China's agriculture has become much more market-oriented. Traders moved products around the country with increasingly regularity and factors adjusted more rapidly. The markets have been shown to have become increasingly competitive, integrated and efficient overtime (Huang et al. 2004). The fully liberalization of domestic cotton and grain markets in China clearly showed that its leaders have been using this opportunity to develop its health domestic agricultural market.

To facilitate market development, the government also has substantially increased its investment in market infrastructure and will continue to invest the market infrastructure as well as to improve its market integration. Leaders see a need to establish an effective national marketing information network. Officials in the ministry of agriculture have been attempting to standardize agricultural product quality and promote farm marketing through development of vertical integrated market. Some also have advocated the creation of farm associations. More generally, all of these moves are part of an effort by leaders to shift fiscal resources that used to be used to support China's expensive price subsidization schemes (including both domestic and international trade subsidies) to productivity- enhancing investments and marketing infrastructure and food quality and safety improvements.

Research and Development. After the 1960s, China's research institutions grew rapidly, from almost nothing in the 1950s, to a system that now produces a steady flow of new varieties and other technologies. China's farmers used semi-dwarf varieties several years before the release of Green Revolution technology elsewhere. China was the first country to develop and extend hybrid rice. Chinese-bred conventional varieties of rice, wheat, sweet potatoes and many other crops were comparable to the best in the world in the pre-reform era. Agricultural technology change has been an engine of China's agricultural growth. China's crop yields are among highest in the world.

A recent study shows that China's agricultural research investment has increased significantly since the late 1990s and is expected to maintain high growth in the coming decades (Hu et. al., 2007). Average annual growth rate of government fiscal investment on agricultural research increased significantly from 5.5 percent in 1995-2000 to 15 percent in 2000-2005. Consequently, agricultural research investment intensity from government (ARII), the percentage of agricultural research expenditure in agricultural GDP, had increased from 0.36 percent in 2000 to 0.53 percent in 2005 (Hu et al., 2007). If this growth rate of investment will be continued, it is expected that ARII will reach about 1 percent by the early 2010 and even higher in the coming decades.

Water Infrastructure Development. Prior to economic reform most of the state's effort was focused on building dams and canal networks, often with the input of corvee labor from farmers. After the 1970s, greater focus was put on increasing the use of China's massive groundwater resources (Wang et al., 2005). By 2005, China had more tubewells than any country in the world, except possibly for India. Although initially investment was put up by local governments with aid from county and provincial water bureaus, by the 1990s the government was encouraging the huge shift in ownership that was occurring as pump sets and wells and other irrigation equipment went largely into the hands of private farming families (Wang, 2000). At the same time, private water markets (whereby farmers pump water from their own well and sell it to other farmers in the village) were also encouraged. The main policy initiative after the mid-1990s in the surface water sector was management reform (with the goal of trying to make water use more efficient). In the 11th Five Year Plan (2006-2010) and long term plan toward 2020, China plans to develop a "Saving-Water-Society" to ensure sustainable water through various economic and regulatory policies and adoption of water saving technologies in agricultural and other sectors.

Other Policies. Outside of agriculture, there have also been many policy responses. These include the promotion of off-farm employment, liberalization of regional labor market and urban employment. In recent years, off-farm income reached more than half of farmers' total income and has become major sources of rural income growth since the 1990s.

7.4 Methodology and Scenarios

7.4.1 Methodology

In order to have better understanding China's agriculture in the coming decades, projections on China's agricultural demand, supply and trade have been conducted based on Agricultural Policy Simulation and Projection Model (CAPSiM) developed by Center for Chinese Agricultural Policy. CAPSiM was developed out of need to have a framework for analyzing policies affecting agricultural production, consumption, price and trade at the national level. CAPSiM is a partial equilibrium model. Most of the elasticities used in the CAPSiM were estimated econometrically using state-of-the-art econometrics and with assumptions that make our estimated parameters consistent with theory. Both demand and supply elasticities change over time as income elasticities depend on the income level and cross-price elasticities of demand (or supply) depend on the food budget shares (or crop area shares).

CAPSiM explicitly accounts for urbanization and market development of the demand side. In our supply side analysis we account for changes in technology, other agricultural investment, environmental trends and competition for labor and land use. Supply, demand and trade respond to changes in both producer and consumer prices. Details of the model description can be found in Huang and Li (2003).

7.4.2 Scenario Development

In projecting China's future food economy, three alternative scenarios are formulated. They are baseline, low agricultural R&D investment, and high agricultural R&D investment. Base year is 2004 and the projection period is to 2020 and 2050. It should be noted that it is not possible to predict any real world, including food economy in China, in the future. Any projections, including those presented below, are under certain assumptions that may change time by time. However, the projections may help us to understand the trends and major driving forces of food economy in the future.

7.4.3 Baseline Scenario

On the demand side, population increase, urban expansion and income growth will continue to be the major driving sources of China's demand for food in the future (Huang et al., 2006). On supply side, institutional reform, technology changes, input increase, irrigation expansion and market liberalization all contributed to successful performance of China's agricultural growth in the past. However, in the future, China's agriculture and food production growth may largely depend on technology changes, particularly on the investment in agricultural R&D (Fan and Pardey, 1997; Huang and Rozelle, 2002; Rozelle and Huang, 2000).

Population has been an important determinant of food balance in the past, but its effects on aggregate food demand will be weakening in the future. Population growth rate peaked in China in the late 1960s and early 1970s. Since then, fertility rates and the natural rate of population growth have begun to fall. In the entire period of 1990s, annual growth rate of population was only 1 percent, which was further reduced to about 0.6 percent only in recent years (NSBC, 2007). According to the UN's projection, while the population will continue to increase in the future, it will rise only from 13.1 in 2005 to about 14.1 billion in 2020 and 14.3 billion in 2030, with an average annual growth rate of 0.5 percent in 2006-2020 and 0.15 percent only in 2021-2030. Indeed, before the middle 21st century, China's population will start to fall. UN projects that China's population will fall to 13.8 billion in 2050, which is about 3.5 percent less than the population in 2030.

While overall population growth will not have significant impact on aggregate food demand, the rapid urbanization will have large impact on food consumption patterns and composition of foods. China's urban sector expanded rapidly in the past and is expected to continue in the coming decades. For example, the shares of urban population increased from 27 percent in 1990 to 44 percent in 2006. Based on population projections of the United Nations (2005), the shares of urban population will rise to 55 percent in 2020 and 62 percent in 2030. By 2050, there will be about three fourth of Chinese living in cities in China. Because the consumption patterns in urban areas differ largely from those of rural residents (Huang and David, 1993; and columns 4 and 7, Table 7), we expect the urbanization will have significantly impacts on the national food demand through substituting staple food (e.g., rice and wheat) by meat and other high value foods in the coming decades.

Income growth will have positive impacts in per capita food consumption for nearly all foods except for rice, wheat, and some coarse grains in the several decades. Given the recent government concerns on the enlarging the gap of incomes between rural and urban, we assume that the growths of income in urban and rural areas will gradually converged over time in the projection period. We further assumes per capita income will continue to grow but with declining growth rates. Urban average annual real income growth rate was 9.6 percent in 2001-2005, we assume this growth rate will decline to about 8 percent in the next decade and gradually fall to 5 percent by 2025 and 4 percent thereafter. The average annual growth rate of per capita income in rural areas was only about 6 percent in 2001-2005, this growth rate is assumed to maintain in the coming decade and then fall gradually to 5 percent in 2025 and 4 percent in 2021-2050.

In 1980s and 1990s, agricultural research investment in real terms grew by about 5 percent annually, but significantly increased recently. The recent recovery in research investments, together with China's commitment to a strong domestic grain economy, leads to the expectation that China will sustain its recent upturn in investment funding over the long run. Under baseline, we assume that the current trend of investment in agricultural research will be continued with an average annual growth of 8 percent in real term in 2006-2020. After 2020, the annual growth rate of investment in agricultural R&D will still remain at 7 percent in 2020-2030 and 6 percent in 2030-2050.

Public irrigation expenditures financed a big part of the construction of the national water control network. The investment in irrigation facilities has been by far the largest component of total construction investment in agriculture. It is several times higher than investment in agricultural research. In this study, we assume the growth of irrigation investment will continue. The annual growth rate will remain at 6 percent in 2001-2020 and about 4-5 percent thereafter. These growth rates are higher than the average growth rates in the past 30 years, but are lower than the rates that have been achieved since the late 1990s.

On trade policies, under baseline, the current tariff rates and non-tariff barriers are assumed to change over 2006-2015. For those agricultural commodities that have positive nominal protection rates, their prices related to the world prices are assumed to decline as China changes the policies to meet the global trade liberalization. These commodities include wheat, maize, other coarse grains, edible oils, and sugar crops. While the prices of other commodities such as rice, vegetable, fruits, livestock products (except for milk), and fish are expected to rise with trade liberalization. We also assume that the remaining border distortion will be eliminated in 2020.

7.4.4 Alternative Scenarios

Two alternative scenarios are developed to examine the impacts of productivity-enhanced investment on China’s food and agricultural economy. They are high and low investments in agricultural R&D. In order to the impacts of these two scenarios, we assume that all assumptions embodied in the baseline discussed above are remained in these two alternative scenarios except for the assumptions on agricultural R&D investment.

High agricultural R&D investment scenario assumes that China will significantly increase its investment in the coming decades. Compared with the baseline, high agricultural R&D investment scenario will have an annual growth rate of 2 percentage points higher. That is, average annual growth rate of agricultural R&D investment will reach 10 in 2006-2020, 9 percent in 2020-2030 and 7 percent in 2030-2050.

Low agricultural R&D investment scenario assumes that China’s commitment to agricultural productivity enhanced investment has reached its peak in recent years and will start to fall in the coming decades. Average annual growth rate of agricultural R&D

investment will fall from more than 10 percent in recent years to 6 percent in 2006-2020, 5 percent in 2020-2030 and 4 percent in 2030-2050.

7.5 Prospects of China's Agriculture in the Future

According to the analysis, per capita food grain consumption in China hit its zenith in the late 1990s and falls over the entire projection period (1st row, Table 7.7). The average rural resident will increase slightly food grain consumption through the late 2000s and fall thereafter. Urban resident food grain consumption has declined and will continue to fall in the coming decades. The ebb of per capita food grain demand at the national level occurs in all years because of the impact of urbanization.

Table 7.7 Per capita direct food consumption (kg/person) in rural and urban China under the baseline scenario, 2004-2050

	China			Rural			Urban		
	2004	2020	2050	2004	2020	2050	2004	2020	2050
Grain	162	152	116	199	214	190	108	104	85
Cereal	151	139	102	192	206	182	93	87	69
- Milled rice	74	73	55	91	105	94	49	48	38
- Wheat	63	58	45	80	88	82	39	36	29
- Maize	6	3	1	9	6	2	2	1	1
- Other	8	4	2	11	8	4	3	2	1
Sweet potato	2	2	1	2	1	1	3	2	1
Potato	8	11	13	6	7	7	11	15	15
Soybean	8	9	9	7	8	8	8	9	9
Edible oils	8	11	13	7	10	12	9	12	13
Sugar	3	4	6	2	2	3	4	6	7
Vegetable	173	258	338	157	243	333	197	270	341
Fruits	44	82	110	22	42	58	76	112	132
Meat:	42	72	100	30	54	75	56	87	111
Pork	29	48	63	23	40	54	37	55	68
Beef	3	5	8	1	2	3	5	8	10
Mutton	2	3	4	1	2	3	3	3	4
Poultry	8	16	25	5	10	15	11	21	29
Egg	14	19	25	9	12	16	21	25	28
Milk	18	47	84	3	24	55	40	65	96
Fish	15	29	49	9	17	30	23	38	57

For rice and wheat, per capita consumption will decline slightly less than total grain consumption. At the national level, per capita rice and wheat consumptions are leveling off and will start to fall in the projection period (3rd row, Table 7.7). But per capita rice and wheat consumption for rural consumers will continue to rise slightly through 2015 (not showing in Table 7.7), reflecting their still positive, albeit small, income elasticities in the next 5-10 years, and fall thereafter for rural consumers (3rd and 4th rows, Table 7.7).

Both rice and wheat consumption for urban consumers, however, falls monotonically over the projection period (the last 3 columns, Table 7.7).

In contrast, per capita demand for edible oils, vegetables, fruits, meats and fish is projected to rise sharply throughout the next 5 decades (Table 7.7). Income and urbanization are two primary determinants of rising demands for these non-staple and high-value food products. For crops, most significant increases in food consumption will be in fruits, vegetables, sugar and edible oils (rows 10-13, Table 7.7).

In the next 5 decades, per capita consumption of meat, milk and fish will be more than double. Meat (port, beef, mutton and poultry) consumption per capita will rise from 42 kg in 2004 to 72 kg in 2020 and 100 kg in 2050. Within meat sector, while starting from a lower level, per capita demand for poultry will increase proportionally more. Fish consumption will be tripled in the next 5 decades. Rural meat demand will grow at higher rate of overall demand, but urbanization trends will shift more people into the higher-consuming urban areas. The projected rise in meat and poultry product demand will stimulate aggregate feed grain demand, particular demand for maize.

Table 7.8. Area, yield and production of major crops under the baseline scenario, 2004-2050

	Area (Million ha)			**Yield (ton/ha)**			**Production (million tons)**		
	2004	**2020**	**2050**	**2004**	**2020**	**2050**	**2004**	**2020**	**2050**
Grains (1)	92.0	89.4	82.8	4.3	5.2	5.3	397	469	441
Grains (2)	92.0	89.4	82.8	4.9	5.8	5.8	451	522	483
Cereal	82.6	80.1	73.7	4.4	5.3	5.4	362	427	400
- Milled rice	28.4	25.1	20.4	4.4	4.9	4.7	125	124	96
- Wheat	21.6	19.0	15.9	4.3	5.2	5.0	92	98	79
- Maize	25.4	28.7	30.8	5.1	6.5	6.8	130	186	208
- Others	7.1	7.3	6.7	2.0	2.6	2.6	15	19	17
Sweet potato	4.9	4.3	3.9	4.2	4.8	4.6	21	21	18
Potato	4.6	5.0	5.2	3.1	4.2	4.4	14	21	23
Soybean	9.6	10.8	11.4	1.8	2.6	2.9	17	28	33
Edible oils	14.4	14.1	14.0	0.5	0.9	1.0	8	12	14
Sugar	1.6	1.6	1.7	5.9	8.5	9.4	9	13	16
Vegetable	17.6	17.7	19.0	20	28	31	355	501	580
Fruits	9.8	10.3	12.1	10	17	20	94	179	245
Cotton	5.7	5.6	5.6	1.1	1.7	1.9	6	10	11
Sum of above	151	150	147						

Baseline projection shows that although total crop areas will decline marginally, the composition of crops is projected to change significantly in the future (Table 7.8). Total crop area hit its historical high in 2000, started to fall in recent years, and is projected to fall slightly in the future (last row, Table 7.8). The decline in crop area is mainly due to the increasing opportunity costs of land for agricultural production during the process of industrialization and urbanization. The overall decline in crop area is mainly due to a large reduction of grain area cereal (row 1). Areas of all grains except for maize will fall through 2050 (the first 9 rows, Table 7.8). A moderate rise in maize area is due to the increasing demand for maize as feed for livestock production. Area of other crops that have positive income elasticity of demand will expand. These include vegetable, fruits, soybean, and sugar crops.

Output growth will mainly come from crops' yield increases (columns 4-9, Table 7.8). But yield growths differ largely among commodities and over projection period. Yield expansion is projected to be more for non-staple food as increasing demand for these commodities will lead to higher prices and induce more productivity enhanced investment in these sectors. The largest yield increase is projected in the first 2 decades and slowdown significantly after 2020. Yields of rice and wheat will reach their peaks in about 2030 and decline a little bit due to weakening demand and therefore the falling prices in the late projection period.

Baseline projections show that China's domestic grain production will increase in 2004-2020 and decline slightly in 2020-2050 (Table 7.9). Total grain production will rise from 397 million metric tons (mmt) (or 451 mmt when rice is measured in paddy) in 2004 to 441 mmt in 2020 with an annual growth rate of 1.05%. However, in the following three decades (2020-2050), grain production will fall annually by 0.02 percent. Among various grains, maize is only crop that will experience significant growth in production toward 2050. Maize production will rise from 130 mmt in 2004 to 186 mmt in 2020 and 208 mmt in 2050, increase by 60 percent in 2004-2050.

Table 7.9. Demand and supply of grain under the baseline scenario, million tons, 2004-2050.

		Utilization					Stock changes	Import	Export
	Production	Total	Food	Feed	Industry	Others			
Grain (1)									
2004	397	400	209	133	24	33	2	10	5
2020	469	478	215	200	29	35	0	12	3
2050	441	451	164	210	48	29	0	15	5
Cereal									
2004	362	365	196	124	16	30	2	10	5
2020	427	436	196	188	20	31	0	12	3
2050	400	410	144	204	36	26	0	15	6
Rice-milled									
2004	125	117	96	8	2	11	9	1	1
2020	124	122	103	7	3	10	0	0	2
2050	96	92	78	2	5	7	0	0	3
Wheat									
2004	92	98	82	5	3	8	0	7	1
2020	98	99	82	5	5	7	0	1	0
2050	79	78	63	1	8	5	0	0	1
Maize									
2004	130	132	8	106	8	10	-4	0	2
2020	186	196	5	170	8	13	0	11	1
2050	208	222	2	193	15	12	0	14	0

Other cereal									
2004	15	19	10	5	3	1	-3	2	0
2020	19	19	6	7	5	1	0	0.6	0.5
2050	17	17	2	7	7	1	0	0.6	0.5
Sweet potato									
2004	21	21	3	9	7	2	0	0.0	0.0
2020	21	21	3	10	6	2	0	0.0	0.1
2050	18	18	2	6	9	1	0	0.0	0.1
Potato									
2004	14	14	10	1	2	2	0	0.1	0.2
2020	21	21	16	1	2	2	0	0.1	0.1
2050	23	23	18	1	3	2	0	0.3	0.0

Domestic grain consumption growth will be slightly higher than production growth in the next five decades (Table 7.9). Most increase in grain demand will come from grain used as feed (column 4, Table 7.9). Total feed demand will rise from 133 mmt in 2004 to 200 mmt in 2020, with 50 percent increase, primarily from maize (column 4). However, the growth rate fell substantially after 2020 as the growth of demand for meat slows down in the late projection period. It is interesting to note that total food gain demand will fall after 2020. This reflects negative income elasticities of demand for food grain and falling population growth. For aggregate grain demand, falling food demand will be more than the rise in feed and industry demand in 2020-2050, which will lead to overall decline of total grain demand from 478 mmt in 2020 to 451 mmt in 2050.

Our baseline projections show many agricultural products will still keep high self-sufficient levels in 2020-2050 (Table 7.10). Although the imports will rise or self-sufficient rates will fall for many of land intensive food products, for those commodities which China has comparative advantage in, their export will rise and self-sufficient levels will exceed 100% under more trade liberalization in the coming decades.

China will achieve nearly self-sufficient in grain in the coming decades. China will continue to export its Japonica rice to Fareast Asian countries. In 2020-2050, rice self-sufficiency will reached 101 to 102 percent, or China will export 1-2 percent of its rice to the world market (rows 3-4). Although China needed to import wheat in the base year (2004), the import will decline and reach self-sufficiency by 2020. Declining wheat import is a result of both falling per capita wheat consumption and rising wheat yield. Although the nation will be a net importer of maize, import will be only about 5 percent of domestic consumption.

Table 7.10. Self-sufficiency rates (%) of food and feed products under baseline projection, 2004-2020

	2004	2020	2050
Grain	99	98	97
Cereal	99	98	98
- Rice	100	101	103
- Wheat	94	100	101
- Maize	102	95	94

- Others	92	100	99
Sweet potato	100	100	100
Potato	101	100	99
Soybean	47	45	43
Edible oils	65	74	70
Sugar	89	88	76
Vegetable	101	102	102
Fruits	101	103	103
Pork	101	101	100
Beef	100	97	97
Mutton	99	97	96
Poultry	101	103	104
Egg	100	100	100
Milk	96	89	83
Fish	102	101	102

On non-grain crops, except for vegetable and fruit, imports of soybean, edible oils and sugar will be high. In the coming decades, China will import 55-60 percent of soybean from the world market to meet its increasing demand in the domestic market. For edible oils (e.g., rapeseeds) and sugar, the imports will also reach 20-30 percent of domestic consumption (Table 7.10). However, baseline also projects that labor-intensive crop production will expand more than domestic demand. Currently, China exports about 1 percent of its vegetable and fruit products to the world market. Baseline projects that despite domestic demand of both vegetable and fruits will rise with income growth, China's will be gradually becoming an important player in vegetable and temperate fruit export markets. We project that about 2 percent of vegetable production in China will be exported in 2020-2050. Fruit export will enjoy even a higher rate. Despite import of tropical and sub-tropical fruits will rise over time, exports will be much more than import. Net export (export – import) will be about 3 percent of total domestic consumption in 2020-2050 (Table 7.10).

In the livestock and aquatic sector, the increases in the domestic production nearly match the increases in demand. In the next 50 years, China will be able to export about 1 percent of pork and 3-4 percent of poultry into world market (Table 7.10). Obviously, part of meat export is due to China's willingness to import maize as we projected under the baseline. Cheaper maize and other feed from the world market helps China to boost its livestock sector. On the other hand, about 3-4 percent of beef and mutton consumption and 10-20 percent of milk consumption will be met by imports. Fish has been the number one agricultural export commodity in China. Baseline projection shows that the export trend in the past will be continued in the future though net export will account for only about 1-2 percent of domestic consumption in 2020-2050 (Table 7.10).

7.6 Implications for R&D Investment

The results of alternative scenarios on investment in agricultural R&D show that the major way China can better protect its future agricultural and food security at nation’s aggregate level is to invest heavily in agricultural technology. China will be able to achieve one of the major components of its food security (grain self-sufficiency) target in the future under high R&D investment scenario. Low R&D investment will lead to import of nearly all agricultural commodities in the coming decades (Table 7.11).

Table 7.11. Changes on self-sufficiency rates (%) of food and feed products under the low and high R&D investment scenarios (compared with the baseline in Table 10) in 2020 and 2050.

	Low R&D investment		High R&D investment	
	2020	2050	2020	2050
Grain	95	92	100	101
Cereal	95	92	100	101
- Rice	98	97	103	105
- Wheat	97	96	102	104
- Maize	91	88	98	98
- Others	99	97	100	100
Sweet potato	99	99	101	101
Potato	97	94	102	103
Soybean	42	37	48	50
Edible oils	71	65	76	74
Sugar	83	68	93	84
Vegetable	98	95	104	105
Fruits	100	97	105	107
Pork	98	96	101	103
Beef	95	94	99	100
Mutton	95	92	99	100
Poultry	101	101	104	106
Egg	99	98	101	101
Milk	85	76	94	91
Fish	98	97	103	106

China could achieve more than full self-sufficiency in overall cereal in the entire projection period if there would be much more investment in agricultural R&D. China could export not only rice to world market, we also project surplus of wheat in China under high agricultural R&D investment scenario. Boosting in maize productivity is projected to turn China from a large net importing feed country to nearly self-sufficient in 2020-2050 (row 5, Table 7.11). Although China's cereal yields are already high, rice yield is still about 15-30% lower than those in USA, Australia and Japan. Chinas' wheat's yield in 2004 was only about 70% of that in Mexico and 50% in France. The potential increase in maize yield is also high. China produced 5.1 tons maize per hectare in 2004, the corresponding figure was more than 8 tons in USA in the same year.

The high R&D investment will also significantly improve China's export on labor-intensive products and reduce its imports of land-intensive products. Compared with the results under baseline, the high R&D investment will expand exports (or self-sufficiency rates) of horticultural products, pork, poultry, and fish by about 2 percent to 4 percent and lower imports of wheat, maize, soybean, other edible oils and some livestock products by about 3 percent to 8 percent (comparing the last column in Tables 7.10 and 7.11).

However, under low R&D investment scenario, self-sufficiency rates of all agricultural commodities will fall by about 2 percent to 6 percent (comparing the last column in Table 7.10 with column 2 in Table 7.11). Grain self-sufficiency level will fall below the national target of 95 percent after 2020 and reach nearly 10 percent by 2050 under the low agricultural R&D investment scenario (row 1, Table 7.11). The low R&D investment will turn China from major rice export to one of major rice importers in 2050. Annual maize import will reach nearly 20-30 mmt in the coming decades.

High agricultural R&D investment will also improve income distribution and help to reduce poverty. China will significantly reduce its poverty population in the coming years. In 2001, China has about 12 percent of its rural population living under US$1/day (Figure 7.3). Under high R&D investment scenario, with rising income from both agricultural and non-agricultural sectors, the rural population under poverty would be completely eliminated by 2020, much advanced than the baseline (after 2030) and the low agricultural R&D investment scenario (by 2040, Figure 7.3).

Figure 7.3: Shares of rural population under poverty (%)

7.7 Concluding Remarks

Nearly three decades of economic reform in China have achieved remarkable economic growth and structural changes. During the 1980s, 1990s and early 2000s, China has become one of the fastest growing economies in the world. GDP grew at nearly 10 percent annually in the past 30 years. Over the course of the reform period, both rural and urban incomes have increased noticeably. The rising income has also associated with substantial reduction of poverty and significant improvement of food security.

China's rapid growth would not have been possible without its domestic economic transformation and its "open-door" policy. The successful growth in agricultural sector facilitates the economic transition from agriculture to industry/service and from rural to urban economy. The growth in agricultural productivity enabled China to release its large pool of abundant rural labor, providing cheap labor for the nation to industrialize its economy. Rising international trade and FDI has been the other engine of economic growth and facilitate China's economic structural changes toward more comparative sectors. These occurred not only among agricultural, industry and agriculture, but also within agricultural sector.

Food security has been one of the central goals of China's agricultural policy. Since the early 1980s, domestic reforms to boost agricultural growth and farm income have covered nearly every aspects of the economy, started from land reform, and then gradually move to both input and output markets, from agricultural sector specific policy to macro economy policy. The reforms have resulted in significant impacts on its economy. China has been able not only to increase its ability to feed its growing population with the extremely limited natural resources, but also developed itself as one of major food and agricultural exporters in the world recently. Per capita availability of food, household food security, and nutrition have all improved significantly. Increased domestic production is almost solely responsible for increased per capita food availability.

China's experience also demonstrates the importance of technological development and public investment in improving agricultural productivity, farmer income, and food security in a nation with limited land and other natural resources. Technology has been engine of China's agricultural productivity growth in the past and will continue to play major role in boosting China's agricultural development and improving the nation's food security in the 21st century.

While there are a number of challenges related to China's agricultural sector, we are still very optimistic concerning China's food economy. The high level of China's food security under the baseline scenario suggests that China's massive import of food is not likely to occur if the current trend of investment in agricultural R&D will be remained in the future. The projection results of high R&D investment scenarios suggest that China could be able to produce nearly all foods to meet its growing demand in the next 50 years if China could further raise its investment in agricultural R&D. In contrast, China's food import will rise significantly if its investment in agricultural R&D would not be increased substantially.

The results from this study also have significant implications to the rest of world. China's agricultural development and technology changes will contribute to the global food security in terms of both increasing food supply and stabilizing or lowering world food prices. China's trade will also provide both opportunities and challenges to the rest of the world. For those countries whose agricultural economic structures are complementary to China there will be emerging opportunities offered by China's increasing imports of some agricultural products. While countries that have similar agricultural export structures to that of China and are competing for the same export markets will have to put extra efforts to restructure their economies and invest more in agricultural R&D.

8 Results for India[7]

8.1 Introduction

This section focuses particularly on future of growth and development in India when certain plausible assumptions on future changes are made and applied through the use of a Computable General Equilibrium (CGE) model (Adam and Bevan, 1998, Dervis, De Melo and Robinson, 1982, Devarajan, Robinson and Lewis, 1996). This model is used to examine the impact of agricultural knowledge, science, and technology (AKST), on the future of agricultural and other workers, wellbeing of various rural and urban households, and on overall growth in the economy. The advantage of using a CGE model is that it interconnects general equilibrium effects on different policy option. For example a study by Narayana et al (1991) shows that the combination of investment of infrastructure with welfare schemes such as food for work programmes is a very effective way of reducing poverty compared to providing food subsidy.

In another study by Clarete and Roumasset (1990) trade liberalization for agricultural commodities was examined and the results show that growth actually depends on the removal of quantitative restrictions on industry. Simulation runs can be designed by using the CGE models so as to get various welfare findings. It is possible to determine the winners and losers due to change in policy or other external shocks. Distributional and sectoral analysis can be carried out by using families of multi-sectoral models such as general equilibrium models (input-output, SAM multiplier, etc.) and more particularly CGE models that go some way towards meeting these desiderata.

Generally, it is more straightforward and therefore better to work with one period in such models. In such a model, the relevant set of markets is usually the list of sectors identified on the production side, plus markets for labor and capital. Moreover, we need to have functions for imports and exports in an open economy. Generally, imports of given sector's output are treated as imperfectly substitutable with the corresponding domestic good, and the model does not consider supply and demand for the imported good in the whole world economy. This may be a limitation, but at the same time we may note that it is not possible to model everything, and there is a trade off. The family of CGE models can address more of distributional and poverty issues compared to trade focused models. It may also be noted here that in the CGE models, the standard equilibrium assumptions can be relaxed by allowing non-neoclassical closures in certain key markets, such as the labor market. This would allow to incorporate unemployment in the model. In case of intertemporal analysis, dynamics can be introduced by allowing economic agents to pursue dynamic optimization. Again this would understandably lead to many additional problems, such as the exact behavioral relationships for expectations formation. Such models would multiply complexities and in a dynamic framework and so modelers often have to decide between attention to behavioral detail as compared to multisectoral analysis. Moreover, even after introduction of such dynamics, one needs to examine whether the key parameters are intertemporally stable. These parameters are generally calibrated deterministically given the base period dataset of the CGE model. So one would have to think whether such treatment is the best way to proceed as by its

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[7] *This section was prepared by Anushree Sinha, together with Poonam Munjal, P K Ghosh, and Palash Baruah and draws on a longer study prepared for this project (Sinha et al. 2008).*

very nature, over period there would be substantial changes in such areas as technical progress in production, the changes in demand structures, and the changing global environment with corresponding impact on external trade. Moreover, projected parameters would have many assumptions and also might have difficult consistency issues.

Under such conditions for the present study we propose a purely deterministic approach to analyze the dynamics of transition, based on a variety of expectations as to the possible evolution of the structure of the economy under study (as provided by a global model, IMPACT). The 'man-machine' dialogue (Hare and Bevan, 1996) is then used where a variety of scenarios can be generated reflecting the alternative AKST projections. However, we do change the labor and investment supply based on certain projections. This implies that in future the labor output ratios are changed. But this is not endogenous in the model.

Thus, having decided to proceed through a comparative static framework, we extend on the CGE model developed by Sinha and Sangeeta (2000) by augmenting the sectoral classifications disaggregating agriculture into major crop sectors (in concordance with the IMPACT model). This gender CGE (GEN-CGE) can address many factors simultaneously thus making it possible to have the various first order and second order relationships determine the outcome which is difficult to otherwise reason out by logical analysis. The various factors that can be explicitly studied through this GEN-CGE are:

1. Trade Policies affecting inputs (tariff shocks)
2. Technological change (productivity shocks)
3. Impacts of “second round” effects of policy changes
4. The outcome of general equilibrium on various household types and types of workers comprising these households.

The GEN-CGE can be used to decompose the effects of policy changes and also can be used to track the distributional consequences of policy choices. The model can evaluate feasible policies or “policy packages” in a systematic fashion. Policy analysis through the use of the model permits comparisons across the set of compatible policy combinations. However, in this paper we use only two policy shocks.

8.2 Assumptions

In the reference run production and agricultural products are assumed to grow at 6 percent in 2025 and decelerate after that to 3.5 percent by 2050.

World prices increase, on average, by 2.3 percent till 2025 and then decelerate to less than 1.0 percent by 2050 (Table 8.1). Moreover, in the reference run, we have shocked the imports tariff in 2025 and 2050.We assume that the peak average tariff is to get reduced by 88 percent in 2025 and by 98 percent in 2050. In the ‘Scenario 1’ the growth till 2025 is as high as 15 percent and accelerates to 17 percent in 2050. Prices also grow by 5 percent till 2025 and by 4 percent till 2050. In case of ‘Scenario 2’ agriculture grows at an average of about 1.4 percent till 2025, decelerates after that and eventually declines by 0.11 percent in 2050. Prices in this scenario reflect similar behaviour, rising by 0.25 percent till 2025 and declining by 0.63 percent in 2050. The scenario 3 has agriculture production falling per year by about 0.49 percent and more sharply by 0.95 percent in 2050. Prices also declined by 0.66 percent till 2025 and by 0.91 percent till 2050. The production shock in the high AKST scenarios is about 15 percent to 1 percent more than agriculture across the various scenarios and years and for prices lower by 3 to 5 percent in 2025 and 2050 respectively. The exogenous shocks to manufacturing production and prices are driven by the global CGE model at ABARE.

Table 8.1: Assumptions on World Prices

	Reference Scenario		Scenario-1		Scenario-2		Scenario-3	
	2025	2050	2025	2050	2025	2050	2025	2050
Rice and rice milling	51.88	61.76	107.89	217.46	0.88	-12.85	-16.55	-45.66
Wheat	68.70	90.89	172.35	422.56	3.25	-17.87	-25.59	-52.77
Maize	87.93	97.17	251.77	590.18	-3.91	-31.61	251.77	-64.59
Other Coarse Grains	58.12	81.28	369.41	572.66	58.02	-42.39	-35.11	-70.86
Pulses	35.63	5.50	135.18	236.84	-26.03	-64.84	-50.59	-82.78
Potato	20.08	-5.43	75.80	108.69	-21.07	-51.81	-39.94	-68.43
Other Crops	97.12	49.27	102.75	157.14	90.09	-8.96	-5.96	-35.67
Oilseeds and edible oils	58.35	41.18	131.06	219.61	6.20	-30.33	-13.10	-51.62
Meat	7.31	89.68	23.51	61.06	-17.69	-21.60	-26.28	-33.96
Fishing	11.80	89.68	23.51	89.68	-17.69	-21.60	-26.28	-33.96
Other agriculture	58.02	49.27	102.75	157.14	90.09	-8.96	-5.96	-35.67
Fertilizers	60.70	49.27	102.75	157.14	90.09	-8.96	-5.96	64.33
Other manufacturing	0.70	49.27	102.75	157.14	0.70	-8.96	-5.96	64.33
Other Services	9.00	49.27	102.75	157.14	90.09	-8.96	-5.96	64.33

The Gender-CGE model incorporates labor categories by gender. The NAS data give total workers in a sector, which were broken up by different types of workers. The share of each type of labor, i.e., female and male within labor categories in a particular sector was generated from the National Sample Survey Organization's (NSSO) household survey on employment/unemployment. Additional information on the various sectors in the model can be found in Sinha et al. (2008) and in the appendix.

8.3 Scenario Results

In this section we examine the distributional consequences of changes in productivity, world prices and trade reforms using the CGE model. The base structure of the economy follows the actual situation of the Indian Economy for the year 1999-00. Furthermore, to estimate the population and workers for the years 2025 and 2050: we have used the base population and employment numbers from the NSSO survey on "Employment Unemployment' for the year 1999-00. Then we also have used employment data for the year 2004-05, that is with a gap of 5 years. Using these data sets we get growth in the various types of workers in these 5 years. With the assumption that labor growth will follow this trend we change the labor supply for the various types of workers. Also, we have got the population growth rates for the years 2025 and 2050, as provided by IFPRI. These growth rates by types of labor are applied on total population and employment (assuming that employment will grow with the similar structure as in the NSSO rounds 55th through 61st) of the base year to get total for 2025 and 2050 (see Table No. 8.2).

Table 8.2: Growth in workers of different types distinguished by gender by aggregate sectors

Growth in 2004-05 over 1999-00	Male					Female					
	Agriculture	Manufacturing	Services	Public	Total	Agriculture	Manufacturing	Services	Public	Total	Grand TOTAL
Regular workers	-18.56%	18.43%	19.79%	-19.64%	9.88%	-20.76%	27.16%	54.43%	-11.57%	35.77 %	14.12%
Casual workers	3.31%	3.85%	24.20%	-41.36%	8.76%	13.21%	19.17%	15.78%	-1.26%	14.08 %	10.61%
helpers+oaw	11.62%	13.14%	25.68%	52.61%	15.74%	26.54%	33.31%	18.98%	-78.81%	26.71 %	19.51%
Average growth per annum											
Regular workers	-3.71%	3.69%	3.96%	-3.93%	1.98%	-4.15%	5.43%	10.89%	-2.31%	7.15%	2.82%
Casual workers	0.66%	0.77%	4.84%	-8.27%	1.75%	2.64%	3.83%	3.16%	-0.25%	2.82%	2.12%
helpers+oaw	2.32%	2.63%	5.14%	10.52%	3.15%	5.31%	6.66%	3.80%	-15.76%	5.34%	3.90%
Average growth 2025											
Regular workers	-93%	92%	99%	-98%	49%	-104%	136%	272%	-58%	179%	70.58%
Casual workers	17%	19%	121%	-207%	44%	66%	96%	79%	-6%	70%	53.07%
helpers+oaw	58%	66%	128%	263%	79%	133%	167%	95%	-394%	134%	97.53%
Average growth 2050											
Regular workers	-185.6%	184.3%	197.9%	-196.4%	98.8%	-207.6%	271.6%	544.3%	-115.7%	357.7 %	141.16%
Casual workers	33.1%	38.5%	242.0%	-413.6%	87.6%	132.1%	191.7%	157.8%	-12.6%	140.8 %	106.13%
helpers+oaw	116.2%	131.4%	256.8%	526.1%	157.4%	265.4%	333.1%	189.8%	-788.1%	267.1 %	195.06%

Source: Authors' work using NSSO DATA 55th Round and 61st Round

The model is used by simulating exogenous shocks adopted for illustrative purposes. The simulations are carried out with an export elasticity of 0.50 and import (Armington) elasticity of 0.75, to represent a comparatively faster movement between domestic consumption and imports but a slower movement for producers. We have set the reference runs for 2025 and 2050, where there had been to change in policy parameters, we also looked at the future possibilities of growth and development by considering that the peak tariff would fall by 88% in the first 25 years with the backdrop of WTO bindings. In the year 2050, this would fall further by nearly another 7 percent. This would mean that the 2050 tariff would be only close to 2 percent.

The lower tariff and the resultant lower import prices would change the relative demand for domestic goods to imports in each sector. These changes depend on the reduction in world prices (and tariff rates whenever applicable) and the elasticities of substitution. The values chosen for behavioral parameters follows common practice in similar CGE models applied to low income developing countries. As in practice, we have assumed that the price elasticity of substitution in consumption is less than unity. Given common Armington elasticities for all sectors, the import share and world prices will play the main role in variation in sectoral production levels and sectoral prices. Reduction in tariff reduces the distortion between domestic and world price of tradeables but this is accompanied with a loss in revenue, at least in a static sense. The productivity growth in the sectors also drive the demand for goods and factors of production.

Wages improve in the reference runs for 2025 and 2050 for all types of workers (Table 8.3). However, the wage rise decelerates in 2050 in the reference runs as we assume that the agricultural and manufacturing production decelerate implying that without changes in the structure of the economy, the growth would not be sustainable in a longer time horizon. In both runs, the wages of regular labor rise more compared to casual labor. Expansion is higher in manufacturing and service sectors that are more intensive in regular labor. So the relative remuneration of regular labor increases with production shocks. Again, the wages of women workers rise relatively faster than those of the male workers. This is because production in the nonagricultural sector--mainly the service sector—increases at a relatively faster rate than agriculture, and this causes demand for regular workers to rise faster. Moreover, as the wages of women workers are lower to start with, the demand for such workers rises at a sharper rate. We do not have any labor market fragmentation here.

Table 8.3: Average wage rate by skill (growth rate in %)

	Base 2000	Reference Scenario				Scenario-1		Scenario-2		Scenario-3	
	Unit = USD	2025	2025-1	2050	2050-1	2025	2050	2025	2050	2025	2050
Labour casual female	34.10	71.43	57.49	142.85	123.04	96.43	257.14	52.14	244.28	41.43	28.57
Labour regular female	195.22	590.19	631.78	1180.38	1352.01	796.75	2124.68	430.84	2018.44	342.31	236.08
Total Female	114.66	513.06	546.39	1026.11	1169.28	692.63	1847.00	374.53	1754.65	297.57	205.22
Labour casual male	73.53	166.39	163.66	332.78	350.24	224.63	599.00	121.46	569.05	96.51	66.56
Labour regular male	204.73	523.10	564.34	1046.20	1207.69	706.18	1883.16	381.86	1789.00	303.40	209.24
Total Female	139.13	428.84	458.46	857.67	981.10	578.93	1543.81	313.05	1466.62	248.73	171.53
Grand Total (female+male)	126.89	466.89	498.19	933.77	1066.12	630.30	1680.79	340.83	1596.75	270.79	186.75

However, the results do point out that labor market fragmentation needs to be developed in any future version, to examine whether women and men respond to labor demand in different ways. This is also to examine if certain sectors have gender wage wedges that could be built in the model to restrict upward movement of wages for women (see Sinha and Adam, 2006).

In the simulations 2025-1 and 2050-1, tariffs are reduced by 88 percent and 98 percent respectively in a static framework. Tariff reduction minimizes the distortion between domestic and world prices of tradables but is also accompanied with a loss in revenue. The level of investment declines and the marginal product of labor declines. Under the assumption of full-employment and competitive market, the consequence of lower prices (tariff cut) is a decline of real wage over time, without any other flanking policies that help raise investment and productivity. As noted above, in our scenario runs the productivity in all sectors are raised resulting in increase in demand. So demand for labor rises increasing the real wage rates as stated (see Table 8.3). As a result the income of all households increases (see Table 8.4), but the income of formal households rise more sharply than that of informal households.

Table 8.4: Private gross income at constant prices (growth rate in %)

	Base 2000	Reference Scenario				Scenario-1		Scenario-2		Scenario-3	
	Unit =10 million USD	2025	2025-1	2050	2050-1	2025	2050	2025	2050	2025	2050
Rural Poor Non Agriculture Formal	123	168.21	179.49	412.11	473.93	227.08	386.88	100.93	84.11	97.56	67.28
Rural Non-Poor Non Agriculture Formal	531	169.51	180.87	415.30	477.59	228.84	389.87	101.71	84.76	98.32	67.80
Rural Poor Agriculture Informal	8007	93.42	99.68	228.88	263.21	126.12	214.87	56.05	46.71	54.18	37.37
Rural Non Poor Agriculture Informal	10031	134.78	143.82	330.21	379.74	181.95	309.99	80.87	67.39	78.17	53.91
Rural Poor Non Agriculture Informal	2807	96.11	102.55	235.47	270.79	129.75	221.05	57.67	48.06	55.74	38.44
Rural Non Poor Non Agriculture Informal	7201	144.07	153.73	352.97	405.92	194.49	331.36	86.44	72.04	83.56	57.63
Total Rural	28701	122.58	130.80	300.32	345.37	165.48	281.93	73.55	61.29	71.10	49.03
Urban Poor Formal	1074	141.00	150.45	345.45	397.27	190.35	324.30	84.60	70.50	81.78	56.40
Urban Non Poor Formal	6464	164.33	175.35	402.61	463.00	221.85	377.96	98.60	82.17	95.31	65.73
Urban Poor Informal	2287	113.14	120.73	277.19	318.77	152.74	260.22	67.88	56.57	65.62	45.26
Urban Non Poor Informal	4616	120.42	128.49	295.03	339.28	162.57	276.97	72.25	60.21	69.84	48.17
Total Urban	14441	140.45	149.87	344.10	395.72	189.61	323.04	84.27	70.23	81.46	56.18
Grand Total	43142	128.56	137.18	314.97	362.22	173.56	295.69	77.14	64.28	74.56	51.42

In the various scenarios output increases due to higher productivity, resulting in demand for labor to rise. This results in increase in the wage rates, more for workers in short supply, i.e., for regular wage earners. The rise in the female regular wage rate is higher than the male regular wage rate in the simulations, because demand for workers with lower wages also rise relatively faster without any other qualification. Similarly, the rise in casual wages is higher for women than for men in the simulations. The earnings of households change as a result of the wage rate changes. Real wage rates of all types of labor increases (Table 8.3). The share of regular workers in formal households is high and these households have gained more than informal households. Moreover, the rural sector trails behind the urban sector though the differences decline, under the high AKST scenarios.

The increase in agricultural productivity would lead to a rise in income of agricultural households also as agricultural production increases. However, as these are future projections, we also have assumed increase in the productivity of the manufacturing sector that leads to higher income in urban and formal households. In our scenarios, both rural and urban households benefit though formal households benefit more than informal households. This is because without a change in the production structure, the share of income of regular workers and employers are higher compared to that of households comprising casual wage workers.

As noted the growth rate of private income will rise in the urban areas relatively more than in the rural areas during the periods concerned. In 2050, both rural and urban households have higher income growth. Moreover, as tariff rates are rationalised the situations of both rural and urban households improve relative to a more restrictive tariff regime. What is important to note is that the difference between average per capita income between rural and urban area declines. For example, in the formal non – agricultural sector both poor and non-poor will witness similar growth rates in 2025 and 2050. Again in the formal households in the urban areas, both poor and non-poor will perform in a similar manner. However, divergence occurs only in the case of households that have more informal (casual, etc.,) workers. This would imply that although productivity of the agricultural/informal sector improves, the benefits would be derived more by regular wage earners or agricultural land owners. Therefore, although the poor would gain gradually through the next 25 to 50 years, inequality will persist unless other supporting policies are designed for small farmers. The extent of inequality may not be as wide as one finds today, with further improvement in technology and with reduced protection, however the relative gains of casual workers seems to be much lower than that of regular workers.

As import prices and consequently domestic prices rise in the scenarios, the resultant import real exchange rate change determines the direction of trade. If the import prices remain lower than domestic prices then imports will rise and vice versa. Export prices and domestic prices determine the export real exchange rate. Hence the rise in export prices in comparison to domestic prices also induces exports to rise, more for manufactured goods as such industries have experienced larger rise in world prices and hence exports prices. As exports rise, this pushes domestic production to rise. So, both price and productivity increase result in domestic outputs to rise more sharply depending on the interrelationships in Scenario 1and less sharply in Scenario 3 (Table 8.5).

Table 8.5: Domestic output by sector (growth rate in %)

	Base 2000	Reference Scenario				Scenario-1		Scenario-2		Scenario-3	
	Unit = 10 million USD	2025	2025-1	2050	2050-1	2025	2050	2025	2050	2025	2050
Rice	1857.64	228.67	244.00	560.24	644.27	308.70	525.94	137.20	114.33	132.63	91.47
Wheat	1171.12	107.12	114.30	262.44	301.80	144.61	246.37	64.27	53.56	62.13	42.85
Maize	127.96	21.02	22.43	51.51	59.24	28.38	48.36	12.61	10.51	12.19	8.41
Other coarse grains	201.85	98.45	105.05	241.21	277.39	132.91	226.44	59.07	49.23	57.10	39.38
Pulses	498.24	348.54	371.91	853.93	982.02	470.53	801.65	209.13	174.27	202.16	139.42
Potatoes	161.72	1135.05	1211.14	2780.86	3197.99	1532.31	2610.61	681.03	567.52	658.33	454.02
Other crops	4787.53	312.24	333.17	764.98	879.73	421.52	718.15	187.34	156.12	181.10	124.89
Oilseeds and edible oils	995.52	107.64	114.86	263.72	303.28	145.32	247.57	64.58	53.82	62.43	43.06
Meat	898.82	158.45	169.07	388.20	446.43	213.91	364.43	95.07	79.22	91.90	63.38
Fishing	483.78	158.45	169.07	388.20	446.43	213.91	364.43	95.07	79.22	91.90	63.38
Other agriculture	2644.54	312.24	333.17	764.98	879.73	421.52	718.15	187.34	156.12	181.10	124.89
Total Agriculture	13828.71	203.00	216.61	497.35	571.95	274.05	466.90	121.80	101.50	117.74	81.20
Other Manufacturing	29423.76	179.36	191.38	439.43	505.34	242.13	412.52	107.61	89.68	104.03	71.74
Other services	30123.65	275.00	293.44	673.75	774.81	371.25	632.50	165.00	137.50	159.50	110.00
Total Non-agriculture	60233.82	250.00	266.76	612.50	704.38	337.50	575.00	150.00	125.00	145.00	100.00
Grand Total	**74062.54**	**145.37**	**155.11**	**356.15**	**409.58**	**196.25**	**334.35**	**87.22**	**72.68**	**84.31**	**58.15**

Exports fare slightly better with import protection for agricultural goods (Table 8.6). In case of non-agricultural goods, manufactured goods would show buoyancy in exports. The finding of the present study does allow us to visualize the possible impacts of policy reforms and identifies the sectors that are relative losers and gainers as a result of such external shocks.

Table 8.6: Imports constant prices (growth rate in %)

	Base 2000	Reference Scenario				Scenario-1		Scenario-2		Scenario-3	
	Unit = 10 million USD	2025	2025-1	2050	2050-1	2025	2050	2025	2050	2025	2050
Rice	20.86	169.02	180.35	414.09	476.20	228.17	388.74	101.41	84.51	98.03	67.61
Wheat	13.15	76.46	81.59	187.33	215.43	103.22	175.86	45.88	38.23	44.35	30.58
Maize	1.44	65.61	70.01	160.76	184.87	88.58	150.91	39.37	32.81	38.06	26.25
Other coarse grains	3.87	128.23	136.82	314.16	361.28	173.11	294.92	76.94	64.11	74.37	51.29
Pulses	5.60	107.46	114.67	263.29	302.78	145.08	247.17	64.48	53.73	62.33	42.99
Potatoes	2.14	-21.35	-22.78	-52.31	-60.15	-28.82	-49.11	-12.81	-10.68	-12.38	-8.54
Other crops	58.02	63.95	68.24	156.69	180.19	86.34	147.09	38.37	31.98	37.09	25.58
Oilseeds and edible oils	21.22	-108.13	-115.38	-264.92	-304.66	-145.98	-248.70	-64.88	-54.07	-62.72	-43.25
Meat	10.46	49.88	53.22	122.20	140.53	67.33	114.72	29.93	24.94	28.93	19.95
Fishing	5.62	61.29	65.40	150.16	172.69	82.74	140.97	36.77	30.65	35.55	24.52
Other agriculture	33.97	95.81	102.24	234.75	269.96	129.35	220.37	57.49	47.91	55.57	38.33
Total Agriculture	176.35	63.60	67.86	155.81	179.18	85.86	146.27	38.16	31.80	36.89	25.44
Other Manufacturing	5930.09	178.67	190.65	437.73	503.39	241.20	410.93	107.20	89.33	103.63	71.47
Other services	598.07	61.84	65.99	151.51	174.24	83.49	142.24	37.11	30.92	35.87	24.74
Total Non-agriculture	6698.98	178.19	190.13	436.56	502.04	240.55	409.83	106.91	89.09	103.35	71.27
Grand Total	6875.33	175.25	187.00	429.36	493.76	236.58	403.07	105.15	87.62	101.64	70.10

Table 8.7: Export by sector at constant prices (growth rate in %)

	Base 2000	Reference Scenario				Scenario-1		Scenario-2		Scenario-3	
	Unit = 10 million USD	2025	2025-1	2050	2050-1	2025	2050	2025	2050	2025	2050
Rice	43.04	160.32	171.07	392.79	451.71	216.44	368.74	96.19	80.16	92.99	64.13
Wheat	27.13	-7.70	-8.22	-18.87	-21.70	-10.40	-17.71	-4.62	-3.85	-4.47	-3.08
Maize	2.96	-108.97	-116.27	-266.97	-307.01	-147.11	-250.62	-65.38	-54.48	-63.20	-43.59
Other coarse grains	4.66	243.02	259.31	595.39	684.70	328.07	558.94	145.81	121.51	140.95	97.21
Pulses	11.54	337.07	359.67	825.82	949.70	455.05	775.26	202.24	168.54	195.50	134.83
Potatoes	3.75	1589.92	1696.51	3895.31	4479.60	2146.39	3656.82	953.95	794.96	922.15	635.97

Other crops	110.91	335.26	357.74	821.39	944.60	452.60	771.10	201.16	167.63	194.45	134.10
Oilseeds and edible oils	59.51	-18.95	-20.23	-46.44	-53.40	-25.59	-43.60	-11.37	-9.48	-10.99	-7.58
Meat	20.82	89.69	95.70	219.73	252.69	121.08	206.28	53.81	44.84	52.02	35.87
Fishing	11.21	87.16	93.00	213.54	245.57	117.66	200.47	52.30	43.58	50.55	34.86
Other agriculture	61.27	378.45	403.83	927.21	1066.30	510.91	870.45	227.07	189.23	219.50	151.38
Total Agriculture	356.80	222.64	237.57	545.47	627.29	300.56	512.07	133.58	111.32	129.13	89.06
Other Manufacturing	2107.82	114.58	122.27	280.73	322.84	154.69	263.54	68.75	57.29	66.46	45.83
Other services	2340.06	383.33	409.02	939.15	1080.02	517.49	881.65	230.00	191.66	222.33	153.33
Total Non-agriculture	4509.23	230.06	245.48	563.64	648.19	310.58	529.13	138.03	115.03	133.43	92.02
Grand Total	4866.02	559.03	596.51	1369.62	1575.06	754.69	1285.76	335.42	279.51	324.24	223.61

The growth in GDP is associated with investment. The investment is estimated to rise gradually, by 833 percent over 25 years under the baseline and by 889 percent under trade liberalization. In 2050, the respective overall growth rates are 2041 and 2347 percent. The lowest growth is in Scenario 3 at 333 percent in 2050. The inflation shown by CPI reflects that this is higher in the longer period and with rising demand as in Scenario 1as both demand and income grow (noted earlier) over the years. However a less protective regime (tariff cuts) would depress price increases. GDP would grow with higher demand, both consumptions and investment.

Caveats

The current CGE is static as the number of laborers and total amount of available capital do not respond to economic incentives. This is useful generally in the short-run, perhaps a year or so. When labor and capital respond to economic incentives over time, the CGE needs to have a dynamic nature. The responses of capital are investment and depreciation. The responses of labor are migration, labor-force participation, and more hours worked, and population growth. We have used a deterministic path through which investment and labor variables are adjusted the end years using projected values. This has changed the investment and labor output ratios in the long run.

We realize that the exacting data requirements of CGE analysis can be a potential source of difficulty, particularly if one is forced to adopt and attempt to reconcile data from multiple sources and which is necessary for building the base data set, for example the SAM. However, as structural change will affect various sectors and with interrelations that flow through all sectors, factors of production, income and consumption, a general equilibrium framework such as the CGE is useful. In particular, such a model is useful to get impacts which would be missed in partial analysis, and may provide a detailed and consistent mode of analysis where partial equilibrium tools do not provide some impact information in a comprehensive manner. At the same time, partial equilibrium would be more suitable to study sector specific issues.

8.4 Conclusions and Future Directions

The major findings of the study are that productivity growth and tariff reduction leads to a rise in real income per annum of all households as their wages rise given rise in demand and due to fall in relative prices as tariff fall. However the households comprising of regular income earners gain relatively more, as the regular wage rates increase in comparison to casual wage rates. However, given a static structure female wage earners benefit more than male wage earners thereby closing the gender gap in wages under present market clearing. Higher production and world prices tend to benefit all income earners and producers, but relatively less casual workers. So, it is all the more important to have higher productivity of workers via AKST to be able to have sustainable growth. Also, women workers need to be addressed specifically in designing AKST as a large number of them are in agriculture (at present AKST has shown positive results for women workers, but further scrutiny is necessary).

We submit that so far our simulations are local approximations based on the assumption that factor/gender proportions do not alter (although there may be top level substitution of capital for labor). To actually take it further requires more research on the economic structure. For example, we would need a theory (and hence a structural model) about the way in which factor markets function and how gender discrimination/differences work. We might want to model two separate labor markets for men and women that would require investigation about how these two markets work.

In discussing various types of labor and specifically distinguished by gender it is important to discuss the segmented labor market (SLM) approach. Furthermore, the CGE model should be modified to incorporate supply response to the “informalization” of the labor force. As demand for women labor rises there would be an increase in wage rates, under the present structure. Also, supply of labor would respond to the wage rates. However, we need to address wage differentials and supply side behavior, which will be different for females and males.

Since taxes add to prices, one must have a price-dependent model to do tax work. Comparative static analysis models the reactions at one point in time. The results show the reaction of the economy at a future period to external shocks and policy changes. The process of adjustment to the new equilibrium is not explicitly represented in such models. Only a comparison in growth rates to the base and the period with shock is made.

9 Conclusions

Growing pressure on food supply and natural resources require new investments and policies for AKST. Tightening food markets indicate that a business-as-usual approach to financing and implementing AKST cannot meet the development and sustainability goals of reduction of hunger and poverty, the improvement of rural livelihoods and human health and equitable, environmentally sustainable development. Innovative AKST policies are essential to build natural, human and physical capital for social and environmental sustainability. Such policies will also require more investment in AKST. Important investments supporting increased supply of and access to food include those in agricultural research and development, irrigation, rural roads, secondary education for girls, and access to safe drinking water.

Under business-as-usual, agriculture will have to face a number of new and difficult challenges. Food security will likely still be a problem 50 years from now. Agricultural production is likely to be increasingly constrained by competition for land and water. There is also heightened global concern for potential impacts on agriculture of future climate change and climate change response policies. Strategies for adapting to new regulations for food safety, and the development of biotechnology and bioenergy pose significant challenges and opportunities. In addition, regional and national income growth, urbanization and growing global inter-connectedness are expected to increase diet diversification and homogenization. Trade liberalization and greater integration of global food markets can support more reliable food supplies and lowered food prices in real terms. But as the reference run shows this is unlikely to be achieved in the coming decades.

With declining availability of water and land that can be profitably brought under cultivation, expansion in area will contribute very little to future production growth. The projected slow growth in crop area places the burden to meet future cereal demand on crop yield growth. The key to improving yields under increasingly constrained conditions lies in technology to improve agricultural productivity in order to regenerate productivity growth. Biotechnology could play an important role here. To adapt to and mitigate the various effects from climate change requires the development of new cultivars. Likewise, $CO2$ emissions can be reduced through new crop management practices supported by appropriate technologies. To achieve such breakthroughs, existing global and regional research-for-development networks for agricultural production technologies and knowledge need to work closely together so that technology and knowledge can flow to allow farmers to face the risks associated with future harvests. Information and communication technologies and traditional and local knowledge could play key roles in the regeneration of future productivity growth. As the alternative policy experiments in this chapter have shown higher, judiciously placed investments in technology development can significantly improve outcomes for food availability and food security.

Results from alternative policy experiments also show that multilateral trade liberalization represents a significant policy option for enhancing agricultural productivity growth through increased AKST investment. The so-called static gains from trade liberalization under the IAASTD scenario are projected to be large enough to exceed the AKST investment needs identified under the alternative AKST scenarios. If gains from future enhanced AKST investment represent part of possible ‘dynamic’ gains associated with enhanced agricultural trade, multilateral trade liberalization should be viewed as a win-win policy option.

The report cautions against the escalation of any trade restrictive policies. In recent times, the increasing awareness of climate change impacts seems to engender various trade restrictive piecemeal policies such as Food Miles, Border Tax Adjustment, etc. These policies with limited climate change mitigation potential will certainly restrict international trade significantly and thereby limiting much needed agricultural productivity and growth for the future. The report serves as a timely reminder for the global policy community that the trade talks should be resuscitated without further delays in order to realize potential gains from further trade liberalization. Such a multilateral initiative seems to be more promising now than ever—as has been shown in the last round of talks--in the sense that any opposition to agricultural reforms in the key economies can be better managed at a time of high food prices.

Analysis on China demonstrates the crucial importance of AKST for agricultural and general economic development and food security in a country with limited land and other natural resources. China’s experience shows how technological development and public investment in improving agricultural productivity can make a difference for farmer incomes and food security with implications for the rest of the world. Technology has been engine of China’s agricultural productivity growth in the past and will continue to play major role in boosting China’s agricultural development and improving the nation’s food security in the 21st century. Growth in agricultural productivity enabled China to release its large pool of abundant rural labor, providing cheap labor for the nation to industrialize its economy. Rising international trade and FDI has been the other engine of economic growth and facilitated China’s economic structural changes toward more comparative sectors.

While there are a number of challenges related to China’s agricultural sector, the outlook concerning China's food economy remains positive. The high level of China’s food security under the baseline scenario suggests that China’s massive import of food is not likely to occur if the current trend of investment in agricultural R&D will be upheld in the future. The projection results of high R&D investment scenarios suggest that China could be able to produce nearly all foods to meet its growing demand in the next 50 years if China could further raise its investment in agricultural R&D. In contrast, China’s food import will rise significantly if its investment in agricultural R&D would not be increased substantially. The results from this study also have significant implications to the rest of world. China’s agricultural development and technology changes will contribute to the global food security in terms of both increasing food supply and stabilizing or lowering world food prices. China’s trade will also provide both opportunities and challenges to the rest of the world. For those countries whose agricultural and economic structures are complementary to China there will be emerging opportunities offered by China’s increasing imports of some agricultural products. While countries that have similar agricultural export structures to that of China and are competing for the same export markets will have to put extra efforts to restructure their economies and invest more in agricultural R&D.

Results from India showed that both investments in AKST and tariff reductions lead to a rise in real income per annum of all households as their wages rise given growth in demand and a decline in relative prices as tariff fall. However, regular-salaried households gain relatively more, as the regular wage rates increase in comparison to casual wage rates. Moreover, female wage earners benefit more than male wage earners thereby closing the gender gap in wages under present market clearing.

10 References

Ahammad, H. and Mi, R. 2005. “Land Use Change Modeling in GTEM: Accounting for Forest Sinks.” ABARE Conference Paper 05.13, presented at the workshop on EMF 22: Climate Change Control Scenarios, Stanford University, California, 25-27 May.

Ahammad, H., and R. Mi. 2005. Land use change modeling in GTEM: Accounting for forest sinks. Australian Bureau of Agricultural and Resource Economics (ABARE) Conference Paper 05.13, presented at the workshop, Energy Modeling Forum 22: Climate Change Control Scenarios, 25-27 May. 2005. Stanford University, Palo Alto, CA.

Adam, Christopher S. and David L. Bevan. 1998. Cost and Benefits of Incorporating Asset Markets into CGE Models: Evidence and Design. Issues, Applied Economics Discussion Paper Series No. 202, University of Oxford.

Alkemade, R., M. Bakkenes, R. Bobbink, L. Miles, C. Nelleman, H. Simons, and T. Tekelenburg, 2006. GLOBIO 3: Framework for the assessment of global terrestrial biodiversity. In A.F. Bouwman, T. Kram, and K. Klein Goldewijk (ed) Integrated modeling of global environmental change. An overview of IMAGE 2.4. Netherlands Environmental Assessment Agency (MNP), Bilthoven, The Netherlands.

Cai, F., D. Wang, and Y. Du. 2002. “Regional Disparity and Economic Growth in China: The Impact of Labor Market Distortions,” China Economic Review. 11(2002).

Clarete, James A and R. Roumasset. 1990. “The Relative Welfare Cost of Industrial and Agricultural Policy Distortions: A Philippine Illustration,” Oxford Economics Papers, 1990.

de Fraiture, C., D. Wichelns, E. Kemp Benedict, and J. Rockstrom. 2007. Scenarios on water for food and environment. In A Comprehensive Assessment of Water Management in Agriculture. Water for Food, Water for Life: Earthscan and IWMI, London and Colombo.

Deng, X., J. Huang, S. Rozelle and E. Uchida. 2006. “Cultivated Land Conversion and Potential Agricultural Productivity in China,” Forthcoming in Land Use Policy. 23(2006), pp: 372-384.

Dervis, K., J. de Melo and S. Robinson. 1982. “General equilibrium models for development policy”, Cambridge: Cambridge University Press.

Devarajan S., S. Robinson and J. Lewis. 1996.: "Getting the Model Right: Applied General Equilibrium Modelling", Cambridge University Press.

Eickhout, B., H. van Meijl, and A. Tabeau. 2006. Modeling agricultural trade and food production under different trade policies. In A.F. Bouwman, T. Kram and K. Klein Goldewijk (ed) Integrated modeling of global environmental change. An overview of IMAGE 2.4.

Eickhout, B., van Meijl, H. and Tabeau, A. 2006. “Modeling agricultural trade and food production under different trade policies.” In A.F. Bouwman, T. Kram and K. Klein Goldewijk (eds.) Integrated modeling of global environmental change. An overview of IMAGE 2.4. Netherlands Environmental Assessment Agency (MNP), Bilthoven, The Netherlands.

Fan, S. 1991. Effects of technological change and institutional reform on production growth in Chinese agriculture. Am. J. Agric. Econ. 73:266-275.

Fan, S. 1997. “Production and Productivity Growth in Chinese Agriculture: New Measurement and Evidence” Food Policy 22 (3 June): 213-228.

Fan, S. and P. Pardey. 1997. “Research Productivity and Output Growth in Chinese Agriculture,” Journal of Development Economics Vol.53 (June 1997):115-137.

FAO (Food and Agriculture Organization). 2006. World agriculture: Towards 2030/2050. Interim report. FAO, Rome.

FAO [Food and Agricultural Organization of the United Nations]. 2002. The State of Food Insecurity in the World 2001, FAO, Rome.

Food and Agriculture Organization (FAO). 2006a. World agriculture: towards 2030/2050. Interim report. FAO, Rome.

Giles, J. 2000. “Risk and Rural Responses in China,” Working Paper, Michigan State University, East Lansing, MI.

Hu, Ruifa, Kuanyu Shi, Yongwei Cui, and Jikun Huang. 2007. “China’s Agricultural Research Investment and International Comparison,” China’s Soft-Science, No.2 (2007): 53-65.

Huang, J. and H. Bouis. 1996. Structural changes in demand for food in Asia. Food, Agriculture, and the Environment Discussion Paper. Washington, D.C. (USA): International Food Policy Research Institute.

Huang, J. and N. Li. 2003. “China’s Agricultural Policy Analysis and Simulation Model – CAPSiM,” Journal of Najing Agricultural University, Vol.3 (No.2, 2003):30-41.

Huang, J. and S. Rozelle. 1996. “Technological Change: Rediscovery of the Engine of Productivity Growth in China’s Rural Economy.” Journal of Development Economics, 49 (2), 337-369.

Huang, J. and S. Rozelle. 1995. "Environmental Stress and Grain Yields in China," American Journal of Agricultural Economics, 77 (1995): 853-864.

Huang, J. and S. Rozelle. 2006. “The Emergence of Agricultural Commodity Markets in China,” China Economic Review, 17 (2006): 266-280.

Huang, J., and N. Li. 2003. China’s Agricultural Policy Simulation and Projection Model-CAPSiM. Journal of Nanjing Agricultural University (Social Science Edition) 3(2): 30-41.

Huang, J., R. Hu, and S. Rozelle. 2003. Agricultural Research Investment in China: Challenges and Prospects. China's Finance and Economy Press, Beijing.

Huang, J., S. Rozelle, and C. Pray. 2002a. "Enhancing the Crops to Feed the Poor," Nature, Vol. 418, 8 August 2002: 678-684.

Huang, J., S. Rozelle, and M. Chang. 2004. “Tracking Distortions in Agriculture: China and Its Accession to the World Trade Organization,” Forthcoming in the World Bank Economic Review. Vol. 18, No.1, 2004, pp: 59-84.

Huang, Jikun and Scott Rozelle. 2002. "Trade Reform, WTO and China’s Food Economy in the 21st Century," Pacific Economic Review, Volume 8 Number2, June 2003, pp: 143-156.

IAASTD (International Assessment of Agricultural Science and Technology for Development). 2008. “Looking into the future for agriculture and AKST (Agricultural Knowledge Science and Technology).” Chapter 5, IAASTD Global Report (forthcoming).

Jin, S., J. Huang, R. Hu, and S. Rozelle. 2002. The creation and spread of technology and total factor productivity in China’s agriculture,” Am. J. of Agric. Econ. 84(4) (November 2002):916-939.

Lardy, N. 2001. Integrating China in the Global Economy. Washington, D.C. (USA): Brookings Institution.

Lee, H.L., Hertel, T. Sohngen, B. and Ramankutty, N. 2005. Towards an Integrated Data Base for Assessing the Potential for Greenhouse Gas Mitigation, Final Report to the US Environmental Protection Agency, Washington DC.

Lin, J. Y. 1992. Rural reforms and agricultural growth in China. Am. Econ. Rev. 82:34-51.

Lohmar, Bryan, Jinxia Wang, Scott Rozelle, Jikun Huang and David Dawe, 2003. “China’s Agricultural Water Policy Reforms: Increasing Investment, Resolving Conflicts, and revising Incentives,” Economic Research Service, Agriculture Information Bulletin, Number 782

MA (Millennium Ecosystem Assessment). 2005. Ecosystems and Human Well-being. Volume 2: Scenarios. Findings of the Scenarios Working Group. Island Press, Washington, DC.

Martin, W. and Anderson, K. 2005. World Bank, Washington DC.

McMillan J, Walley J, Zhu L. 1989. The impact of China’s economic reforms on agricultural productivity growth. J. Polit. Econ. 97:781-807.

Millennium Ecosystem Assessment (MEA). 2005. Ecosystems and human well-being. Volume 2: Scenarios. Findings of the Scenarios Working Group. Island Press, Washington, DC.

MOA [Ministry of Agriculture]. China Agricultural Development Report, 2000 and 2002. China's Agricultural Press, Beijing.

Narayana, N.S.S., K.S. Parikh and T.N. Srinivasan. 1991. “Agriculture, Growth and Redistribution of Income: Policy Analysis with a General Equilibrium Model of India”, North Holland, Amsterdam / Allied Publishers, New Delhi.

NBSC [China National Statistical Bureau]. China Statistical Yearbook. Various issues from 1985 to 2007. Beijing: China Statistical Press.

NSBC (Rural Survey Department, National Statistical Bureau of China). China rural household survey yearbook, various issues from 1982 to 2004. Beijing: State Statistical Press.

Nyberg, A. and S. Rozelle. 1999. Accelerating China's Rural Transformation. The World Bank, Washington DC.

Rosegrant, M.W., X. Cai, and S.A. Cline. 2002. World Water and Food to 2025: Dealing with Scarcity. IFPRI, Washington, DC.

Rosegrant M. W., M. S. Paisner, S. Meijer, and J.Witcover. 2001. Global Food Projections to 2020: Emerging Trends and Alternative Futures. Available at http://www.ifpri.org/pubs/books/globalfoodprojections2020.htm (Accessed October 25, 2007). IFPRI, Washington, DC.

Rosen, Daniel H., Scott Rozelle and Jikun Huang. 2004. Roots of Competitiveness: China's Evolving Agriculture Interests, Institute for International Economics, Washington, DC, July 2004.

Rozelle, Scott and Jikun Huang. 2000. "Transition, Development and the Supply of Wheat in China," Australian Journal of Agricultural and Resource Economics, 44(2000):543-571.

Sinha, A., Poonam Munjal, P K Ghosh, and Palash Baruah. 2008. Exploring Alternative Futures for Agricultural Knowledge, Science and Technology (KST). Prospects for the Economy, Workers and Households under Alternative Scenarios of World Prices. Prepared for the ACIAR project. Mimeo.

Sinha, A., K.A. Siddiqui, and Poonam Munjal. 2003. Impact of Globalization on Home Based and Other Women Workers: a Macro Analysis. National Council for Applied Economic Research Paper. Unpublished. (September).

Sinha, Anushree and Sangeeta, N. 2000. "Value Added from the Informal Sector: Lessons from SAM with Formal/Informal Disaggregation from India" presented in the 4th Meting of Expert Group on Informal Sector Statistics (Delhi Group), Geneva, August.

Sinha, Anushree and N Sangeeta. 2003. "Gender in Macroeconomic Framework" in Tracking Gender Equity under Economic Reforms: Continuity and Change in South Asia (eds. S. Mukhopadhaya and M. Sudarshan), Kali for Women and IDRC.

Sonntag, B. H., J. Huang, S. Rozelle and J. H. Skerritt. 2005. China's Agricultural and Rural Development in the Early 21st Century, Australian Government, Australian Centre for International Agricultural Research, 2005.

Thornton, P. K., R.L. Kruska, N. Henninger, P.M. Kristjanson, R.S. Reid, F. Atieno, A. Odero, and T. Ndegwa. 2002. Mapping poverty and livestock in the developing world. Accessible at http://www.ilri.org/InfoServ/Webpub/Fulldocs/Mappoverty/index.htm (Accessed 26 October 2007). ILRI, Nairobi, Kenya.

Thornton, P.K., P.G. Jones, T. Owiyo., R.L. Kruska, M. Herrero, P. Kristjanson, A. Notenbaert, N. Bekele, and A. Omolo and contributions from others. 2006. Mapping climate vulnerability and poverty in Africa. Report to the Department for International Development, [Online] Accessible at http://www.dfid.gov.uk/research/mapping-climate.pdf (Accessed 26 October 2007). ILRI, Nairobi, Kenya.

United Nations. 2005. World Population Prospects: The 2004 Revision. United Nations, Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat. UN, New York, New York.

Wang, J. 2000. Property Right Innovation, Technical Efficiency and Groundwater Management: Case Study of Groundwater Irrigation System in Hebei, China, 2000, Ph.D. Thesis, Chinese Academy of Agricultural Sciences.

Wang, J., J. Huang, Q. Huang and S. Rozelle, 2005. "Privatization of Tubewells in North China: Determinants and Impacts on Irrigated Area, Productivity and the Water Table", Hydrogeology Journal, 2005 [Forthcoming]

World Bank. 2002. World Development Indicators 2002. Washington, D.C.

11 Appendix 1: Modelling frameworks IMPACT, GTEM, CAPSim, and GEN-CGE

11.1 The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT)

11.1.1 Introduction

IMPACT was developed in the early 1990s as a response to concerns about a lack of vision and consensus regarding the actions required to feed the world in the future, reduce poverty, and protect the natural resource base (Rosegrant et al., 1995). In 2002, the model was expanded through inclusion of a Water Simulation Model (WSM) as water was perceived as one of the major constraints to future food production and human well-being (Rosegrant et al., 2002).

11.1.2 Model structure and data

The current IMPACT model combines an extension of the original model with a WSM that is based on state-of-the-art global water databases (Rosegrant et al., 2002). The water module projects the evolution of availability and demand with a base year of 2000 (average of 1999-2001), taking into account the availability and variability in water resources, the water supply infrastructure, and irrigation and nonagricultural water demands, as well as the impact of alternative water policies and investments. Water demands are simulated as functions of year-to-year hydrologic fluctuations, irrigation development, growth of industrial and domestic water uses, and environmental and other flow requirements (committed flow). Off-stream water supply for the domestic, industrial, livestock, and irrigation sectors is determined based on water allocation priorities, treating irrigation water as a residual. Environmental flows are included as constraints.

The food module is specified as a set of 115 country or regional sub-models. Within each sub-model, supply, demand and prices for agricultural commodities are determined for 32 crop, livestock, and fish commodities and fishmeal, sugar and sweeteners, fruits and vegetables, and low value and high value fish. These country and regional sub-models are intersected with 126 river basins—to allow for a better representation of water supply and demand—generating results for 281 Food Producing Units (FPUs). The “food” side of IMPACT uses a system of food supply and demand elasticities incorporated into a series of linear and nonlinear equations, to approximate the underlying production and demand functions. World agricultural commodity prices are determined annually at levels that clear international markets. Demand is a function of prices, income and population growth. Growth in crop production in each country is determined by crop prices and the rate of productivity growth. Future productivity growth is estimated by its component sources, including crop management research, conventional plant breeding, wide-crossing and hybridization breeding, and biotechnology and transgenic breeding. Other sources of growth considered include private sector agricultural research and development, agricultural extension and education, markets, infrastructure and irrigation. IMPACT projects the share and number of malnourished preschool children in developing countries as a function of average per capita calorie availability, the share of females with secondary schooling, the ratio of female to male life expectancy at birth, and the percentage of the population with access to safe water (see also Rosegrant et al., 2001; Smith and Haddad, 2000). The model incorporates data from FAOSTAT (FAO, 2003); commodity, income, and population data and projections from the World Bank (2000), the Millennium Ecosystem Assessment (2005), and the UN (2000) and USDA (2000); a system of supply and demand elasticities from literature reviews and expert estimates (Rosegrant et al., 2001); and rates for malnutrition (UN ACC/SCN, 1996; WHO, 1997) and calorie-child malnutrition relationships developed by Smith and Haddad (2000).

Application

IMPACT has been used for analyzing the current and future roles of agricultural commodities and impacts on food security and rural livelihoods, including the future of fisheries (Delgado et al., 2003); the role of root and tuber crops (Scott et al. 2000a, 2000b); and the 'livestock revolution' (Delgado et al., 1999). IMPACT has also been applied to regional analyses as well as selected country-level studies, for example, China (Huang et al., 1997), Indonesia (SEARCA/IFPRI/CRESECENT 2004), Sub-Saharan Africa (Rosegrant et al., 2005a) and Central Asia (Pandya-Lorch and Rosegrant, 2000). IMPACT has also been used to analyze structural changes, including the impact of the Asian economic and financial crisis (Rosegrant and Ringler, 2000); longer-term structural changes in rural Asia (Rosegrant and Hazell, 2000); as well as global dietary changes (Rosegrant et al., 1999). The model has also been used to describe the role of agriculture and water for achieving the Millennium Development Goals (Rosegrant et al., 2005b; von Braun et al., 2004).

Model runs have been carried out for individual centers of the CGIAR, the World Bank and the Asian Development Bank. The model has also been used for agricultural scenario analysis of the Millennium Ecosystem Assessment (MEA 2005; Alcamo et al., 2005), and is currently being used for the Global Environmental Outlook (GEO-4) assessment carried out by UNEP. Other work includes investigations into regional and global scale impacts of greenhouse gas mitigation in agriculture and theoretical large-scale conversion to organic food production.

Uncertainty

In the following tables, the points related to uncertainty in the model are summarized, based on the level of agreement and amount of evidence.

Table A.1: Overview of major uncertainties in IMPACT

Model Component	Uncertainty
Model structure	Based on partial equilibrium theory (equilibrium between demand and supply of all commodities and production factors) Underlying sources of growth in area/numbers and productivity Structure of supply and demand functions and underlying elasticities, complementary and substitution of factor inputs. Water simulations and connection between Water and Food modules

Parameters	Input parameters: Base year, 3-year centered moving averages for area, yield, production, numbers for 32 agricultural commodities and 115 countries and regions, and 281 Food Producing Units Elasticities underlying the country and regional demand and supply functions Commodity prices Drivers Output parameters: Annual levels of water supply and demand (withdrawals and depletion), both agricultural and nonagricultural, food supply, demand, trade, international food prices, calorie availability, and share and number of malnourished children
Driving Force	Economic and demographic drivers: Income growth (GDP) Population growth Technological, management, and infrastructural drivers: Productivity growth (including management research, conventional plant breeding) for rainfed and irrigated areas Rainfed and irrigated area growth Livestock feed ratios Changes in nonagricultural water demand Supply and demand elasticity systems Policy drivers: Commodity price policy as defined by taxes and subsidies on commodities, drivers affecting child malnutrition, food demand preferences, water infrastructure, etc.
Initial Condition	Baseline – 3-year average centered on 2000 of all input parameters and assumptions for driving forces
Model operation	Optimization in Water Simulation Model using GAMS

Source: Based on MEA (2005)

Table A.2: Level of confidence in different types of scenario calculations from IMPACT

Level of Agreement/ Assessment	High	Established but incomplete: Projections of Rainfed Area, Yield Projections of Irrigated Area, Yield, Projections of Livestock Numbers, Production Number of Malnourished Children Calorie availability Climate variability	Well established: Changes in Consumption Patterns and Food Demand
	Low	Speculative:	Competing explanations: Projections of Commodity Prices Commodity Trade Climate change
		Low	High
	Amount of evidence (theory, observations, model outputs)		

Source: Based on MEA (2005)

11.2 The Global Trade and Environment Model (GTEM)

11.2.1 Introduction

GTEM has been developed by the Australian Bureau of Agricultural and Resource Economics (ABARE) specifically to address policy issues with global dimensions and issues where the interactions between sectors and between economies are significant. These include issues such as international climate change policy, international trade and investment liberalisation and trends in global energy markets.

11.2.2 Model structure and data

GTEM is a multiregion, multisector, dynamic, general equilibrium model of the global economy. GTEM is a multi-region, multi-sector, dynamic, computable general equilibrium model (CGE) of the global economy, developed and maintained at the Australian Bureau of Agricultural and Resource Economics (ABARE). CGE models are widely used as an analytical framework to study economic issues of national, regional and global dimension. CGE models provide a representation of economies, including the specification of trade relations with the economies of rest of the world. These models provide an economy-wide perspective and are very useful when:

The numerous, and often intricate, interactions between various parts of an economy are of critical importance. As for agriculture, such interactions occur between agriculture sectors themselves (e.g., competing for limited productive resources including various types of land) as well as between agricultural sectors with other sectors/actors which either service agricultural sectors or operate in the food and fiber chain including downstream processors, traders and distributors, final consumers and governments (e.g., public policies).

The research objective is to analyze counterfactual policy alternatives and/or plausible scenarios about how the future is likely to evolve. Examples could include the implications for agriculture of likely multilateral trade liberalization in the future, the implications for agriculture of future growth in food demand and shifts in consumer preference, or the role of bioenergy in climate change mitigation and implications for agriculture.

For analyzing such issues, the modeling of sectoral interactions is fundamental (e.g., among agriculture, energy, processing and manufacturing as well as services), trade (domestic and international), and existing policies. Given their economy-wide coverage, some variant of this type of models has become a part of the Integrated Assessment models (e.g., IMAGE; Eickhout et al., 2006).

A particular strength of CGE models is their ability to analyze the interactions between different sectors such as agricultural sectors, manufacturing sectors and services. In their conventional usage, CGE models are flexible price models and are used to examine the impact of relative price changes on resource allocations (of goods and factors) across a range of economic agents. Thus, in addition to providing insights into the economy-wide general equilibrium effects of policy changes, CGE models allow key inter-industry linkages to be examined. However, most CGE models, including the particular model used in this report, are not well suited to address income distributional issues within a regional economy: only average adjustments in the regional economy can be simulated. In particular, CGE models should be handled with care for long-term projections since some fundamental changes in the economic structure of a region cannot be adequately simulated by a CGE model. Therefore, CGE models are only used in this IAASTD, and also in this paper, for assessing the global economic consequences of trade liberalization.

The key structural features of GTEM include:

A computable general equilibrium (CGE) framework with a sound theoretical foundation based on microeconomic principles that accounts for economic transactions occurring in the global economy. The theoretical structure of the model is based on the optimizing behavior of individual economic agents (e.g., firms and households), as represented by the model equation systems, the database and parameters.

A recursively dynamic analytical framework characterized by capital and debt accumulation and endogenous population growth, which enables the model to account for transactions between sectors and trade flows between regions over time. As a dynamic model, it accounts for the impacts of changes in labor force and investment on a region's production capabilities.

The representation of a large number of economies (up to 87 regional economies corresponding to individual countries or country groups) that are linked through trade and investment flows, allowing for detailed analysis of the direct as well as flow-on impacts of policy and exogenous changes for individual economies. The model tracks intraindustry trade flows as well as bilateral trade flows, allowing for detailed trade policy analysis.

A high level of sectoral disaggregation (up to 67 broad sectors, with an explicit representation of 13 agricultural sectors) that helps to minimize likely biases that may arise from an undue aggregation scheme.

A bottom-up "technology bundle" approach adopted in modeling energy intensive sectors, as well as interfuel, interfactor and factor-fuel substitution possibilities allowed in modeling the production of commodities. The detailed and explicit treatment of the energy and energy related sectors makes GTEM an ideal tool for analysing trends and policies affecting the energy sector.

A demographic module that determines the evolution of a region's population (and hence, the labor supply) as a function of fertility, migration and mortality, all distinguished by age group and/or gender.

A detailed greenhouse gas emissions module that accounts for the major gases and sources, incorporates various climate change response policies, including international emissions trading and quota banking, and allows for technology substitution and uptake of backstop technologies.

For each regional economy, the GTEM database consists of six broad components: the input–output flows; bilateral trade flows; elasticities and parameters; population data; technology data; and anthropogenic greenhouse gas emissions data. For the input–output and bilateral trade flows data, and the key elasticities and parameters, the GTAP version 6 database (see https://www.gtap.agecon.purdue.edu/databases/v6/default.asp) has been adapted. The databases for population, energy technology and anthropogenic greenhouse gas emissions, have been assembled by ABARE according to GTEM regions using information from a range of national and international sources. The base-year for GTEM is 2001. For this exercise, the model database has been aggregated to 21 regions that correspond to the five IAASTD sub-global regions and to 36 commodities that include 12 agricultural sectors and one fisheries sector.

GTEM equations are written in log-change forms and the model is solved recursively using the GEMPACK suite of programs (http://www.monash.edu.au/policy/gempack.htm). For IAASTD modeling purposes, the GTEM projection period expends to 2050. The model simulation provides annual projections for many variables including regional gross national product, aggregate consumption, investment, exports and imports; sectoral production, employment and other input demands; final demand and trade for commodities; and greenhouse gas emissions by gas and by source. A detailed description of the theoretical structure of GTEM can be found in Pant (2002, 2007). Pezzey and Lambie (2001) describe the key structural features of GTEM and Ahammad and Mi (2005) discuss an update on the modeling of GTEM agricultural and forestry sectors.

11.2.3 Application

GTEM has been applied to a wide range of medium- to long-term policy issues or special events. These include climate change response policy analysis (e.g., Ahammad et al., 2006; Ahammad et al., 2004; Fisher et al., 2003; Heyhoe, 2007; Jakeman et al., 2002; Jakeman et al., 2004; Jotzo, 2000; Matysek et al., 2005; Polidano et al., 2000; Tulpulé et al., 1999); global energy market analysis (e.g., Ball et al., 2003, Fairhead et al., 2002; Heaney et al., 2005; Mélanie et al., 2002; Stuart et al., 2000); and on agricultural trade liberalization issues (e.g., Bull and Roberts 2001; Fairhead and Ahammad, 2005; Freeman et al., 2000; Nair et al., 2005; Nair et al., 2006; Roberts et al., 1999; Schneider et al., 2000).

Uncertainty

Table A.3: Uncertainty

Model component	Uncertainty
Model structure	Based on general equilibrium theory. Conforms to a competitive market equilibrium—no ‘supernormal’ economic profit. Structured on nested supply and demand functions representing technologies, tastes, endowments and policies. Incorporates the Armington demand structure—a commodity produced in one region treated as an imperfect substitute for a similar good produced elsewhere. Total demand equals total supply—for all commodities at the global level and for production factors at the regional level.
Parameters	Input parameters: Base year input-output flows and (bilateral) trade flows for 67 commodities and 87 countries and regions. Numerous elasticities underlying demand and supply equations. Technical coefficients for anthropogenic greenhouse gas emissions.
Driving Force	Regional income growth (GDP). Population growth. Changes in policies (taxes and subsidies). Technological changes—productivity growth and energy technology options. The choice of the model closure, i.e., the distinction between exogenous (drivers or shocks) and endogenous (determined or projected) variables of the model, is quite flexible. The above variables, e.g., could also be determined endogenously within the model for some specific economic closure characterized by a well specified set of economic and demographic shocks.
Initial Condition	The 2001 global economy in terms of production, consumption and trade.
Model operation	Suite of GEMPACK programs.

11.3 CAPSiM- China's Agricultural Policy Simulation and Projection Model

11.3.1 Introduction

China's Agricultural Policy Simulation and Projection Model (CAPSiM) was developed at the Center for Chinese Agricultural Policy (CCAP) in the mid-1990s as a response to the need to have a framework for analyzing policies affecting agricultural production, consumption, prices, and trade in China (Huang et al., 1999; Huang and Chen, 1999). Since then CAPSiM has been periodically updated and expanded at CCAP to cover the impacts of policy changes at regional and household levels (Huang and Li, 2003; Huang et al., 2003).

11.3.2 Model structure and data

CAPSiM is a partial equilibrium model for 19 crop, livestock and fishery commodities, including all cereals (four types), sweet potato, potato, soybean, other edible oil crops, cotton, vegetable, fruits, other crops, six livestock products, and one aggregate fishery sector, which together account for more than 90% of China's agricultural output. CAPSiM is simultaneously run at the national, provincial (31) and household (by different income groups) levels. It is the first comprehensive model for examining the effects of policies on China's national and regional food economies, as well as household income and poverty.

CAPSiM includes two major modules for supply and demand balances for each of 19 agricultural commodities. Supply includes production, import, and stock changes. Demand includes food demand (specified separately for rural and urban consumers), feed demand, industrial demand, waste, and export demand. Market clearing is reached simultaneously for each agricultural commodity and all 19 commodities (or groups).

Production equations, which are decomposed by area and yield for crops and by total output for meat and other products, allow producers' own- and cross-price market responses, as well as the effects of shifts in technology stock on agriculture, irrigation stock, three environmental factors—erosion, salinization, and the breakdown of the local environment—and yield changes due to exogenous shocks of climate and other factors (Huang and Rozelle, 1998b; deBrauw et al., 2004). Demand equations, which are broken out by urban and rural consumers, allow consumers' own- and cross-price market responses, as well as the effects of shifts in income, population level, market development and other shocks (Huang and Rozelle, 1998a; Huang and Bouis, 2001; Huang and Liu, 2002).

Most of the elasticities used in CAPSiM were estimated econometrically at CCAP using state-of-the-art econometrics, including assumptions for consistency of estimated parameters with theory. Demand and supply elasticities vary over time and across income groups. Recently, CAPSiM shifted its demand system from double-log to an “Almost Ideal Demand System” (Deaton and Muellbauer, 1980).

CAPSiM generates annual projections for crop production (area, yield and production), livestock and fish production, demand (food, feed, industrial, seed, waste, etc), stock changes, prices and trade. The base year is 2001 (average of 2000-2002) and is currently being updated to 2004. The model is written in Visual C++.

11.3.3 Application

CAPSiM has been frequently used by CCAP and its collaborators in various policy analyses and impact assessments. Some examples include China's WTO accession and implications (Huang and Rozelle, 2003; Huang and Chen, 1999), trade liberalization, food security, and poverty (Huang et al., 2003; Huang et. al., 2005a and 2005b), R&D investment policy and impact assessments (Huang et al., 2000), land use policy change and its impact on food prices (Xu et. al., 2006), China's food demand and supply projections (Huang et. al., 1999; Rozelle et al., 1996; Rozelle and Huang, 2000), and water policy (Liao and Huang, 2004).

11.3.4 Uncertainty

Tables A.4 and A.5 below summarize points related to uncertainty in the model, based on the level of agreement and amount of evidence.

Table A.4: Overview of major uncertainties in CAPSiM

Model component	Uncertainty
Model structure	Based on partial equilibrium theory (equilibrium between demand and supply of all commodities and production factors) One country model (international prices are exogenous)
Parameters	Input parameters: Some household data on production and consumption may not be consistent with national and provincial demand and supply functions Elasticities underlying the national and provincial demand and supply functions International commodity prices Drivers Output parameters: Annual levels of food and agricultural production, stock changes, food and other demands, imports and exports, and domestic prices at national level Annual levels of food and agricultural production, food and other demands at provincial and household level
Driving force	Economic and demographic drivers: Per capita rural and urban income Population growth and urbanization Technological drivers Yield response with respect to research investment, irrigation, and others Livestock feed rations Policy drivers Cultivated land expansion/control Public investment (research, irrigation, environmental conservation, etc.) Trade policy Others
Initial condition	Baseline: Three-year average centered on 2001 of all input parameters and assumptions for driving forces
Model operation	Visual C++ programming language

Table A.5: Level of confidence in different types of scenario calculations with CAPSiM

Level of Agreement/ Assessment	High	Established but incomplete Projections of R&D and irrigation investment Projections of livestock feed ratios Impacts on farmers income	Well established Changes in crop area and yield Changes in food consumption in both rural and urban areas Food production and consumption at household level by income group
	Low	Speculative	Competing explanations Projections of commodity prices Commodity trade
		Low	High
	Amount of evidence (theory, observations, model outputs) More than 20 papers published in Chinese and international journals based on CAPSiM		

11.4 Gender (GEN)-Computable General Equilibrium (CGE)

11.4.1 Introduction

The Gen-CGE model developed for India is based on a Social Accounting Matrix (SAM) using the Indian fiscal year 1999-2000 as the base year (Sinha and Sangeeta, 2000). Generally SAMs are used as base data set for CGE Models where one can take into account multi-sectoral, multi-class disaggregation. In determining the results of policy simulations generated by CGE model, a base-year equilibrium data set is required, which is termed calibration. Calibration is the requirement that the entire model specification be capable of generating a base year equilibrium observation as a model solution. There is a need for construction of a data set that meets the equilibrium conditions for the general equilibrium model, viz. demand equal supplies for all commodities, non-profits are made in all industries, all domestic agents have demands that satisfy their budget constraints and external sector is balanced. A SAM provides the most suitable disaggregated equilibrium data set for the CGE model.

The SAM under use distinguishes different sectors of production having a thrust on the agricultural sectors and different factors of production distinguished by gender. The workers are further distinguished into rural, urban, agricultural, non agricultural and casual and regular types. The other important feature of the SAM is the distinction of various types of households and each household type being identified with information on gender worker ratios. As the model incorporates the gendered factors of production it is enabled to carry out counterfactual analysis to see the impact of trade policy changes on different types of workers distinguished by gender which in turn allows the study of welfare of households again distinguished by ratio of workers by gender. Households are divided in to rural and urban groups, distinguished by monthly per capita expenditure (MPCE) levels. Rural households include poor agriculturalists, with MPCE less that Rs. 350; non-poor agriculturalists (above Rs. 351); and non-agriculturalists at all levels of income. Urban households are categorized as poor, with MPCE of less than Rs. 450 and the non-poor, with MPCE of between Rs. 451 and 750.

11.4.2 Model structure and data

The Gen-CGE model follows roughly the standard neoclassical specification of general equilibrium models. Markets for goods, factors, and foreign exchange are assumed to respond to changing demand and supply conditions, which in turn are affected by government policies, the external environment, and other exogenous influences. The model is Walrasian in that it determines only relative prices and other endogenous variables in the real sphere of the economy. Sectoral product prices, factor prices, and the foreign exchange rate are defined relative to a price index, which serves as the numeraire. The production technology is represented by a set of nested Cobb-Douglas and Leontief functions. Domestic output in each sector is a Leontief function of value-added and aggregate intermediate input use. Value-added is a Cobb-Douglas function of the primary factors, like capital and labor. Fixed input coefficients are specified in the intermediate input cost function. The model assumes imperfect substitutability, in each sector, between the domestic product and imports. All firms are assumed to be price takers for all imports. What is demanded is the composite consumption good, which is a constant elasticity of substitution (CES) aggregation of imports and domestically produced goods. Similarly, each sector is assumed to produce differentiated goods for the domestic and export markets. The composite production good is a constant elasticity of transformation (CET) aggregation of sectoral exports and domestically consumed products. Such product differentiation permits two-way trade and gives some realistic autonomy to the domestic price system. Based on the small-country assumption, domestic prices of imports and exports are expressed in terms of the exchange rate and their foreign prices, as well as the trade tax. The import tax rate represents the sum of the import tariff, surcharge, and applicable sales tax for each commodity group. The foreign exchange rate, an exogenous variable in the base model, is in real terms. The deflator is a price index of goods for domestic use; hence, this exchange rate measure represents the relative price of tradable goods vis-a-vis nontradables (in units of domestic currency per unit of foreign currency).

11.4.3 Application

The GEN-CGE model can be used for studying the impact of tariff changes, removal of non-tariff barriers (measured as tariff equivalents), changes in world GDP, changes in world prices, and changes in agricultural technology on employment by sector, prices, household income and welfare. One version of this model has been used for studying the impact of trade reforms in India in 2003 under a project with IDRC in Canada.

11.4.4 Uncertainty

Table A.6: Overview of major uncertainties in GEN-CGE model

Model Component	Uncertainty
Model Structure	Labor skill
Parameters	Taken from past studies, literature
Driving force	Exogenous variables to the model
Initial condition	Base level SAM
Model operation	Data based

Table A.7: Level of confidence for scenario calculations

Level of Agreement/ Assessment	High	Established but incomplete Trade reform analysis on employment	Well-established Trade reform analysis on the economy
	Low	Speculative The impact on migration of workers	Competing Explanations Trade off between welfare and growth
		Low	High
	Amount of Evidence (Theory, Observations, Model Outputs): Please see references for model outputs		