THE IMPACTS OF EXPECTED STRUCTURAL CHANGES IN DEMAND FOR AGRICULTURAL COMMODITIES IN CHINA AND INDIA ON WORLD AGRICULTURE

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

ABSTRACT

Tangen, Alyssa, M.S., Department of Agribusiness and Applied Economics, College of Agriculture, Food Systems, and Natural Resources, North Dakota State University, December 2009. The Impact of Expected Structural Changes in Demand for Agricultural Commodities in China and India on World Agriculture. Major Professor: Dr. Won W. Koo.

The objective of this study is to evaluate the changes in import and export demand in China and India on the United States and global agriculture in 2018. A spatial equilibrium model is developed to optimize production and trade in China, India, and other major importing and exporting regions in the world. This research focuses on four primary crops: wheat, corn, rice and soybeans. In the model China and India are divided into 31 and 14 producing and consuming regions, respectively. The model also includes five exporting countries and ten importing countries/regions.

The results indicate that India will be able to stay largely self-sufficient in 2018 and China will increase its soybean and corn imports to meet rising domestic demand. The research also gives perspectives on production and trade in the United States and other major exporting and importing countries.

ACKNOWLEDGEMENTS

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure | Page

LIST OF APPENDIX TABLES

Table Page

CHAPTER I. INTRODUCTION

The twenty-first century has brought about a changing landscape in global agriculture. New challenges are arising in order to feed the growing world population on the same amount of arable acres. In the past fifty years, technology has made enormous strides in improving yields, which has allowed for the record harvests evident in recent years. However, technology is increasing at a decreasing rate and whether technology will be able to keep up with increasing demand remains to be seen. Additionally, acres are being taking out of production to accommodate growing populations and urbanization. These conditions have led to questions of how agriculture will have to continue to change to meet this challenge and how this will affect competitiveness in global trade.

Another changing aspect is the countries that are emerging as major players in global agricultural markets. Over the past twenty years, developing countries are playing increasingly important roles, along with developed nations that have dominated the trade in the past, such as the United States, the European Union nations, and Japan. Developing nations have experienced economic prosperity and have thus been increasing their exports due to gains in technology and imports to feed growing populations and changing diets. Asia is one region whose developing nations are emerging in global agricultural trade.

Asia has emerged as one of the regions with the largest economic and population growth, with this growth led by China and India. Because of their sheer size, these two countries dominate trade in this region. In land area, China is only slightly smaller than the United States and India is about a third of the size of China (The World Factbook, 2009). However, their main presence is in their large and rapidly growing populations. The historical trend of their population growth is shown in Figure 1.1 Currently, these two nations' populations are ranked first and second in the world, with China's population measured at 1.3 billion and India's at 1.1 billion (The World Factbook, 2009). Population growth in these two countries is unprecedented, with China and India's population growing 14 and 32 percent, respectively, since 1990 (Population Division Department of Economic and Social Affairs). Population growth is expected to increase at a decreasing rate for China, while India is projected to surpass China in total population by 2045 (Population Division Department of Economic and Social Affairs).

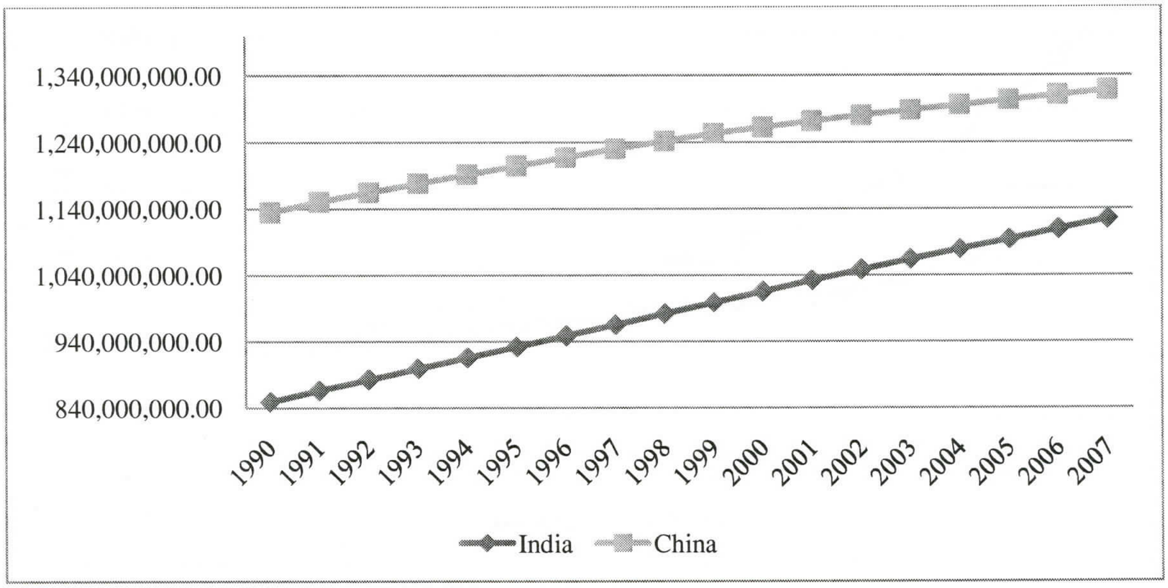


Figure 1.1. Total Populations of China and India 1990-2007 (The World Bank Group, 2009)

Another feature of these two nations that sets them apart is their rapid economic growth. Figure 1.2 depicts the historical trend of per capita Gross National Income (GNI) in China and India. Since 2000, China has seen an average growth rate of 10 percent in Gross Domestic Product (GDP), while India has been able to maintain an average of 7.1 percent (The World Bank Group, 2009). This growth has led to China and India being currently ranked as third and fifth in the world for GDP, respectively (World Fact Book, 2009). While the current economic crisis has affected these two economies, they have been able to retain their economic growth, just at a slower pace than previously. The World Bank projects that China will experience 6.5 percent GDP growth in 2009 and India is projected to achieve 7.1 percent growth in the 2008-2009 year (The World Bank, 2009). After this time period, projections by the United States Department of Agriculture (USDA) indicate an average growth rate of 7.6 percent for China and 7.5 percent for India, for the 2009 to 2018 time period (Economic Research Service, 2009).

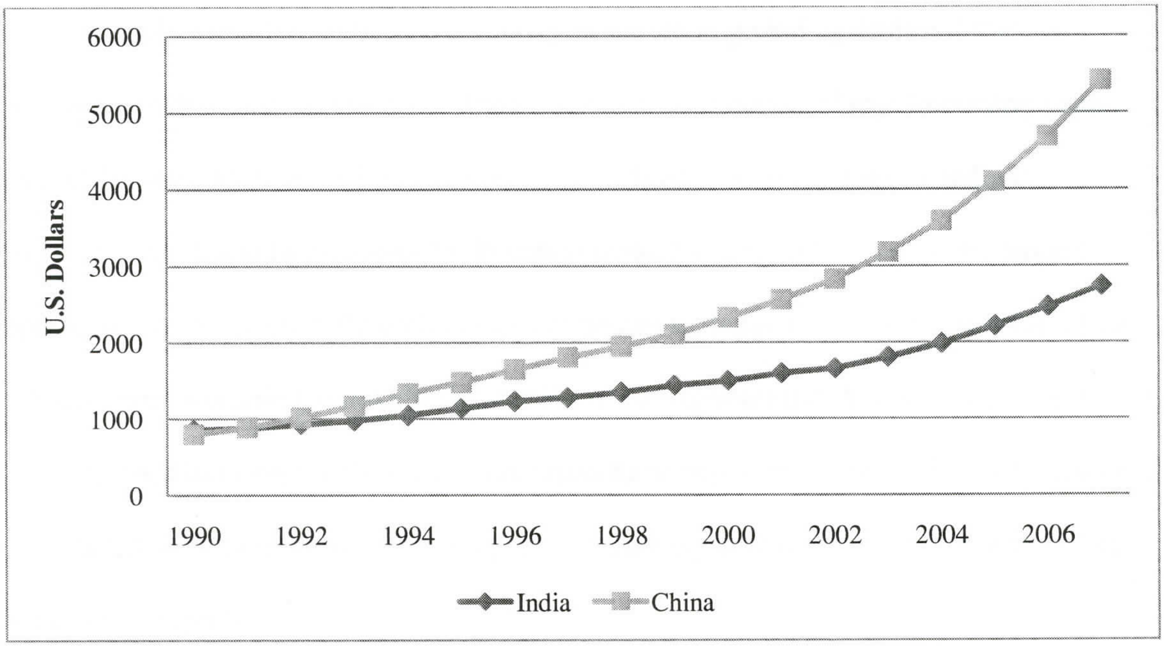


Figure 1.2. Gross National Income Per Capita for China and India 1990-2007 (The World Bank Group, 2009)

As consumers, the Chinese are exhibiting signs of this economic growth. Their preferences now include more expensive foodstuffs such as fruits, vegetables, and meats, and less food grains such as wheat and rice. These changing preferences mean the country will be demanding more of certain kinds of grains, such as those used for feedstuffs to meet the demand of the growing livestock sector. However, grain production is expected to decrease as more land and resources are used to accommodate growing urban areas.

As per capita income is increasing, Indian consumers are also including more fruit and vegetables in their diet. However because of cultural differences in comparison with China, India has not seen a large increase in meat consumption, though the livestock sector is still increasing to meet the growing demand for dairy products. The resulting increases in grain demand will likely result in India becoming a major grain importing country; a new role for a country that has also been self-sufficient until recent years.

Already these two nations are gaining presence in global agricultural trade as a result of their changing preferences. Both countries have become large importing countries of vegetable oils, such as soybean and palm oil. China, which is ahead of India in economic growth and in measures to liberalize trade, has grown to become the largest importer of soybeans globally with imports expected to expand to include over half of all soybean imports within the next ten years (Food and Agricultural Policy Research Institute, 2009). In addition while both of these countries have exported grains in the past, they have since started to keep more stocks to prepare for growing demand in hopes of minimizing the need for imports.

As these two nations grow and evolve, their growing import demands will certainly affect global agriculture and the trade flows of global grain trade. China and India have made strides to open their borders and allow for more liberal trade regulations, which will help them as they face the challenge of feeding their growing populations. But as these two nations require more grain, what will the impact be on other countries either with similar import demands or as exporting countries?

Objectives

The purpose of this study is to examine the expected changes in import and export demand of Chinese and Indian grains and oilseed and the effects of these changes on world agriculture. More specifically, the study will look at the changes in import and export demand, as a result of changing consumption patterns, in these two countries and how that will impact agriculture in the United States and other major importing and exporting countries.

Specific objectives are as follows:

1. To determine the optimal production and trade flows of wheat, corn, rice and soybeans in China and India based on their resource endowments.
2. To predict Chinese and Indian crop production and trade flows and their impacts on world agriculture under different scenarios.
3. To evaluate the competiveness of the United States and other major exporting countries in exporting grains to China, India, and other major importing countries.

Methodology and Scope

To conduct the study a global multi-commodity optimization model based on a mathematical programming algorithm will be used. This model will focus on the imports and exports of wheat, corn, rice, and soybeans in 2018. To determine trade flows in 2018, crop production data will be projected from historical data using a time trend analysis. Consumption data in 2018 will be taken from the Economic Research Service, a division of the United States Department of Agriculture (USDA), publication *USDA Agricultural Baseline Projections for 2009-2018*, the Food and Agricultural Policy Research Institute's

(FAPRI) publication *2009 U.S. and World Agricultural Outlook*, and an econometric estimation. Production and consumption data will determine import and export demand for all regions; trade flows will then be determined based on comparative advantage. This will allow an analysis of changes in trade patterns as a result of changing consumption in these major developing countries.

Organization of Study

There are five additional chapters in this study. Chapter two is background information on the evolution of agriculture and trade in China and India and their roles in world grain trade. Chapter three is a literature review summarizing past research done on similar topics. Chapter four provides research methodology and modeling. Chapter five explains the empirical results of the global multi-commodity optimization model. Chapter six provides a summary and conclusions.

CHAPTER II. BACKGROUND INFORMATION ON CHINA AND INDIA

Global agriculture is experiencing a number of new challenges. These new challenges include the changing role of developing countries, increasing biofuel production, climate change, and increasing food security issues. In addition, technology, which has fueled production growth through increased yields, is increasing at a decreasing rate and there are increasingly less resources available to be used in agriculture production. The global community is faced with how to manage these challenges in an environment where there are escalating demands on production.

The changing role of developing countries is playing an expanding role in global grain markets. According to the principles of competitive advantage, developed nations have a comparative advantage in producing capital and technology intensive commodities and developing countries have a comparative advantage in producing labor-intensive commodities, including agricultural goods. This is due to developed nations being endowed with capital and technology and thus able to purchase large quantities of grain, and developing nations being labor endowed and thus able to use their resources to produce grain. These roles have shifted over the past thirty years. While there are cases where these roles are still intact, Japan is a developed nation that is large grain importer. There are many cases where it is not, the United States is the largest exporter of wheat, corn, and soybeans in the world. In relation to agricultural productivity, in recent years, inputs have been highly substitutable; agricultural products are capital and technology intensive in developed countries, while they are still labor intensive in developing nations.

Developing countries, while still large grain producers in some cases, are increasingly becoming large importing countries in order to feed growing populations.

China and India are excellent examples of this shift. China, while still often an exporter of rice, wheat, and in some year's corn, is now the world's largest importer of soybeans. India is still an exporter of rice and wheat, though both countries are exporting less as they reserve more to feed their own growing population.

Similar to many other developing countries, China and India have not been large importing countries of grain. This is a shift that is expected to happen over the next ten years as growing populations and changes in consumer preferences due to economic prosperity begin to play a larger role. While these two countries have been large grain producers, particularly in rice and wheat, these shifts in consumer preferences will increase their need for grains used as feedstuffs. Consumers in China and India are now consuming more meat and dairy products and less of their staple food grains of rice and wheat. This means more demand for corn and soybeans to feed growing livestock industries.

As mentioned, China and India are large producers of rice and wheat. In the 2007/2008 growing season, China and India produced 30 and 22.2 percent of the world rice crop, respectively (Foreign Agricultural Service, 2009). In that same period, China and India produced 17.9 and 12.4 percent of the world wheat crop (Foreign Agricultural Service, 2009). Figures 2.1 and 2.2 shows the role of China and India in global rice and wheat production from 1990/1991 to 2008/2009. The figures show that wheat production has increased slightly in both countries while rice production has stayed the same in China and increased slightly in India. In the same time, global rice production has shown a pattern of steady but small growth. While global wheat production has been more volatile comparatively, and has also shown a slight increase.

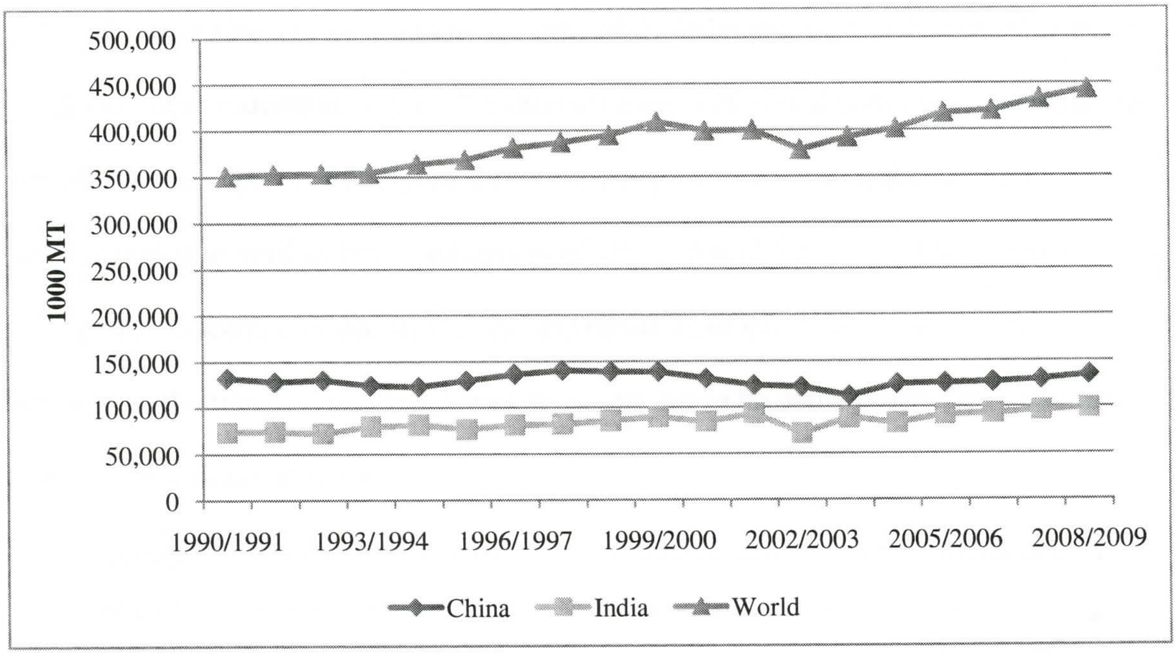


Figure 2.1. World Rice Production 1990/1991 – 2008/2009 (Foreign Agricultural Service, 2009)

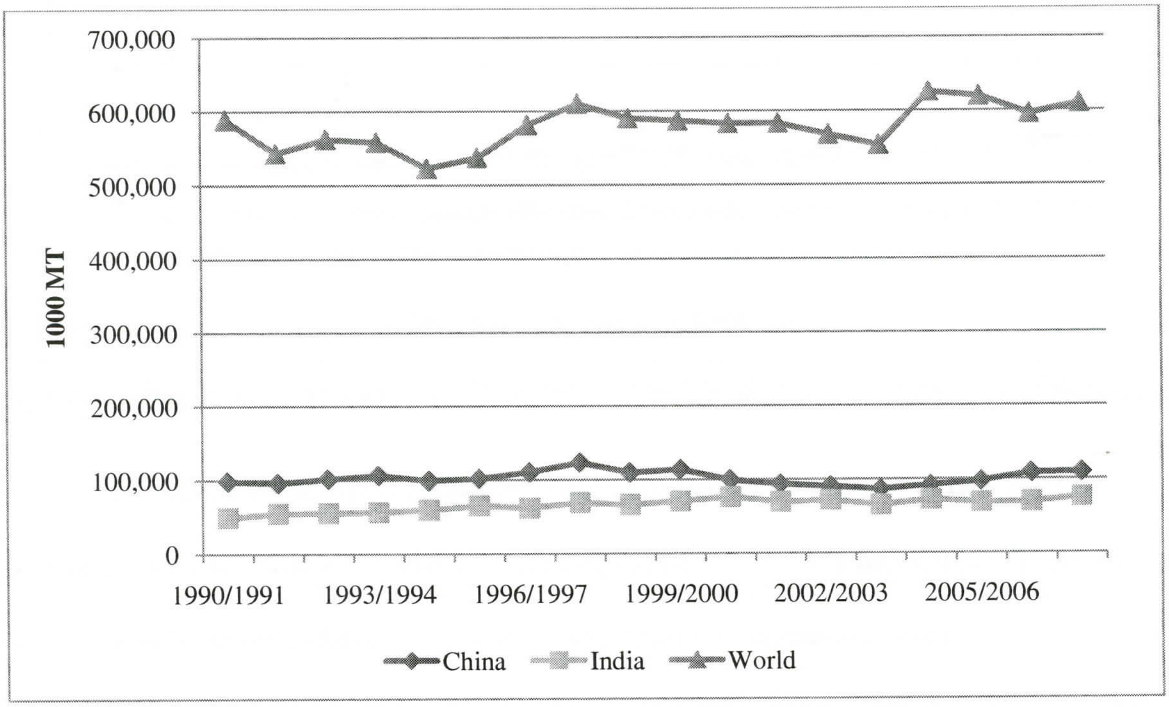


Figure 2.2. World Wheat Production 1990/1991 – 2007/2008 (Foreign Agricultural Service, 2009)

China is also a large producer of corn, while India produces only a small share of the global corn production. Figure 2.3 shows the trend of global corn production and the role of China and India. The figure shows the steep increase in global corn production in the time period as well as increased corn production in both China and India. Similar to corn, global soybean production has also increased significantly as shown in Figure 2.4. Soybean production in China has stayed relatively the same while production in India has experienced a slight increase.

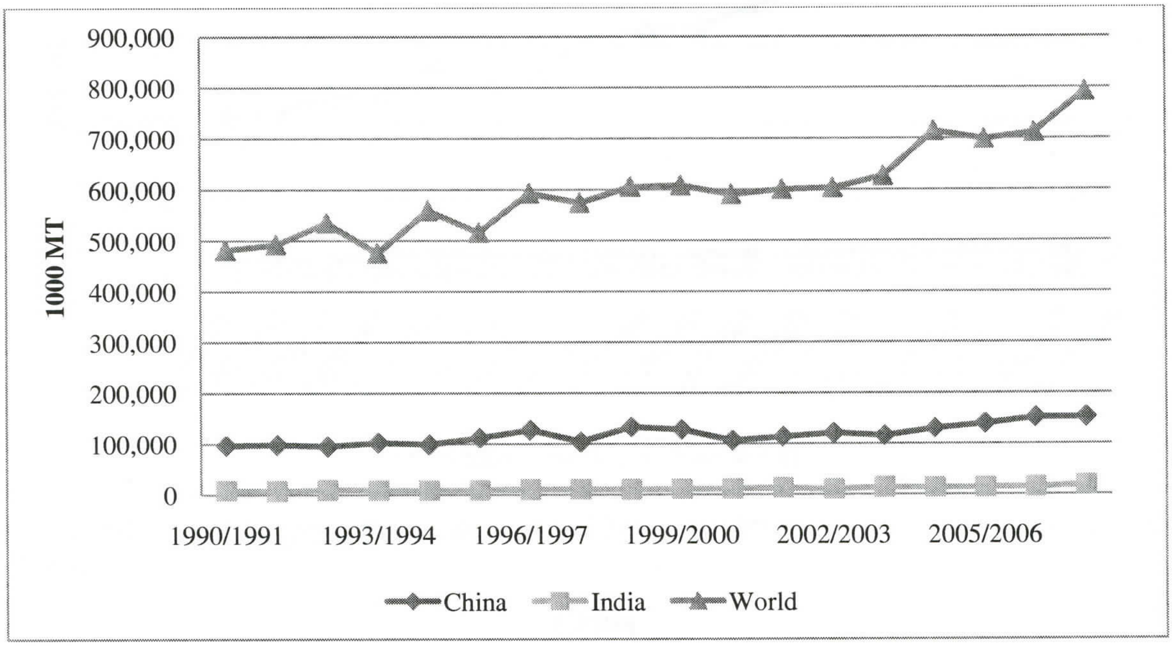


Figure 2.3. World Corn Production 1990/1991 – 2007/2008 (Foreign Agricultural Service, 2009)

Production in these two countries is not expected to slow down; however, their domestic needs are expanding which is making the need to import inevitable. As livestock sectors in both countries have expanded to meet changing consumer demands, both countries have expanded their production of corn and India has expanded its production of soybeans. China has been unable to produce enough soybeans to feed its growing livestock sector and thus has shifted to become a large soybean importer to be able to provide for the industry. Cereal production, while still important in both countries as wheat and rice are a staple of the diet, has seen some growth mostly to keep up with the demand provided by the growing population. The following information on China and India will give background on historical changes in their economies, changes in their consumption, grain production, and their role in global grain trade.

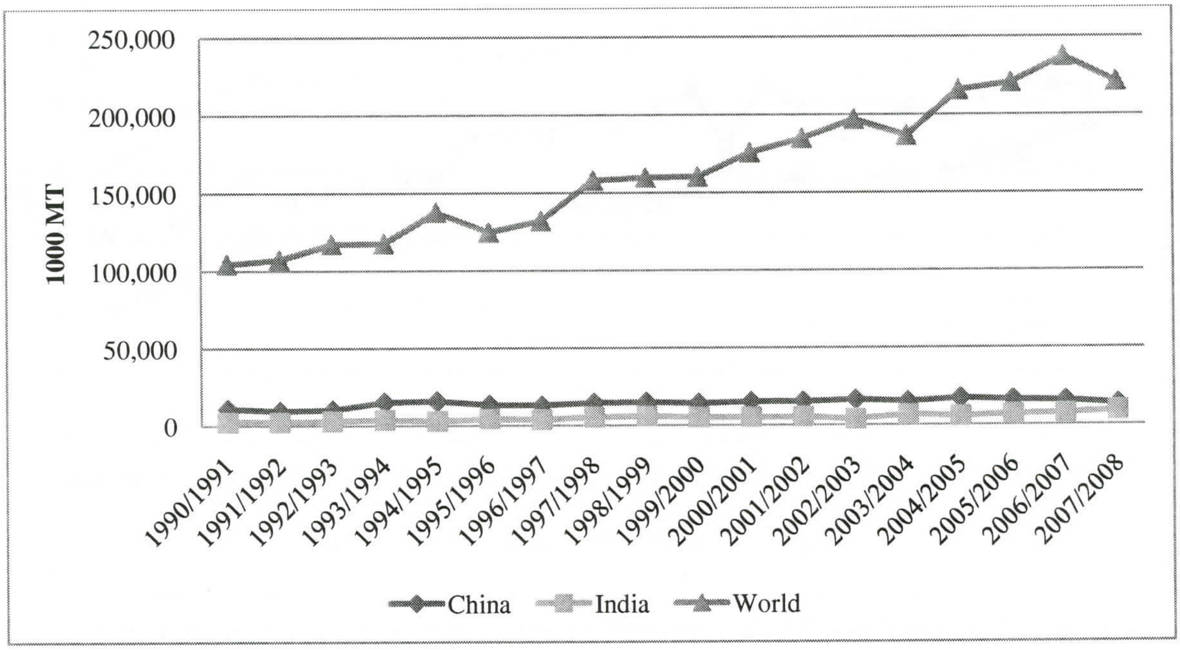


Figure 2.4. World Soybean Production 1990/1991 – 2007/2008 (Foreign Agricultural Service, 2009)

China

The evolution of Chinese agriculture began with government reforms in the late 1970s. These reforms began the process of removing the communal farm system and giving production decisions back to individual producers. Producers were now able to sell their products in a free market system, once they had fulfilled quota obligations. The government also implemented processes that helped to initiate the use of technology that was being used abroad. This allowed for vast technological gains, which greatly improved yields and thus production. Also, this began the process of the Chinese beginning its own research, which has allowed the nation to continue to expand its yield potential, Figure 2.5 shows the historical growth of yields since 1980 for wheat, corn, rice and soybeans. Since these reforms, agricultural production and exports in China have tripled (Food and Agriculture Organization, 2003).

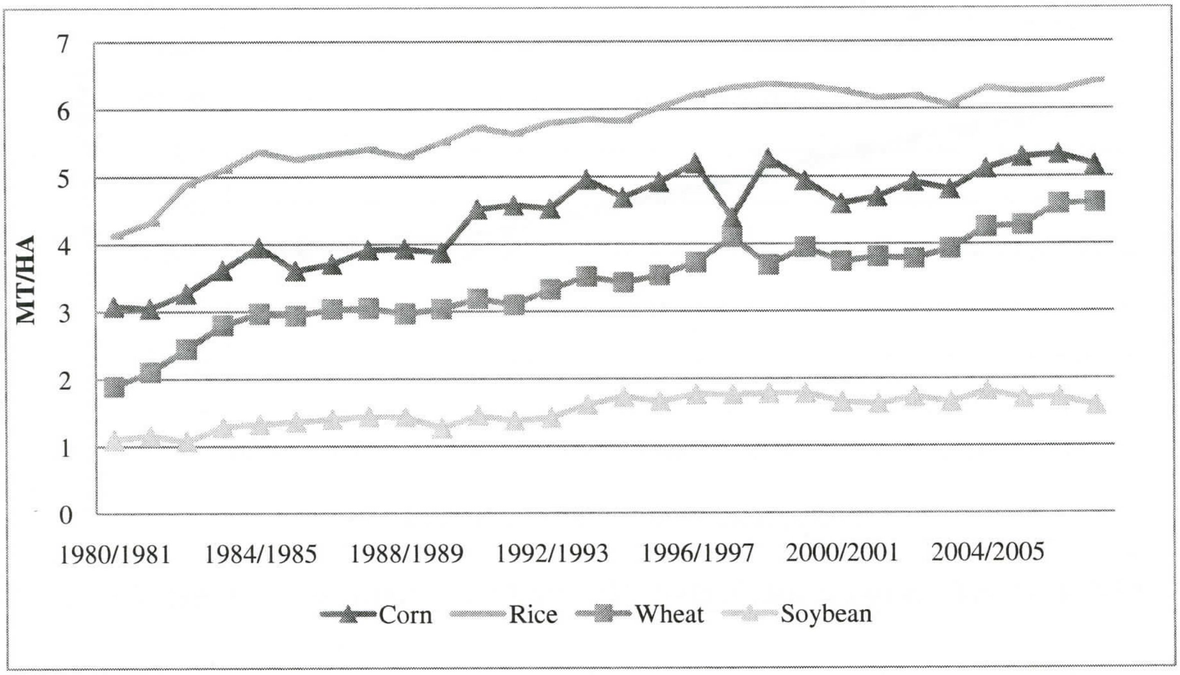


Figure 2.5. Historical Yield Data from China 1980/1981-2008/2009 (Foreign Agricultural Service, 2009)

These reforms also allowed for individuals who were not interested in agricultural production to begin careers in non-agriculture production fields by creating township and village enterprises. The possibility of greater employment opportunities and reforms that allowed people to choose different careers led to people pouring into urban areas. At the time of the reforms, only 17.9 percent of the population lived in urban areas; by 2006 that percentage had increased to 44.9 percent (China Statistical Yearbook 2008). Figure 2.6 shows the trend of increased urbanization in China. As urban areas swell, urban populations demand a larger amount of resources. More water is needed to fulfill the growing needs of urban consumers. Also as cities expand, land is taken out of production to accommodate the growing urban housing and infrastructure needs.

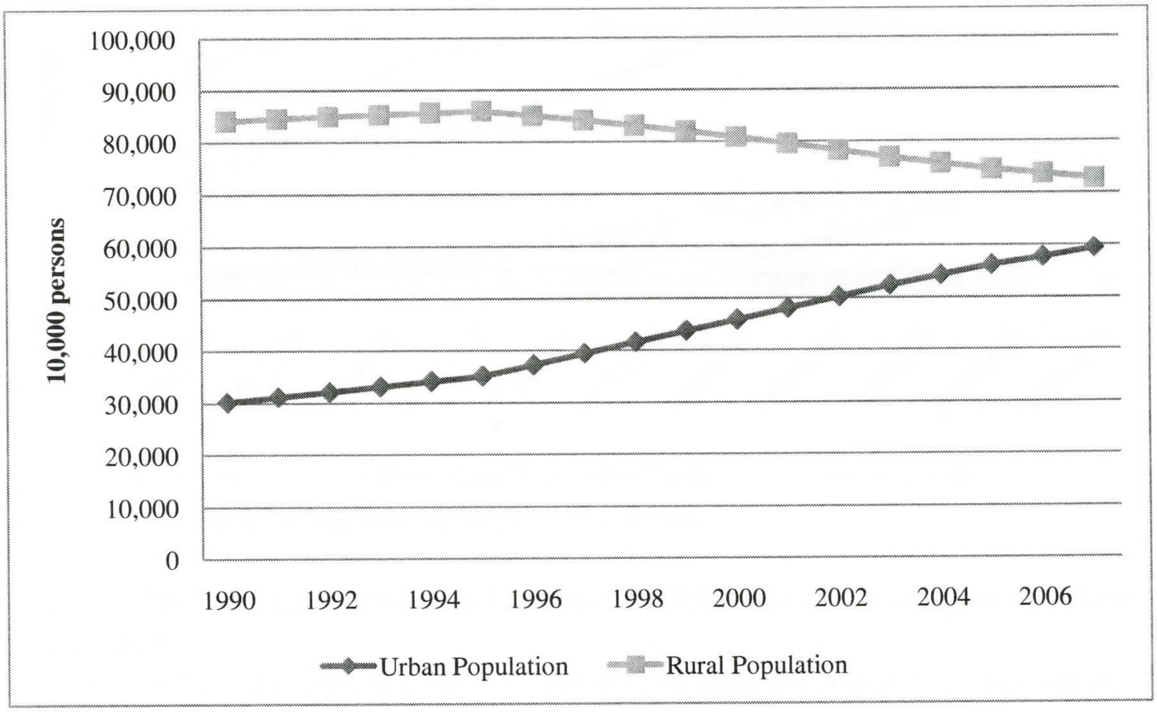


Figure 2.6. Trend of Urbanization in China 1990-2008 (China Statistical Yearbook 2008)

Since the reforms, China's economy has seen great economic prosperity. It has been reported that Chinese per capita GDP has increased by nine times and their value of exports by ten (Food and Agriculture Organization, 2003). As mentioned as Chinese consumers experience this growth in income, they consume more meat, vegetables, fruits, and oils. Figure 2.7 shows the changes in domestic consumption of grains and meats since the time of the reforms. While increases in rice and wheat consumption remain high, they are not increasing at the same rate as corn and soybeans. Corn and soybeans show a sharp increase since the reforms. In the category of meats, there is a sharp increase in swine consumption, though beef and veal and broiler consumption is also increasing at a lesser rate.

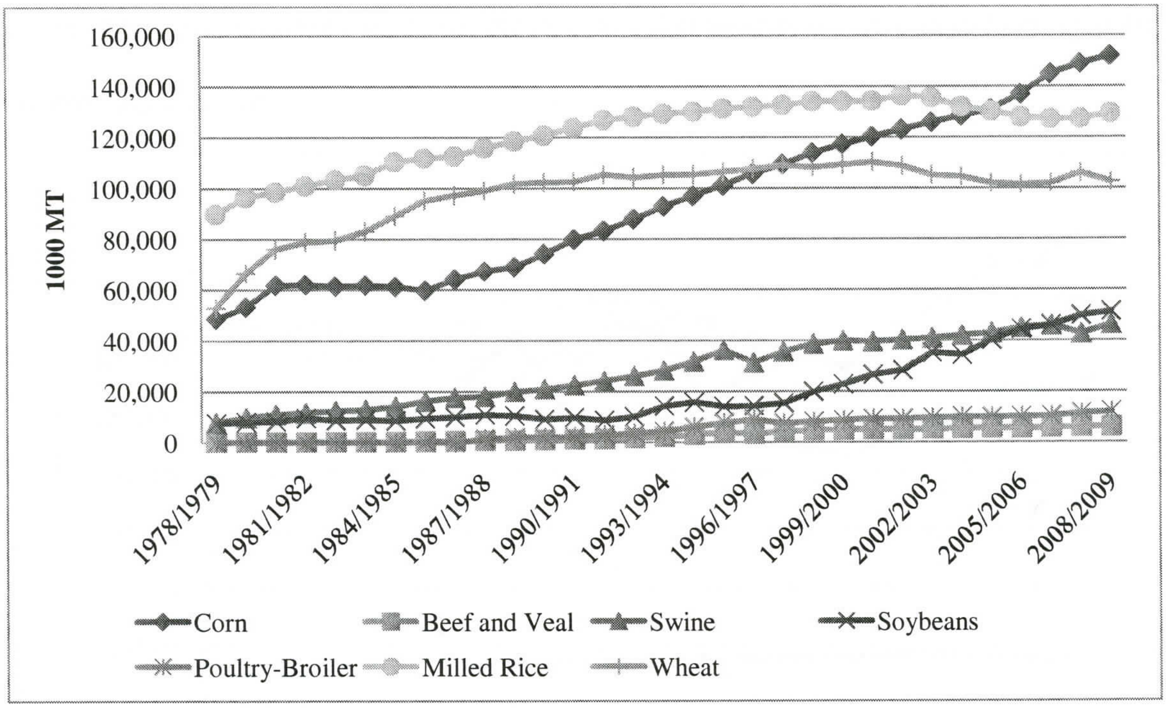


Figure 2.7. Domestic Consumption in China 1978/1979-2008/2009 (Foreign Agricultural Service, 2009)

To meet these changing consumer preferences, grain production has changed, as shown in Figure 2.8. China is producing more corn to meet the needs of the growing livestock industry. In addition, its soybean imports have grown and China is now the largest importer of soybeans in the world (Foreign Agricultural Service, 2009). Production of rice and wheat, while still important to their agriculture sector, has remained relatively flat. Comparatively, China is one of the top producers of wheat, rice, and corn in the world despite the small amount of exports of these crops at present.

China will struggle to produce enough to meet growing demand. There is limited opportunity to expand arable land. In fact, land for production will decrease as the growing population expands urban areas that are located along the coast, which is good production land. Also, there is a growing demand for water in China, and so there will be less water available for irrigation, which is needed in some areas to produce crops. As a result, the contribution of technology becomes more important. As seen in Figure 2.5, yields are increasing; however, future increases are not expected to increase enough to keep up with the growing demand.

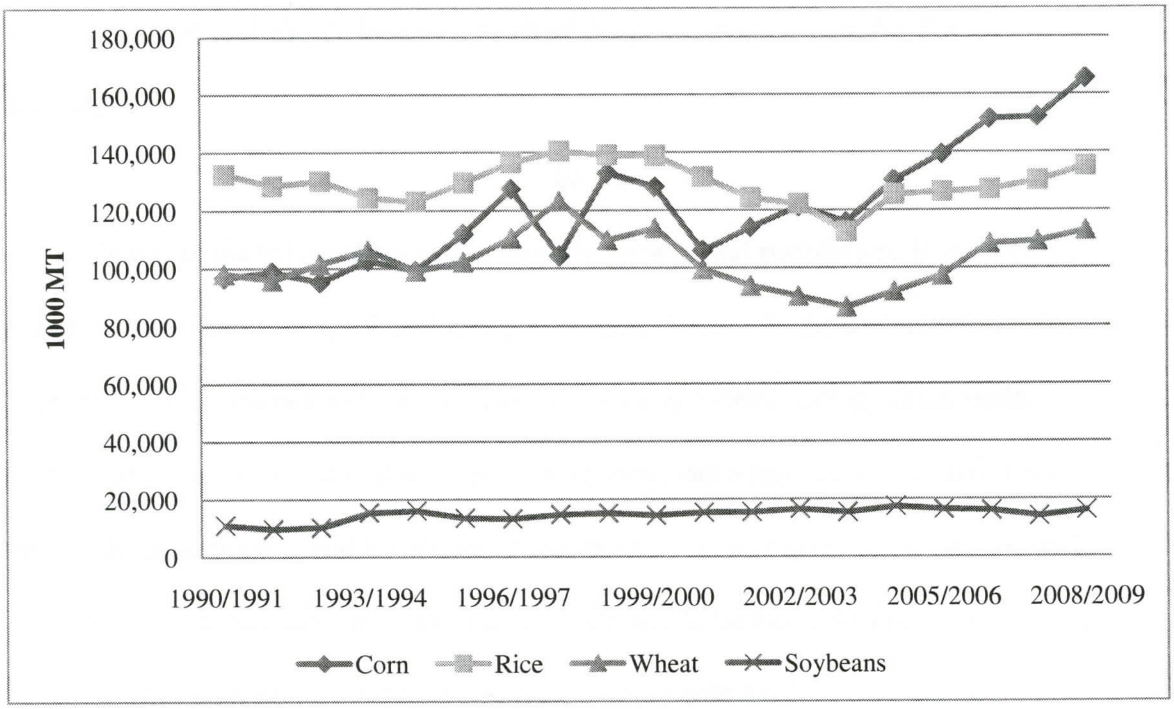


Figure 2.8. Grain Production in China 1990/1991-2008/2009 (Foreign Agricultural Service, 2009)

In the area of grain trade, imports have been variable, shown in Figure 2.9, with wheat imports decreasing and not a significant amount of corn or rice imports. The main trend to observe is in soybeans. This is a trend that is expected to continue and is a direct result of growth in the livestock sector. The soybeans are needed for protein in animal feed and China is not able to produce enough to meet this growing need; as a result, there is a sharp increase in imports. Exports are even more variable, shown in Figure 2.10, with the government keeping stocks in some years to help alleviate the need for imports in subsequent years.

It is important to note the trend in corn. China plays a pivotal role in the global corn market. It is the second largest producer of corn; producing 22 percent of the global crop in 2008 (Foreign Agricultural Service, 2009). However, its exports are controlled by the government through export subsidies and tax rebates. Therefore, its exports are largely unpredictable and can have a substantial impact on global corn prices. In addition, China does export rice and wheat, because much of the production is kept for domestic consumption.

India

India, while behind China in economic growth and population, is quickly making strides to have just as large of a global presence as China. As far as trade, India did not have much of a presence until its reforms in the early 1990s, during which trade liberalization measures were discussed. Since then, India has moved towards a more market-based economy and has experienced more economic growth. While the trade reforms have not had the same effect as with China, India has a different government structure; though it also is beginning to play a larger role in global agriculture.

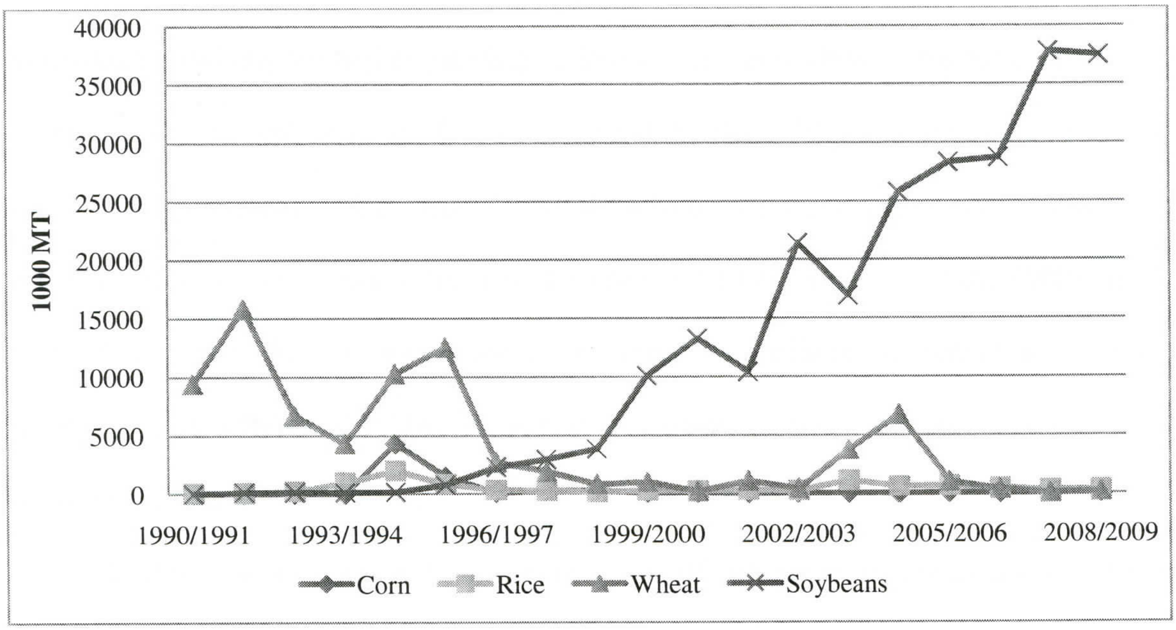


Figure 2.9. China Grain Imports 1990/1991- 2008/2009 (Foreign Agricultural Service, 2009)

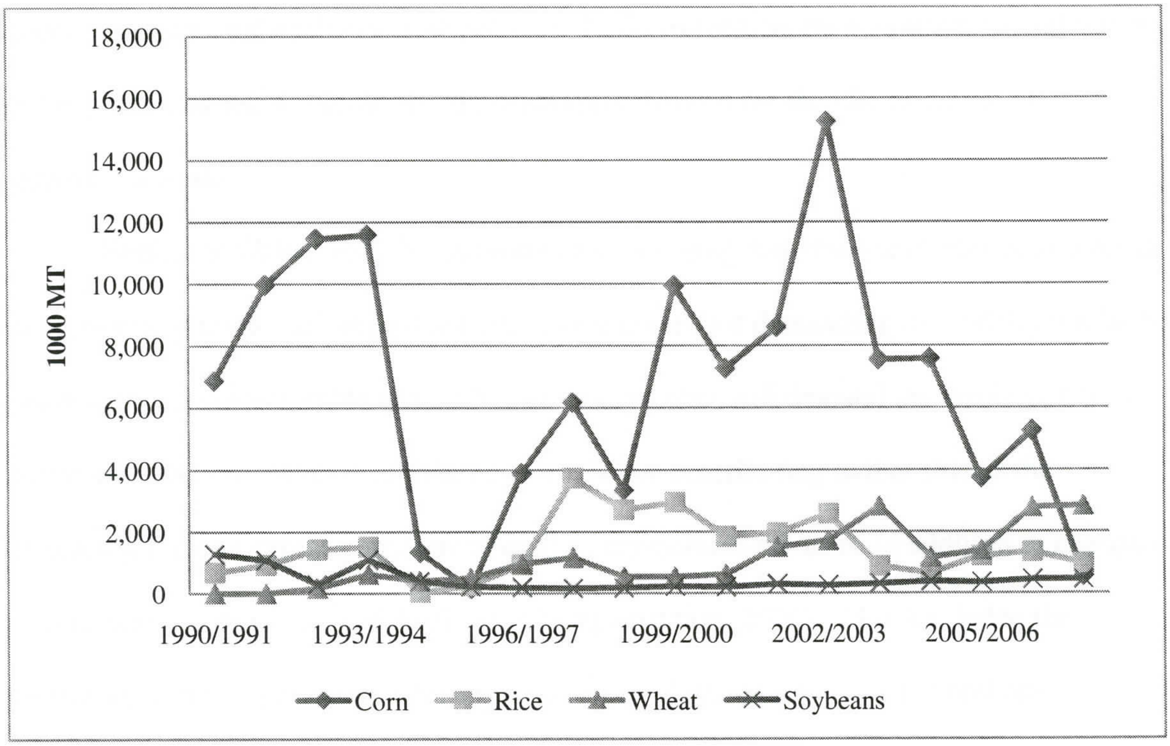


Figure 2.10. China Grain Exports 1990/1991 – 2008/2009 (Foreign Agricultural Service, 2009)

Indian agriculture experienced large growth in the mid-1960s with improvements in technology providing for higher yielding varieties of rice and wheat. This led to the creation of the Agricultural Price Commission and the Food Corporation of India in 1965. These two government entities strived to set the minimum support prices for rice and wheat, to prevent prices from falling below a specified level. Throughout the 1960s and 1970s, Indian agriculture prospered due to an increase in public investment in agriculture. However by the 1980s and 1990s, this public investment declined, and input and output subsidies increased.

In 1991, the economy in India had reached difficult times with fiscal and balance of payment problems. This led to the 1991 reforms that provided short-term stabilization measures to reduce the fiscal deficit and the value of the currency, and removed barriers for foreign capital. Looking further into the future, the government also implemented fiscal, trade, industrial, and exchange rate policies. It also reformed the nation's financial sector and capital markets. Collectively, these reforms allowed for the liberalization of agricultural trade.

Similar to China, India's consumers are changing their food preferences as a result of economic growth. In the past ten years, consumers are demanding more dairy products, poultry, meat, and vegetable oils. Also while consumer still demand the staple grains of wheat and rice, this demand is shifting. One factor contributing to this shift is the increasing price of cereal grains, as a result of agricultural reforms, in addition to changes in consumer tastes (Food and Agricultural Organization, 2006). This has led to the decreasing trend in per capita consumption of cereal grains since 1991 (Food and Agricultural Organization, 2006). In the future, the demand for oilseeds is expected to increase drastically. Figure 2.11 shows the trend of consumption of wheat, corn, rice, and soybeans in India.

Agriculture production in India saw large increases during the Green Revolution. However, subsequent improvements in yields have not been significant, with India having some of the lowest yields in the world. India struggles with moisture stress and being able to irrigate enough land to keep its production growing. Two-thirds of India's production land is limited to one growing season each year primarily due to moisture stress, though this is changing as measures to provide irrigation are expanding (Food and Agricultural Organization, 2006).

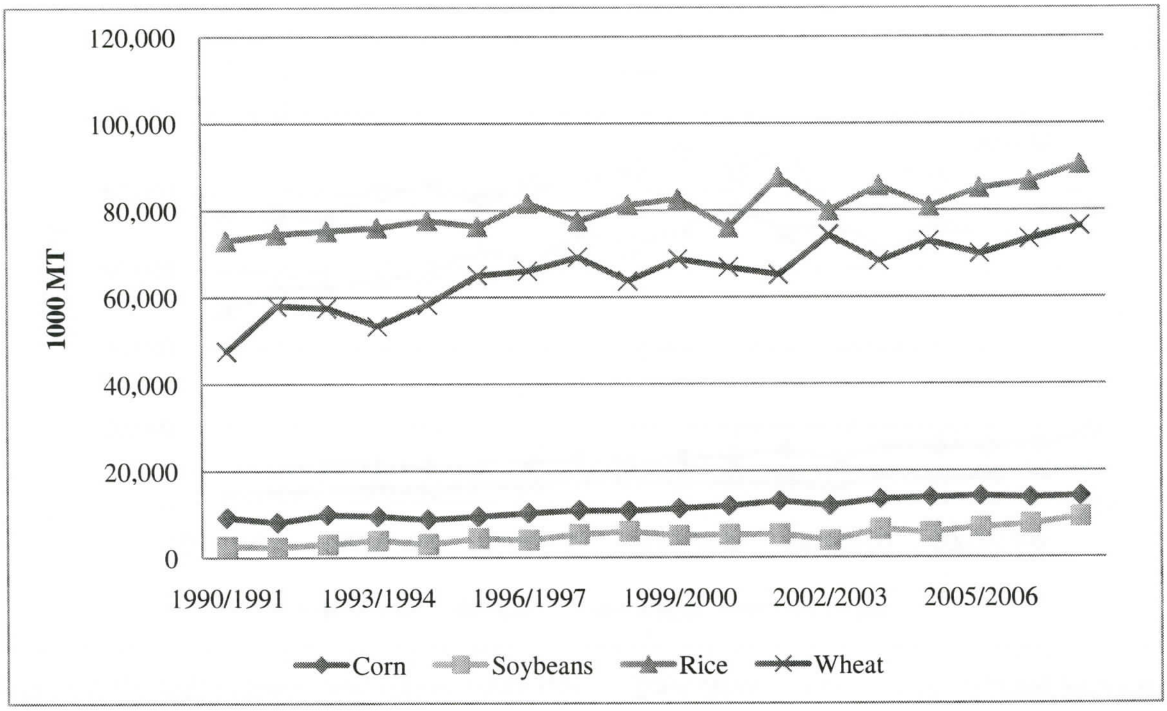


Figure 2.11. India Grain Consumption 1990/1991 – 2008/2009 (Foreign Agricultural Service, 2009)

The largest crop in India is paddy rice, accounting for more than 20 percent of the value for all crops produced (Food and Agricultural Organization, 2006). The second largest crop produced is wheat, which accounts for approximately 10 percent of total crop value (Food and Agricultural Organization, 2006). Wheat production has increased due to technology gains in the Green Revolution in the 1960s; however, gains have been at a much slower rate since 1970/1971 (Food and Agricultural Organization, 2006). India's third largest individual crop is sugar cane, followed by cotton. Oilseed production has been increasing as a result of government policy to make India self-sufficient in oilseeds. As a result, oilseeds accounted for 9 percent of total crop output in 1980/1981 and grew to 13 percent in 1990/1991 (Food and Agricultural Organization, 2006). This policy, however, has since been removed and as a result, oilseeds accounted for only 7 percent of total crop output in 2000/2001 (Food and Agricultural Organization, 2006). It should be noted that India does not have much soybean production, as the main oilseed produced is groundnut.

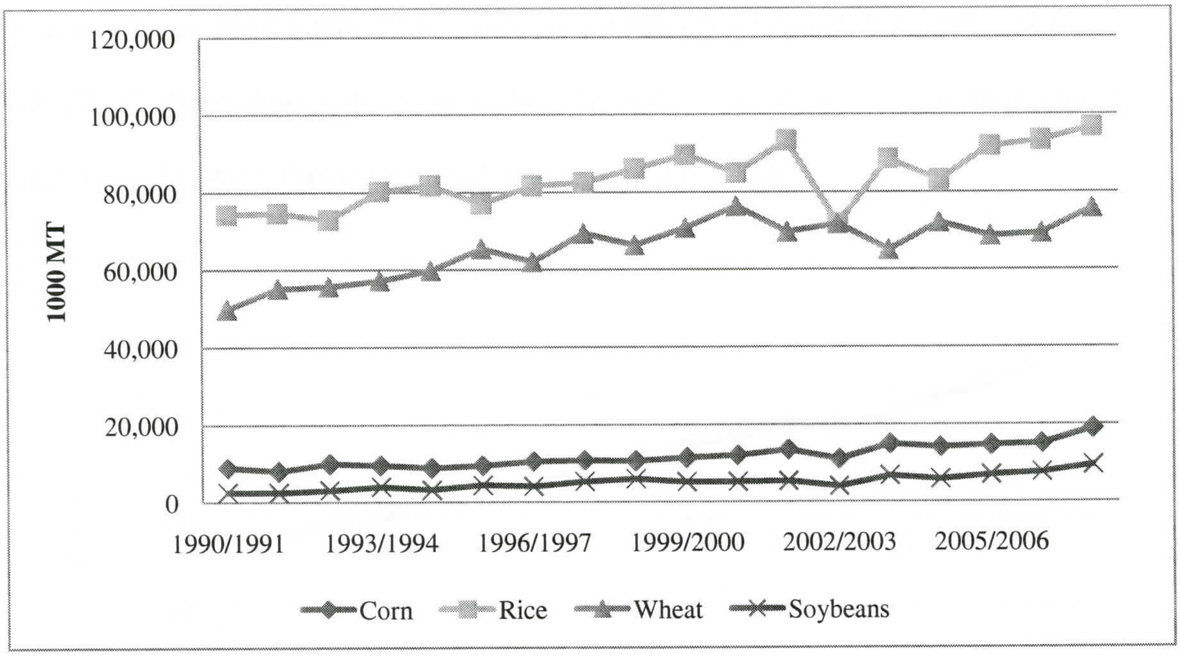


Figure 2.12. India Grain Production 1990/1991 – 2008/2009 (Foreign Agricultural Service, 2009)

As mentioned, Indian consumption of dairy products and meats, such as poultry, is increasing. The livestock sector is growing to meet the rising demand. While livestock contributed to 17.5 percent of total agricultural output in 1980/1981, this has grown to 28 percent in 2000/2001 (Food and Agricultural Organization, 2006). Although meat consumption is growing, the largest area of growth is for dairy products. Figure 2.13 shows the trend of milk consumption in India since 1990.

Indian grain imports are expected to expand to meet the rising needs of the growing population. The fact that India has been able to stay relatively self-sufficient in grains in the past is misleading, as the Indian government has been able to hold stocks of grain when prices are low and then utilize them in future years. This practice of retaining grain stocks is depicted in the trend of Indian grain exports shown in Figure 2.14. If the prediction for India's population and consumption hold, this practice will no longer be possible and India will have to turn to imports to meet rising demands. Figure 2.15 shows the historical trend of grain imports for the four main grains discussed in this research from 1990/1991 to 2008/2009. Other than in the case of wheat, there have not been any significant imports of grain since the trade liberalization reforms of the early 1990s.

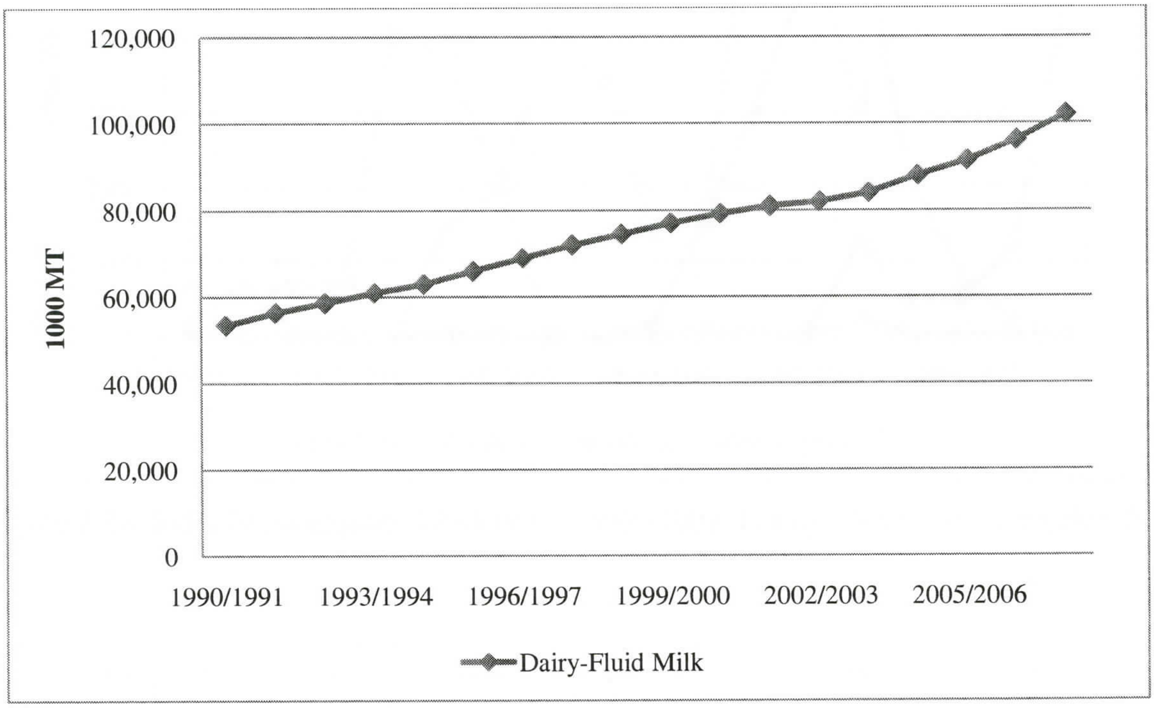


Figure 2.13. Dairy (Fluid Milk) Consumption in India 1990/1991 – 2008/2009 (Foreign Agricultural Service, 2009)

Due to changing consumption patterns and the growing populations of China and India, the strategy of keeping large grain stocks to reduce import demand may no longer be possible. Grain trade in these two countries will eventually have to expand to meet the growing needs of their populations. Trade is not without challenges due to limitations of infrastructure and with each of their governments still playing a protective role in trade. To move forward, these governments will have to reduce trade barriers and prepare their countries to move commodities more efficiently with better infrastructure systems. In the future, a shift of increasing imports in these two large developing nations is certain to affect global agriculture and agricultural trade.

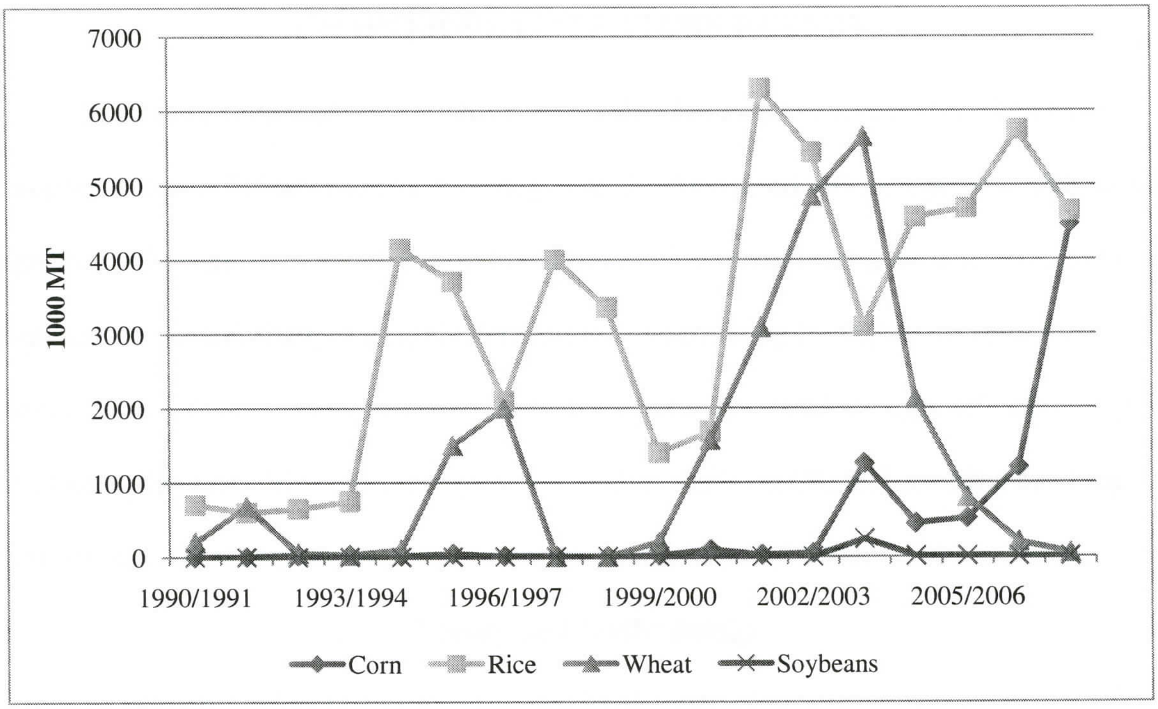


Figure 2.14. India Grain Exports 1990/1991 – 2008/2009 (Foreign Agricultural Service, 2009)

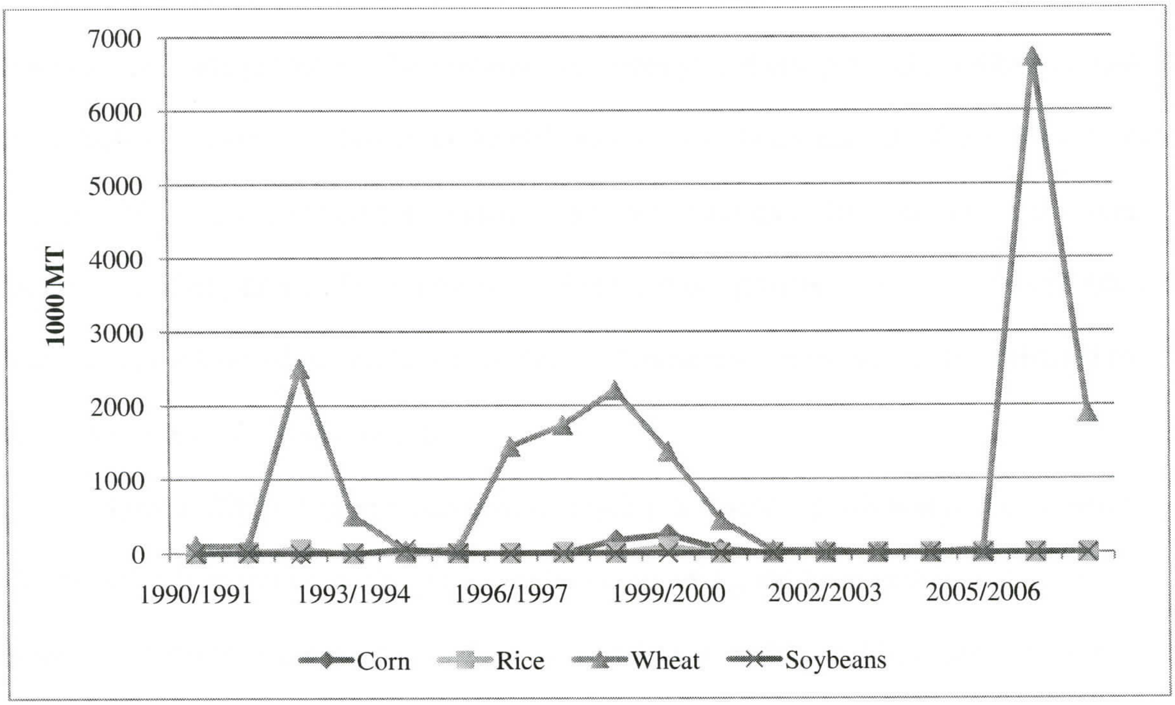


Figure 2.15. India Grain Imports 1990/1991 – 2008/2009 (Foreign Agricultural Service, 2009)

CHAPTER III. LITERATURE REVIEW

Literature reviewed for this study can be divided into two categories. The first category contains literature on methodology and theory behind utilizing general and partial equilibrium models to evaluate international trade. The second category is research on the impact of structural changes in grain demand and determining its impact on future trade flows. Some of the previous research evaluates similar structural changes affects on import and export demand. Many of these previous studies focus on China, because it has long been considered as an important country in global agricultural trade.

Theory and Methodology

A study by Takayama (1967) is considered foundation research for using mathematical programming to determine international trade flows. This study set the framework for using a series of mathematical programming models to evaluate an international trade problem. The research compares partial and general equilibrium models in evaluating a trade issue based on the objective of cost minimization. The results indicate that general and partial equilibrium models are faulted for their difficulties in determining the balance of payments. The study offers that there is a possible solution to this problem; however at the time of the study the solution to this problem was still being evaluated to determine whether it was efficient.

Spreen (2006) demonstrates how to develop a spatial equilibrium model in which the objective is to minimize the transportation costs of a good from supply to demand points. The study discusses the equilibrium of prices over time and how to extend the model to include multiple products. Spreen provides examples of using such models, citing his research in developing the world orange juice model, the world banana model, and the

Florida grapefruit model. He concludes that while price endogenous spatial equilibrium models have many uses, they are limited in the fact that they do not provide statistical inferences. Instead, these models generate point estimates of production, consumption, and price.

Impact of Structural Changes on Global Grain Trade

Various studies have been done to evaluate how increasing income and population growth will affect import demand for China and India. Lu and Kersten (2006) evaluated whether rising grain production would be able to keep up with growing consumption needs through the use of a regionalized multi-market model, China's Agricultural Regional Market Equilibrium Model (CARMEM), which was based on the SWOMPSIM modeling framework. However, they did not extend the research to determine import or exports. Wang and Davis (1998) used a time series econometric approach to determine supply and demand of grain and then used a grain balance sheet that accounted for wastage and stocks to determine trade. They determined that China would need to import 32 million tons by 2010 to satisfy rising domestic demand (Wang and Davis, 1998). Carter and Zhong (1991) use regression analysis to analyze grain supply and demand. They found that by the late 1990s China would have to import over 20 percent of its grain to meet domestic consumption needs (Carter and Zhong, 1991). In the case of India, less research has been conducted. A study by Mohanty et al. (1998) evaluated grain demand in India using an income elasticity approach as a result of changing consumer preferences and production. The results determined that India would become an importing country of wheat and corn (Mohanty et. al., 1998). While these studies evaluated structural changes and the impact on grain demand, they did not analyze how growing import demand would affect world agriculture and global grain trade.

Other research, much of which addresses China's growing consumption, has been conducted primarily in the past ten years. A study by Wilson et. al. (2005) evaluated the affect of different structural changes on grain trade. The three structural changes evaluated were the increase of corn ethanol production in the United States, rapid growth in Brazilian soybean production, and growth in income and population in China. The objective was to evaluate how these structural changes would affect global grain production and trade of wheat, corn, soybeans, barley, sorghum, and rice in 2025.

An econometric approach was used to determine future production and consumption of the aforementioned grains. A spatial optimization model was used to determine the future trade flows. Trade flows were determined by demand, the cost of production in importing countries, and the cost of marketing from exporting countries to importing countries. The results indicated many implications for global agriculture, with the most notable being the expansion of soybean production in Brazil and the shift away from wheat production in the United States (Wilson et. al., 2005).

Zhuang and Koo (2007) evaluated the global implications of China's economic growth on various sectors. A general equilibrium model, more specifically a multi-region Global Trade Analysis Project (GTAP) model, is used. This model makes the assumption of constant return to scale and perfect competition. To conduct the analysis, 87 countries and regions were aggregated into 10 countries and regions. There were 11 sectors evaluated: grains, other primary agriculture, processed food, gas and oil, natural resource based industries, textiles and wearing apparel, light manufactures, heavy manufactures, transportation and machinery and equipment, utilities and housing and construction services, and other services.

The results conclude that world welfare will increase, with China accounting for 95.3 percent of total welfare gains (Zhuang and Koo, 2007). China's total trade balance for all sectors will increase, while in other countries and regions total trade balance will decrease. Output of all sectors in China will increase as a result of rapid economic growth. However, production of grains and other agriculture products in China are limited by land scarcity.

Koo and Taylor (2009) used a spatial equilibrium model to study the impact of changes in the Chinese grain and oilseed industries in 2020 on world agriculture. This study focuses on corn, wheat, rice, and soybeans. Production was determined using historical production data for 2005 and forecasted to 2020 using an econometric approach. Four scenarios were analyzed to account for 5, 10, 15, and 20 percent increases in yields in 2020.

Their results concluded that under a 5 percent increase in yield, China would import corn, soybeans, and wheat. Under the second scenario of a 10 percent increase in yield, there will be significant decrease in corn imports and some in soybeans. Wheat imports will remain steady and China would be self-sufficient in rice. In the case of a 20 percent increase in yields, China will no longer need to import rice or corn; however, China will still need to import soybeans and wheat. In addition, the research goes further to explain under each scenario what the impact will be to the other major importing/exporting countries. Their research is very similar to the focus of this study; however, this study is extended to include India, which is also expected to have a significant impact on global grain trade.

Haq and Mielke (2009) evaluated how economic growth in low-income, middle-income, high-income and BRIC (Brazil, Russia, India, and China) countries will affect global agri-food trade. While this study did not determine the specific affects for individual countries, it did analyze income elasticities as it affects international trade. They analyzed a few different questions; do income elasticities in these four categories differ by time period, are income elasticities for imported agri-food products in BRIC countries similar to other countries at the same level of economic development, and are income elasticities of import demand in BRIC countries similar to each other. Income elasticities were evaluated over three periods and various product sectors.

In the agri-food category, Brazil, Russia, and China's income elasticities were similar to that of middle-income countries. India's elasticities were similar to those of a low-income country. Their hypothesis that middle-income countries are the agri-food import growth markets of the future is strongly supported only for China and Russia. While this analysis differs from the others evaluated, it does support the idea that China is a large import growth market for agriculture. However, their results indicate that India will be more price sensitive and thus may not import many agricultural commodities as a result. However, this analysis is pertinent for agri-food products and not grain specifically, as will be the focus of this study.

Landes, Price, and Seeley (2000) evaluate the impact of developing countries' economies on U.S. agriculture. The rationale behind the study is that the United States is a large exporter, and developing countries are accounting for a growing share of world trade through increasing agricultural imports. Alternative scenarios are used to model different levels of income growth and exchange rates. The model used is the country-linked system (CLS) model developed by the Economic Research Service (ERS), a division of the USDA. This model incorporates 42 country and regional models with a food and agricultural policy simulator for U.S. agriculture. The affects are determined on five different categories of countries: developing Asia, Africa and the Middle East, Latin America, transition economies (Former Soviet Union and Central/Eastern Europe), and developed countries (excluding the United States). Their research indicates that if developing and transition countries/regions' income growth slowed or currencies in these countries have a greater depreciation in comparison with the U.S. dollar, there would be a large global impact. In relation to developing Asia, this region was found to have the largest potential to impact global and U.S. agriculture markets.

Von Witzke et. al. (2008) analyzes the impact of different global trends on agriculture in the European Union (EU). The global trends evaluated in their model were the growth in world population, increased urbanization and income growth as they affect food consumption, climate change, availability of natural resources, the role of organic farming, technology changes, and the trade-off between food production and bio-energy production. They used a partial equilibrium model to determine the changes in supply and demand of wheat, corn, oilseeds, and other grains. The results determine that each of these factors has various affects on global agriculture. The end result is that while the supply of grain in the EU will increase, it would not be enough to satisfy rising demand and world prices will increase as a result. The EU will become a net importer of wheat, oilseeds, and other grains. Their analysis provides insight into the shift of developing countries to net importing countries and developed countries to net exporting countries.

Research evaluating structural changes on import demand of wheat by Fabiosa (2006) illustrates how rising income affects global grain trade. The research evaluates the affect of a westernized diet in Indonesia on its large wheat-processing sector. The study estimates income elasticities on wheat flour and noodle consumption. In addition, Fabiosa expands his research to analyze different scenarios and how they will affect trade. The first scenario is focused on policy, and evaluates the affect of the removal of an applied duty, value added tax (VAT), and sales tax. The second scenario evaluates the affect of fast income growth, estimating income growth to be the same as China. In order to analyze trade, a partial equilibrium model using the new demand estimates was utilized.

The results determine that by removing the trade barriers, wheat flour consumption expands. Because Indonesia does not produce wheat, wheat imports must increase with the expansion in wheat flour consumption, which would increase world wheat prices. The second scenario also increases consumption, imports, and world and domestic prices; however, the impacts were not as large as in the first scenario. The study also explains which countries will be the largest wheat suppliers to Indonesia and indicates that the largest export potential was for China, India, and Australia, because these countries are able to provide wheat at a lower price.

It is clear that structural changes in demand in these major developing countries will have a global impact. While much of the past research utilizes similar methodology, there is a lack of research that evaluates the impact of growing consumption in both China and India on global agriculture. It is apparent from past literature that a spatial equilibrium model has been used to address similar research objectives. However, this research topic is unique and will provide results that will provide implications for major grain and oilseed producing and consuming countries all over the world.

CHAPTER IV. METHODOLOGY AND MODEL DEVELOPMENT

This chapter outlines the spatial equilibrium model. In addition, the methods, data collection, baseline and alternative scenarios are explained.

Conceptual Framework of the Model

This study addresses the impact of changes in demand for four principle crops, wheat, corn, rice, and soybeans, using a spatial equilibrium model based on a mathematical programming algorithm. Spatial equilibrium models are commonly used to address trade flows as a result of changes in supply or demand. This model was chosen to address the objective of this study, because it provides detailed information about trade flows based on a set of constraints related to the supply and demand of agricultural commodities. While an econometric model could be used to estimate imports and exports of commodities in countries, it would be unable to provide information as to where the commodity was imported from or being exported to. In addition, the spatial equilibrium model optimizes trade flows of commodities on the principle of comparative advantage in terms of production and distribution costs of commodities from producing regions to consuming regions in domestic and foreign countries.

To evaluate the impact of structural changes of demand in China and India on other major importing and exporting countries, the world was divided into 17 countries and regions. The exporting countries are Argentina, Australia, Brazil, Canada, and the United States. The importing countries/regions are Japan, Mexico, the European Union-27, South Africa, the Former Soviet Union-Middle East, Latin America, North Africa, South Korea, South Asia, and Southeast Asia. China and India are treated as both importing countries and exporting countries. Also, it is important to note that since China and India are evaluated independently they are excluded from the Southeast Asia and South Asia regions, respectively. Further explanations of the countries included in producing/consuming regions are included in Table 4.1. Figure 4.1 shows alternative trade flows for the four crops from exporting countries to importing countries.

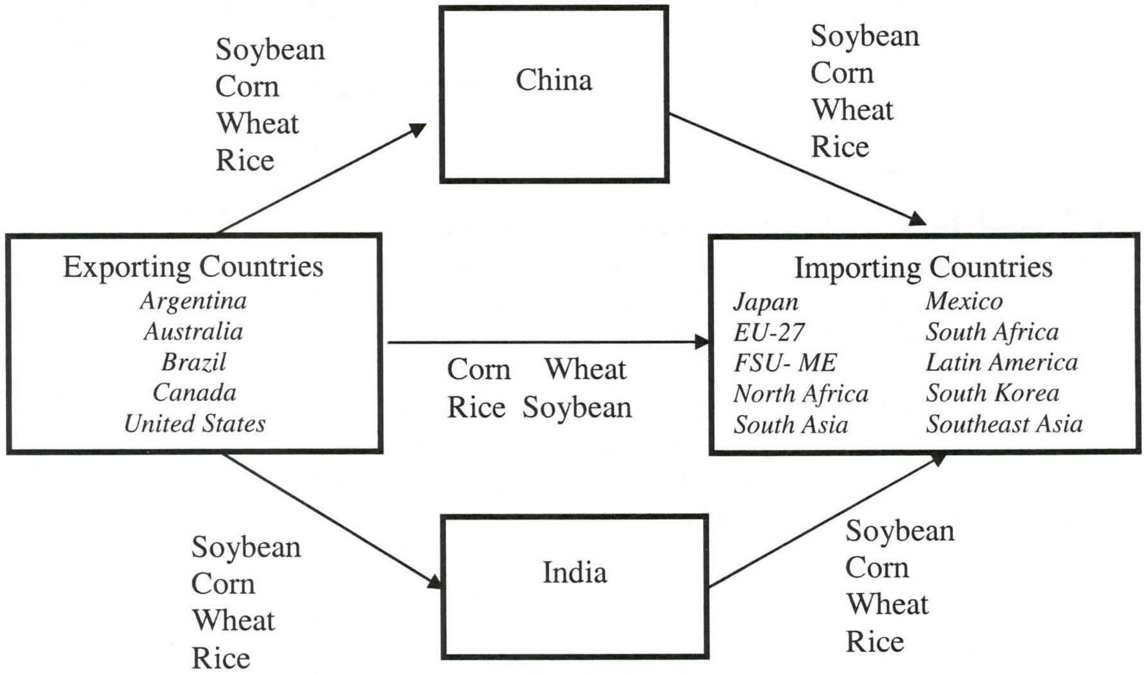


Figure 4.1. Theoretical Model of Trade Flows

The modes of transportation used for this study are rail, truck, and barge for domestic transportation and ocean vessels for inter-country shipments.

In the case of some of these importing/exporting countries, there are significant differences in production conditions among regions within a country. As a result Canada, the United States, Brazil, China and India are divided into several producing and consuming regions. Canada is divided into 6 regions (Quebec (CQB), Ontario (CON), Manitoba (CMB), Saskatchewan (CSK), Alberta (CAL), and British Columbia (CBC)), the United States into 17 regions (Table 4.2 and Figure 4.2), Brazil into two regions (North

(BRZ2) and South (BRZ1)), China into 31 regions (Table 4.3 and Figure 4.3), and India into 14 regions (Table 4.4 and Figure 4.4). Including the addition of the inter-country regions, there are 83 producing and consuming regions included in the model.

Table 4.1. Exporting and Importing Countries and Regions

Region	Symbol	Countries/Regions Included
Argentina	ARG	Argentina
Australia	AUS	Australia
Brazil	BRZ	Brazil
Canada	CAN	Canada
China	CHN	China (See Table 4.3)
EU-27	EUR	Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Faroe Islands, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom
Former Soviet Union-Middle East	FSU-ME	Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Moldova, Russia, Tajikistan, Turkmenistan, Ukraine, Uzbekistan, Bahrain, Gaza Strip, Iran Iraq, Israel, Jordan, Yemen, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, Turkey, United Arab Emirates, West Bank
India	IND	India (See Table 4.4)
Japan	JAP	Japan
Latin America	LAT	Bolivia, Chile, Colombia, Ecuador, Falkland Islands, French Guiana, Guyana, Paraguay, Peru, Suriname, Uruguay, Venezuela,
Mexico	MEX	Mexico
North Africa	NAF	Algeria, Egypt, Libya, Morocco, Tunisia
South Africa	SAF	Angola, Benin, Botswana, Burkina, Burundi, Cameroon, Canary Islands, Cape Verde, Central Africa Republic, Chad, Comoros, Congo, Cote d'Ivoire, Djibouti, Equatorial Guinea, Eritrea, Fr. Ter. Africa, Gabon, Gambia, Terr. Ghana, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Madeira islands, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Reunion, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Somalia, South Africa, St. Helena, Sudan, Swaziland, Tanzania, Togo, Uganda, Western Sahara, Zambia, Zimbabwe
South Asia	SA	Afghanistan, Bangladesh, Bhutan, Maldives, Nepal, Pakistan, Sri Lanka
Southeast Asia	SEA	Brunei, Cambodia, Indonesia, Laos, Malaysia, Philippines, Singapore, Thailand, Vietnam
United States	US	United States (See Table 4.2)

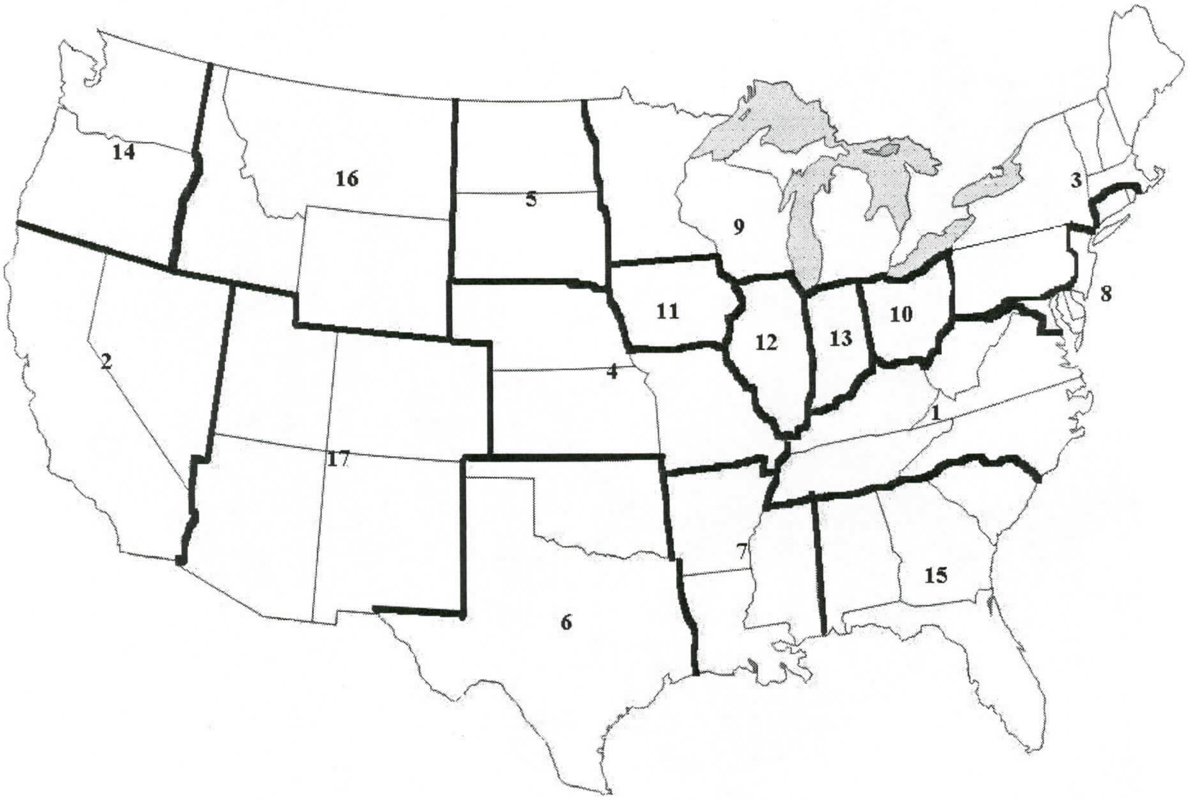


Figure 4.2. Producing and Consuming Regions in the United States

Table 4.2. Producing and Consuming Regions in the United States

Region	Symbol	States Included in Region
1	US1	Kentucky, North Carolina, Tennessee, Virginia, West Virginia
2	US2	California, Nevada
3	US3	Maine, Massachusetts, New Hampshire, New York, Pennsylvania, Vermont
4	US4	Kansas, Missouri, Nebraska
5	US5	North Dakota, South Dakota
6	US6	Oklahoma, Texas
7	US7	Arkansas, Mississippi, Louisiana
8	US8	Connecticut, Delaware, Maryland, New Jersey, Rhode Island
9	US9	Michigan, Minnesota, Wisconsin
10	US10	Ohio
11	US11	Iowa
12	US12	Illinois
13	US13	Indiana
14	US14	Oregon, Washington
15	US15	Alabama, Florida, Georgia, South Carolina
16	US16	Idaho, Montana, Wyoming
17	US17	Arizona, Colorado, New Mexico, Utah

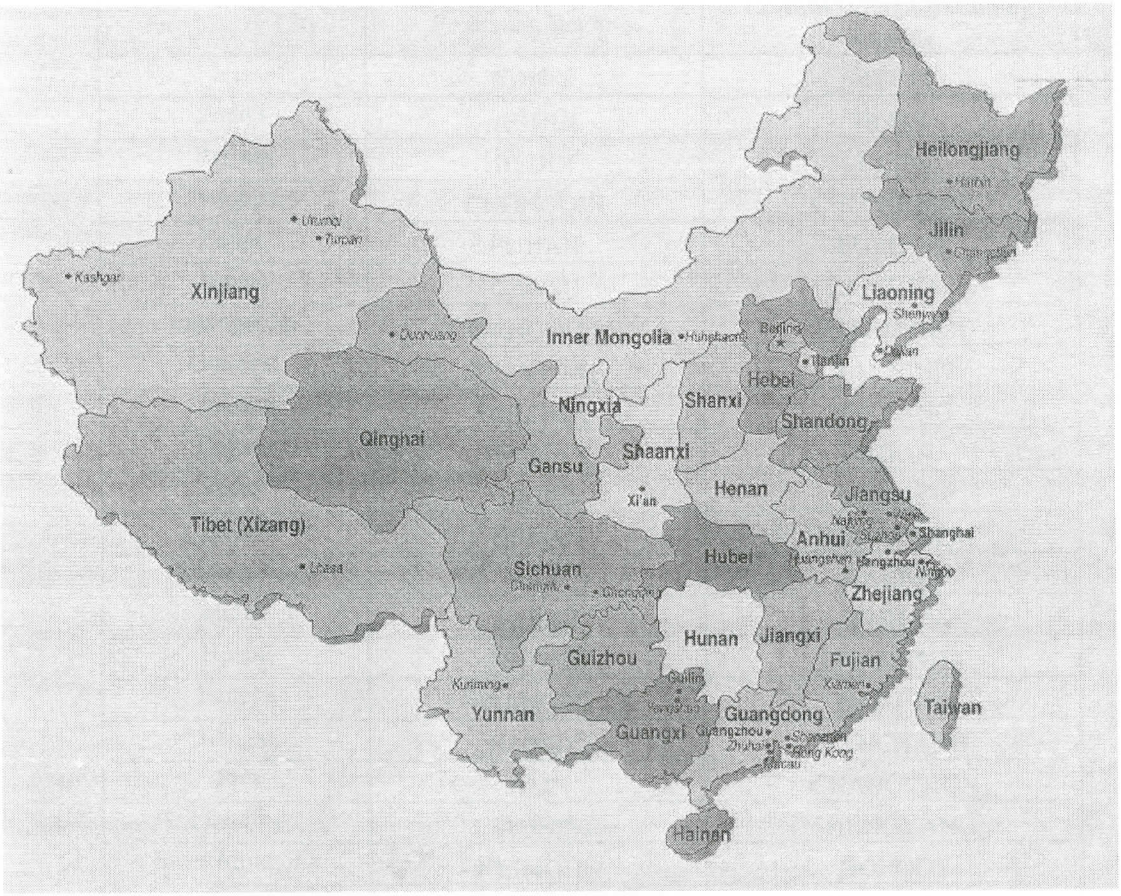


Figure 4.3. Producing and Consuming Regions in China (China the Beautiful)

Table 4.3. Producing and Consuming Regions in China

Province or City	Producing Regions	Corresponding Consuming Regions
	Symbol	Symbol
Anhui	ANHUI	HEFEI
Beijing	BEIJIN	BEIJINC
Chongqing	CHONGQIN	CHONGQINC
Fujian	FUJIAN	FUZHOU
Gansu	GANSU	LANZHOU
Guangdong	GUANGDONG	GUANGZHOU
Guangxi	GUANGXI	NANNING
Guizhou	GUIZHOU	GUIYANG
Hainan	HAINAN	HAIKOU
Hebei	HEBEI	SHIJIAZH
Henan	HENAN	ZHENGZHOU
Heilongjiang	HLJ	HARBIN
Hubei	HUBEI	WUHAN
Hunan	HUNAN	CHANGSHA
Jiangsu	JIANGSU	NANJING
Jiangxi	JIANGXI	NANCHANG
Jilin	JILIN	CHANGCHUN
Liaoning	LIAONING	SHENGYANG
Inner Mongolia	NEIMONG	HOHOOT
Ningxia	NINGXIA	YINCHUAN
Qinghai	QINGHAI	XINING
Shaanxi	SHAANXI	XIAN
Shandong	SHANDONG	JINAN
Shanghai	SHANGHAI	SHANGHAIC
Shanxi	SHANXI	TAIYUAN
Sichuan	SICHUAN	CHENGDU
Tianjin	TIANJIN	TIANJINC
Xinjiang	XINGJIANG	URUMQI
Xizang	XIZHANG	LASHA
Yunnan	YUNNAN	KUNMING
Zhejiang	ZHEJIANG	HANGZHOU

Figure 4.4. Producing and Consuming Regions in India

Table 4.4. Producing and Consuming Regions in India

Region	Symbol	States Included in Region
1	IND1	Himachal Pradesh
2	IND2	Punjab, Haryana
3	IND3	Uttarakhand
4	IND4	Rajasthan, Uttar Pradesh
5	IND5	Gujarat
6	IND6	Madhya Pradesh
7	IND7	Chhattisgarh
8	IND8	Bihar
9	IND9	Jharkhand
10	IND10	Orissa
11	IND11	West Bengal
12	IND12	Sikkim, Arunachal Pradesh, Assam, Meghalaya, Nagaland, Manipur, Mizoram, Tripura
13	IND13	Maharashtra, Andhra Pradesh, Karnataka
14	IND14	Kerala and Tamil Nadu

Mathematical Model

The spatial equilibrium model for this study is similar to the model used by Koo and Taylor (2009). The objective function of the model is to minimize the production cost of wheat, corn, rice, and soybeans in each producing region and the distribution costs (transportation costs) associated with shipping crops from production regions to both domestic consuming regions and foreign consuming regions. The objective function is mathematically presented as follows:

1. $$W = \sum_c \sum_i (PC_{ci}) A_{ci} + \sum_c \sum_i \sum_j t_{cij} Q_{cij} + \sum_c \sum_i \sum_p t_{cip} Q_{cip} + \sum_c \sum_p \sum_q (t_{cpq} + \lambda_q) Q_{cpq} + \sum_c \sum_p \sum_q (t_{cpq} + \lambda_q + \alpha) Q^{p}_{cpq} + \sum_c \sum_q \sum_j t_{cqj} Q_{cqj}$$

i = the index of producing regions in exporting countries

j = the index for consuming regions located in both importing and exporting countries

p = the index for ports in exporting countries

q = the index for ports in importing countries

PC_{ci} = cost of producing crop c in producing region i

A_{ci} = the area used to produce crop c in producing region i in hectares

t = per metric ton transportation cost

Q = the quantity of crop shipped in metric tons

α = represents the tariff applied for shipping through the Panama Canal

λ_q = import duty imposed by importing country

The first term represents the total production cost, which is the product of production cost of crop c in producing region i and harvested area of crop c in the production region. The second term represents the cost of transportation from producing region to consuming region within the exporting country. The third term represents the transportation cost from producing regions to ports for export. The fourth term represents ocean transportation cost from a port in an exporting country to a port in an importing country including import tariffs. The fifth term is similar to the fourth; however, it includes the cost of the required tariffs for utilizing the Panama Canal. The final term represents the interior transportation cost from an importing port to consuming regions within the importing country.

The objective function is optimized subject to the following constraints:

2. $Y_{ci} A_{ci} \geq \sum_{j} Q_{cij} + \sum_{p} Q_{cip}$

3. $\sum_{c} A_{ci} \leq TA_{i}$

4. $A_{ci} \geq MA_{ci}$

5. $\sum_{i} Q_{cij} + \sum_{q} Q_{cqj} \geq D_{cj}$

6. $\sum_{c} \sum_{i} Q_{cip} \leq PCA_{p}$

7. $\sum_{c} \sum_{p} \sum_{q} Q^{p}_{cpq} \leq PCC$

8. $\sum_{i} Q_{cip} = \sum_{q} Q_{cpq}$

9. $\sum_{p} Q_{cpq} = \sum_{j} Q_{cqj}$

Y = crop yields per hectare in producing regions of exporting countries

TA = the total arable land in each producing region of an exporting country

MA = the minimum land used for each crop in producing regions of exporting countries

D = the demand for each crop in consuming regions of both importing and exporting countries

PCA = represents the handling capacity in each port of an exporting country

PCC = the handling capacity of the crop through the Panama Canal

Equation 2 indicates that the production of crop c in producing region i must be equal to or greater than the quantity consumed of the crop that is transported to domestic consuming regions and to exporting ports. Equation 3 makes the provision that production is limited by the amount of arable land, indicating that the total area harvested for all crops in a production region cannot exceed that of total arable land available in a production region. Equation 4 makes the assumption that crops produced in a production region will not change considerably, due to soil type, grower knowledge, and capital availability, and thus the area harvested for crop c will be greater or equal to the minimum land used for the crop in the producing region. Equation 5 states that demand for crop c is less than or equal to the amount produced and imported in a consuming region. Equations 6 and 7 indicate handling capacity at export ports and the Panama Canal, respectively. The total amount of agriculture commodities shipped through export ports and the Panama Canal should be less than its handling capacity. Equations 8 and 9 state that ports in exporting and importing countries cannot store grain and are considered as transportation points. Thus, Equation 8 indicates that the quantity sent from a producing region to an export port must be equal to the quantity exported to an importing port, and Equation 9 indicates that the quantity sent from an exporting port to an importing port must be equal to the quantity sent from the importing port to the consuming region(s).

The Base and Alternative Scenarios

The Base model is based on average production conditions in 2005, 2006, and 2007. Consumption data are based on 2007 data. The exception in both production and consumption data are China and India, in which data availability requires that production estimates be based on an average of 2003, 2004, and 2005 data and consumption data on 2005. Production data are expressed in 1000 hectares (area harvested) and metric ton/hectare (yield) and consumption data are expressed in 1000 metric ton. The Base model is calibrated using theoretical data for the supply of and the demand for crops in importing and exporting countries given supply and demand conditions in these years to determine the optimal solution under the Base model. The Base-18 model is the same as the Base Model; however, with projected production and consumption of the four crops in the year 2018.

Six alternative scenarios are developed to evaluate the impact of different supply and demand conditions on the production of the crops in exporting countries and trade flows from exporting countries to importing countries. Scenarios 1, 2, 3, and 4 determine the impact of changes in technology. Scenario 1 uses the same production and consumption data from the Base-18 model; however, yields in India are increased by 20 percent from the 2018 projection. Scenario 2 is similar to Scenario 1, except yields for China are increased by 20 percent from the 2018 projection. Scenario 3 is similar to the previous two; however, yields in India are decreased by 20 percent from the 2018 projection. Scenario 4 is the same as Scenario 3; however, yields in China are decreased by 20 percent from the 2018 projection. These four alternative scenarios are developed mainly due to uncertainty associated with crop yields resulting from weather conditions.

Scenarios 5 and 6 are used to determine the affect if consumption in China and India surpass what is projected. The model is the same as the Base-18 model in both scenarios; however, Scenario 5 increases consumption by 5 percent in each of India's consumption regions and Scenario 6 increases consumption by 5 percent in each of China's consumption regions.

Data Collection

The data required for this model can be broken down into five categories: production cost for all of the crops in all producing regions, domestic transportation cost (including rail, truck and barge), ocean shipping rates, production (crop yields and area harvested) in producing regions, and consumption (per capita consumption, per capita income and population data) in consuming regions.

Cost data include the cost of production, domestic transportation cost (using rail, barge, and truck), and ocean shipping rates. Production costs for all crops in all regions were obtained *The Cost of Producing Crops Around the World* (Global Insights, 2004). Domestic transportation costs were obtained primarily from the *Grain Transportation Report* (Agricultural Marketing Service, 2002, 2003). Additional domestic transportation information for China was obtained from the Henan University of Technology, Zhengzhou, China. U.S. and Canadian rail transportation rates were obtained from the *Public Waybill* data (Surface Transportation Board, 2002). Additionally, U.S. domestic transportation data were obtained from the *Grain Transportation Digest* (ProExporter, 2004). Ocean shipping rates were obtained from *Ocean Shipping Rates for Grains* (Maritime Research, Inc., 2004). Tariffs are also added as a cost in the model, and thus import tariffs were obtained from the publication *World Tariff Profiles 2008* (World Trade Organization, 2008).

In order to determine agricultural trade, it is necessary to determine what and how much each region produces and consumes. Production data were obtained using crop yields and area harvested to determine the amount of available production. Crop yields are expressed in metric ton/ hectare and area harvested is expressed in 1000 hectares, which is consistent with most international agricultural data sources. Crop yields and area harvested for most producing regions were obtained from the *Production, Supply, and Distribution* online database (Foreign Agricultural Service, 2009). Production data for regions in China were obtained from the Henan University of Technology, Zhengzhou, China. Production data for regions in India were obtained from *State Wise Area Production and Yield Statistics* online database (Department of Agriculture and Cooperation of the Ministry of Agriculture for the Government of India, 2009). Production data for regions in the United States were obtained from the *Crops* online database (National Agricultural Statistics Service, 2009). Production data for regions in Canada were obtained from various volumes of their *Field Crop Reporting Series* (Statistics Canada).

Domestic consumption is calculated using per capita consumption and population. Data for most regions were obtained from the *World Development Indicators Quick Query* (The World Bank Group, 2009) and the *Production Supply and Distribution* online database (Foreign Agricultural Service, 2009). Population data for regions in India were obtained from the *Domestic Product of States of India 1960-1961 to 2006-2007* (EPW Research Foundation, 2009). Population data for regions in China were obtained from the *China Statistical Yearbook 2008* (China National Bureau of Statistics, 2008). Population data for regions in the United States were obtained from the U.S. Census Bureau and for region in Canada from Statistics Canada.

Crop Production in 2018

In order to project forward from the Base model, crop yields are estimated for all four crops for the year 2018. To do this, a standard time trend regression is used to determine the change in yields in the projected year. Data were obtained for the years 1990 to 2007 from the aforementioned sources to determine the trend. However, in some cases the period of time varies based upon data availability. The time trend regression is represented by:

10. $Y_{ci} = \beta_0 + \beta_t T$

Y_{ci} = yield of crop c in region i.

T = time trend variable.

The estimated coefficient of the time trend variable is used to project crop yields for each crop in 2018. The projections for yields in all four crops are then evaluated to obtain the average yield increase across all production regions, because the increase in estimated yields are substantially different in the producing regions, and thus the yields are averaged under the assumption that production technology will spread from one region to another due to the exchange of technology. Average yields are 15 percent for wheat, 18 percent for corn, 14 percent for soybeans, and 18 percent for rice. These percentage increases are then applied to the yield data in the Base Model to determine crop yields in 2018. The area harvested is determined by the model. The production data used in the Base and Base-18 models are presented for all four crops in Tables A.2., A.3., A.4., and A.5.

Consumption in 2018

The objective of this research is to evaluate the impact on global agriculture of structural changes of demand in China and India. Therefore, the projection of consumption in 2018 is an integral part of this analysis. Domestic consumption estimates for 2018 were taken from *FAPRI 2009 U.S. and World Agricultural Outlook* (FAPRI, 2009). An alternative domestic consumption projection came from the *USDA Agricultural Baseline Projections for 2009-2018* (Economic Research Service, 2009). In evaluating these two different domestic consumption projections some estimates were similar and some consumption projections varied greatly due to the assumptions made in the analysis and aggregation issues when forming consuming regions. As a result, it was important to estimate consumption of each crop in each region (per capita consumption for each of the four crops) based on per capita income and a time trend variable.

A demand model for each crop is specified as a function of income and trend to represent consumer taste and preference as:

11. $C_{it} = \alpha_0 + \alpha_1 Y_t + \alpha_2 TR + e_t$

C_{it} = per capita consumption of crop t in region i

Y_t = per capita income in region t

TR = time trend variable

e_t = error term

Equation 11 represents per capita consumption, which is determined by per capita income and a time trend variable. Since the error term of Equation 11 is serially correlated, an AR (1) model is used to estimate the equation.

The estimated model is used to project per capita consumption for 2018. Per capita income in 2018 was calculated using the *Real GDP Growth Projections* from FAPRI's *World Macroeconomics,* available in their publication *FAPRI 2009 U.S. and World Agricultural Outlook.* To determine per capita income, and later to determine consumption as a whole for the region, population projections were also taken from *FAPRI 2009 U.S. and World Agricultural Outlook.*

Once consumption of each crop was determined, the results were compared to the projections of FAPRI and the USDA to evaluate whether the projections are consistent. The results from all three sources for wheat, corn, rice, and soybeans are presented in Table A.1.

The final domestic consumption projections used in the analysis for the Base-18 model and Alternative Scenarios 1-6 are taken primarily from the econometric analysis conducted in this study. The final domestic consumption projections are then divided into consuming regions, which is only of importance for countries with multiple consuming regions, China and India, based on the proportion of the country's population that resides in that consuming region. These proportions can change over time. Therefore, a time trend regression, similar to Equation 10, is run on regional populations. The final domestic consumption projections for 2018 are shown in Table 4.5 along with those used in the Base model.

Table 4.5. Total Domestic Consumption in the Base and Base-18 Models

	Wheat		Corn		Soybean		Rice	
Region	Base	Base-18	Base	Base-18	Base	Base-18	Base	Base-18
	----------------------------1000 Metric Ton-------------------------------							
ARG	5130	5158	7000	8521	36163	56586	375	505
AUS	6200	8252	320	433	43	48	346	563
BRZ	10480	11894	41500	52511	33820	55905	8317	8691
CAN	7317	7608	11149	17579	1784	2603	320	488
CHN	100122	106003	136352	181348	44540	62356	127111	127450
EUR	116536	134580	63400	58955	16113	17340	3240	3773
FSU-ME	117132	134702	26721	34000	4882	6473	8348	10121
IND	76839	85369	14291	19616	9458	11423	91053	108456
JAP	6000	5517	16600	16418	4218	3913	8177	7779
KOR	3000	2682	8633	11295	1386	1575	4670	4295
LAT	8619	10405	15378	18715	3929	3791	5315	5691
MEX	5500	6155	32000	41570	3710	5099	759	941
NAF	35894	41278	15664	18834	1575	1582	3721	4952
SA	33065	33065	5274	5274	175	175	38934	40405
SAF	28770	35000	48860	54270	1383	1660	57898	58000
SEA	10995	14294	28499	39405	5096	6383	97233	138367
US	27597	33110	252719	312396	49801	65348	3917	5488

Transportation Costs

Transportation costs are divided into three categories:

1. Inland shipping costs from producing regions to consuming regions or ports
2. Costs for shipping from an exporting country's ports to an importing country's ports
3. Inland shipping costs from importing port to consuming region

Inland shipping costs from producing regions to consuming regions and ports are only applicable to countries with multiple producing and consuming regions, such as China, India, Brazil, Canada, and the United States. In other countries/regions, the producing and consuming regions are the same and thus domestic shipping costs are not needed. These inter-country shipments are typically done by rail, though truck shipments are also used primarily for inter-country shipments in the United States. The model does allow for some shipments from producing regions in the United States and Canada to consuming regions in the United States, Canada, and Mexico. Inland shipping from consuming regions to ports is done by truck and rail; however, the United States also utilizes barge transportation in the Mississippi River system.

The cost of shipping from exporting countries to importing countries is calculated using ocean freight rates, along with import tariffs. Each country/region has one or more importing/exporting port(s); however, South Asia and India share ports as India is located in the optimal location for South Asia to receive imports. The model assumes no port handling fees.

Inland shipping costs from import ports to consuming regions are only applicable to China and India. Since other countries that are divided into multiple production/consumption regions, Canada, Brazil, and the United States, are not importing countries the inland shipping costs from ports to consuming regions is not included. The mode of transportation from importing ports to consuming regions is done primarily by rail.

CHAPTER V. EMPIRICAL RESULTS

Chapter 5 discusses the results of the Base and Base-18 models and the alternative scenarios. Each optimal solution outlines the production, consumption, and trade flows of the four crops. The alternative scenarios evaluate China and India individually for changes in technology and consumption. This chapter is divided into three parts: (1) The results of the Base model compared to the Base-18 model, or production and trade conditions under the current conditions compared to those in 2018 (2) alternative scenario results for changes in production and consumption in China (3) alternative scenario results for changes in production and consumption in India.

Base and Base-18 Model

This section will evaluate the production, consumption, and trade flows for the Base model, under current supply and demand conditions, and the Base-18 model with supply and demand conditions estimated for the year 2018, for all four crops in all producing and consuming regions. Because the focus of this study is China and India, the results for these two countries will be evaluated independently to show the change over time. In addition, production and trade in the United States and Canada will be outlined, because these two nations are large exporting countries and due to the diverse production conditions within these countries.

China's Production, Consumption and Trade

China is evaluated on its production, consumption, exports, and imports for the current period and in 2018. Table 5.1 presents the results from both models. Production in the Base model demonstrates that corn is the leading crop, comprising 36 percent of all grain production. Rice, wheat, and soybeans account for 33, 26.5, and 4 percent, respectively. In relation to trade, China only imports and does not export in the Base model. Imports are primarily soybeans, with imports accounting for 65 percent of domestic consumption. China imports a small amount of wheat, with imports accounting for 0.8 percent of domestic consumption. Rice is also imported and accounts for 2.9 percent of domestic consumption.

Table 5.1. Production, Consumption, and Trade for China in the Base and Base-18 Models

	Model	Production	Consumption	Export	Import
	----------million metric ton----------				
Wheat					
	Base	99.31	100.12	-	0.76
	Base-18	106.00	106.00	-	-
Corn					
	Base	136.35	136.35	-	-
	Base-18	176.77	181.35	-	4.58
Soybean					
	Base	15.52	44.54	-	29.02
	Base-18	17.96	62.36	-	44.40
Rice					
	Base	123.47	127.11	-	3.63
	Base-18	128.57	127.45	1.12	-

In the Base-18 model, it is evident that consumption patterns have changed since the base year. In 2018, corn accounts for 38 percent of total grain consumed, compared with 33 percent in the Base model. Soybeans account for 13 percent of total grain consumed, which is a 40 percent increase in the amount of soybeans consumed compared to the Base model. Rice and wheat are staples in the Chinese diet; however, between the base year and 2018, the amount of rice and wheat consumed has increased by only 0.2 and 5.8 percent, respectively. This could be interpreted to mean that as income increases, Chinese consumers will consume less rice and wheat and more meat products. Since consumers in China are consuming more meat, shown by its growing livestock industry, the result is an increased demand for corn and soybeans to be used as feedstuffs.

Grain production has also increased, due mainly to the advancement of farming technology. Corn remains the primary crop, accounting for 41 percent of grain production. Rice, wheat, and soybeans account for 30, 25, and 4 percent, respectively. China's role in trade has also changed. Despite the increase in corn production, China imports a small amount of corn in 2018 with imports accounting for 2.5 percent of domestic consumption. In addition, China has increased its imports of soybeans with imports accounting for 71 percent of domestic consumption. China has also become a small net exporter of rice with 0.9 percent of its rice production being exported to Japan.

To demonstrate the domestic and trade flows of the commodities, Figures 5.1, 5.2, 5.3, and 5.4 each outline the flows for each of the four grains. Figure 5.1 shows the domestic flow of wheat in China. The largest producing region in both models is Henan, followed by Shandong and Hebei. In the Base model, China produces less wheat. As a result, there are more domestic flows of wheat to satisfy domestic consumption. Also in the Base model, China imports wheat with .76 million metric tons being imported and consumed in Guangzhou. This wheat originated from the U.S. Pacific Northwest.

Domestic flows of corn are shown in Figure 5.2. The largest corn producing provinces are located in the Northeast and Eastern Central regions of China, with the largest being Shandong followed by Heilongjiang, Jilin, Hebei, and Henan. The major producing regions remain the same in both models as do domestic flows. While China does produce more in the Base-18 model, it is unable to keep up with the growing domestic demand and thus becomes a net importer of corn in the Base-18 model. The corn imports originate from Argentina and are being sent to the port in Guangzhou.

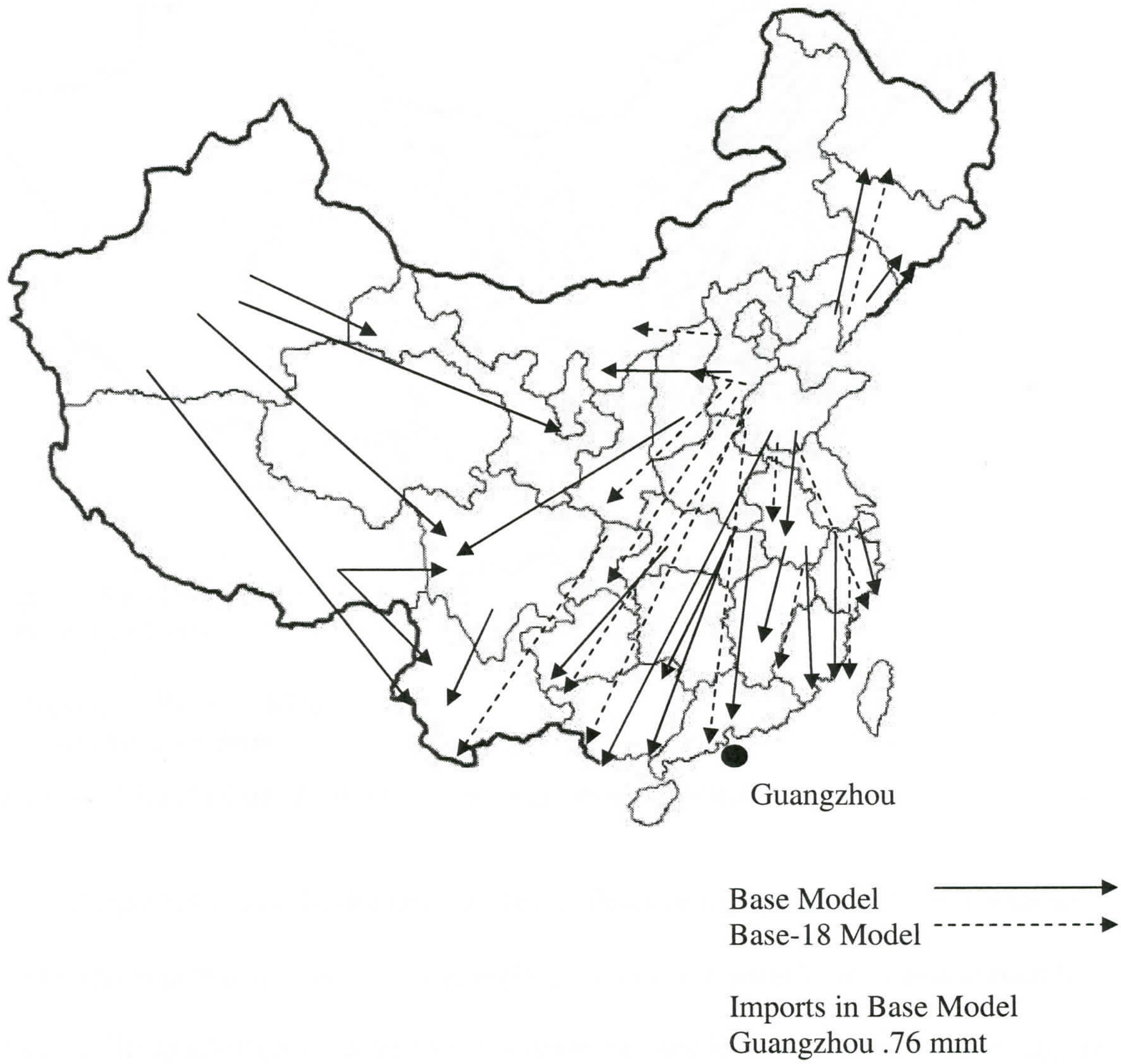


Figure 5.1. China's Wheat Domestic Flows for the Base and Base-18 Models

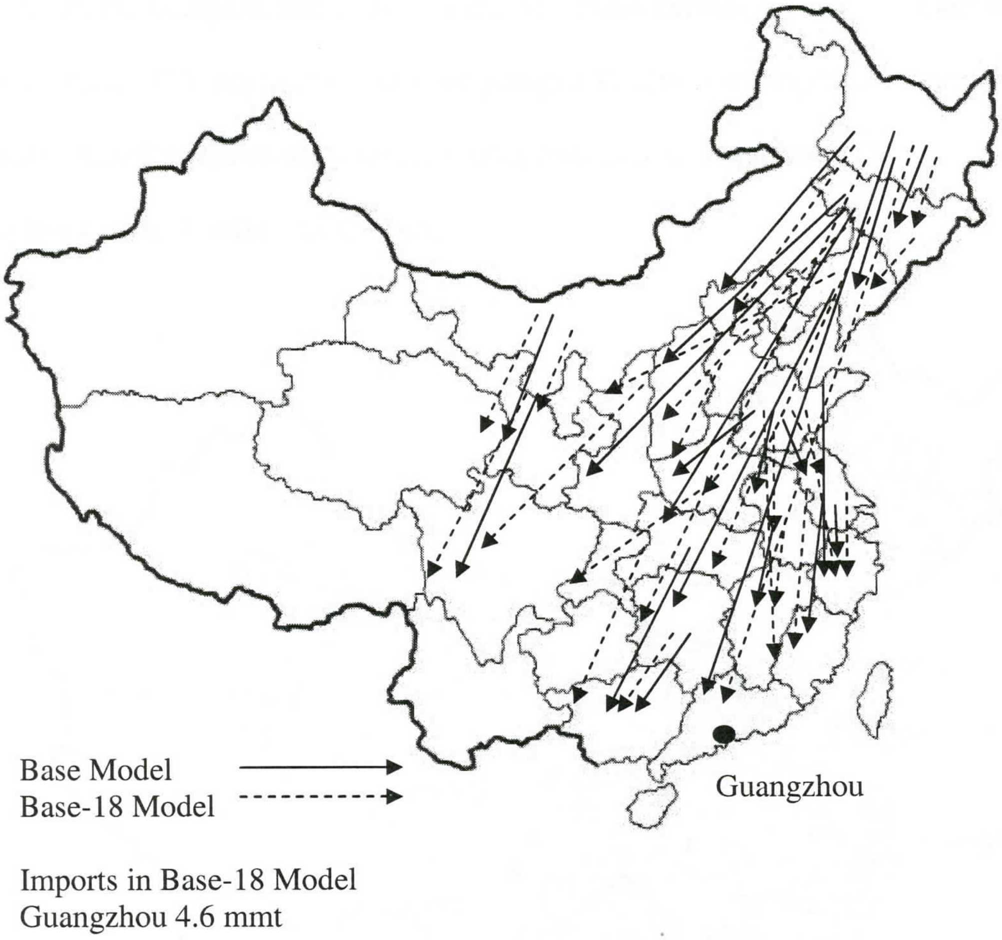
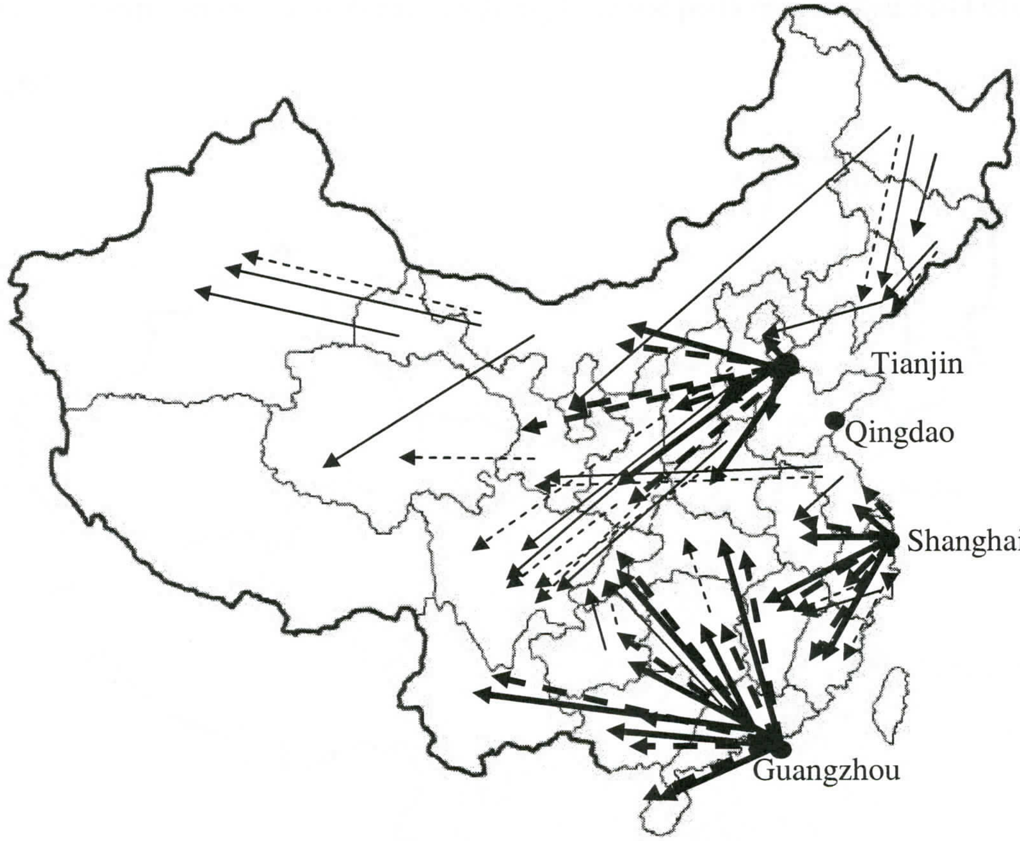


Figure 5.2. China's Corn Domestic Flows and Imports for the Base and Base-18 Models

Figure 5.3 shows the domestic and trade flows of soybeans from both producing regions and import ports to consuming regions. China's imports have increased mainly because of its quickly growing demand for soybeans, and its comparative disadvantage in producing soybeans. Once again, the largest producing region is Heilongjiang in Northeast China in both models. Other large producing provinces are Shandong, Shaanxi, Jilin, and Jiangsu. As production increases in the Base-18 model, there is a noticeable decrease in domestic flows to western China. However, there is a large increase in demand along the coastal and eastern provinces, where population growth over the period has been the most significant. In the Base model, Brazil exports soybeans to China to meet demand in

Guangzhou, Shanghai, and Tianjin, and Argentina's exports are going to meet demand in Guangzhou. U.S. soybean exports are going to Tianjin and Qingdao. In the Base-18 model, Brazil's exports are going to Guangzhou and Shanghai and U.S. exports are going to Guangzhou, Tianjin, and Qingdao.



Base Model
Base-18 Model
Base Model Imports
Base-18 Model Imports

Imports in Base Model

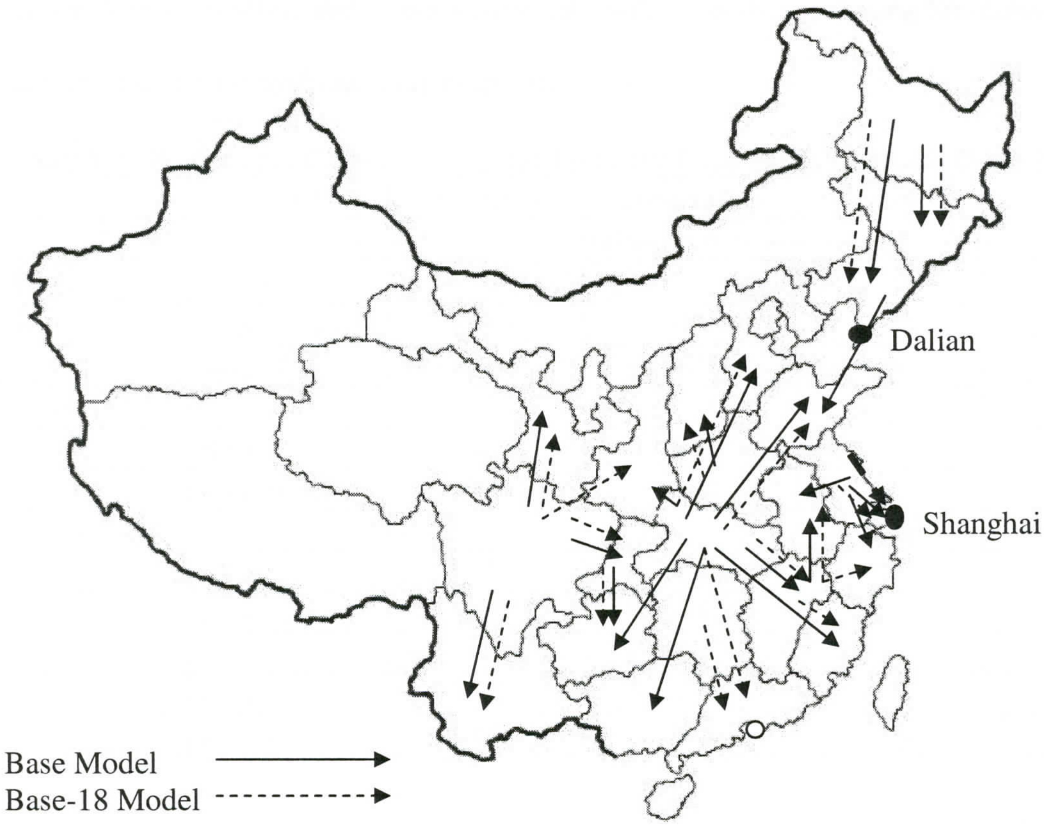
Guangzhou	11.6 mmt
Tianjin	8.2 mmt
Shanghai	7.7mmt
Qingdao	1.4 mmt

Imports in Base-18 Model

Guangzhou	16.5 mmt
Tianjin	14.0 mmt
Shanghai	11.5 mmt
Qingdao	2.3 mmt

Figure 5.3. China's Soybean Domestic Flows and Imports for the Base and Base-18 Models

Figure 5.4 shows the domestic flows of rice in China. While domestic flows do vary in the two models, there is not a significant change between the two time periods. The largest producing regions in both models are Heilongjiang, Hubei, Hunan, Sichuan and Jiangsu. The increased production in the Base-18 model allows for China to become a small net exporter of rice with exports going from the ports in Shanghai and Dalian to Japan.



Exports in Base-18 Model
Shanghai .7 mmt
Dalian .3 mmt

Figure 5.4. China's Rice Domestic Flows and Exports for the Base and Base-18 Models

India's Production, Consumption and Trade

The results of the Base and Base-18 models for India, shown in Table 5.2, indicate the changes in production, consumption, and trade. In the Base model, the primary grain consumed is rice, which accounts for 47 percent of the total grain consumption. This is followed by wheat, corn, and soybeans, which account for 40, 7.5, and 5 percent of grains consumed, respectively. Production in the Base model indicates that rice is the primary crop produced, as it accounts for 47 percent of all grain production. This is followed closely by wheat, which accounts for 41.5 percent, and distantly by corn and soybeans, which account for 7.5 and 3.8 percent, respectively. Trade in the Base model demonstrates that India exports wheat and imports soybeans, with imports accounting for almost 24 percent of domestic soybeans consumption.

Table 5.2. Production, Consumption, and Trade for India in the Base and Base-18 Models

	Model	Production	Consumption	Export	Import
	--------------------------------million metric ton----------------------------------				
Wheat					
	Base	80.02	76.84	3.62	-
	Base-18	92.00	85.37	6.63	-
Corn					
	Base	14.29	14.29	-	-
	Base-18	19.62	19.62	-	-
Soybean					
	Base	7.23	9.46	-	2.23
	Base-18	10.87	11.42	-	0.56
Rice					
	Base	91.05	91.05	-	-
	Base-18	108.46	108.46	-	-

In the Base-18 model, consumption of the four major grains in India has changed, though not as severely as seen in China. Rice and wheat remain the staple grains in the Indian diet. Consumption of rice has increased slightly in 2018 and accounts for 48 percent of all grain consumed. Wheat consumption in 2018 has decreased to 38 percent of all grain consumption, from the previous 40 percent of grain consumption in the Base model.

Consumption of corn and soybeans has increased by 37 and 21 percent, respectively, since the base year; however, the amount is still relatively small.

Production in 2018 is similar to that in the base year. Rice remains the largest crop accounting for 47 percent of total production, which is the same as the base year. Wheat is the second largest crop, but has now decreased slightly to account for 39.8 percent of grain production, compared to 41.5 percent in the base year. Corn has grown to account for 8.5 percent of all grain production, an increase of 37 percent since the base year. Soybeans production has expanded by 50 percent since the base year and now accounts for 4.7 percent of the total grain production. Production has shifted to meet changing demands; however, the Indian diet has not changed significantly to require a large shift in domestic production.

India's trade in the Base-18 model illustrates how production and consumption patterns have altered over time. While India is a net exporter of wheat in the base year, increases in technology have allowed for increased wheat exports in 2018. Soybeans, while not a widely produced or consumed crop in India, becomes the only crop imported in the Base-18 model with imports accounting for 4.9 percent of domestic consumption.

To illustrate domestic and trade flows in the Base and Base-18 models, Figures 5.5, 5.6, 5.7, and 5.8 show the flows for each of the four crops. Figure 5.5 shows the domestic and trade flows for wheat in both models. In the figure, the major areas of production are in the North. Regions 2 and 4, which are made up of Punjab, Haryana, Rajasthan, and Uttar Pradesh, produce over 80 percent of total wheat production in both the Base and Base-18 models. Thus, these regions supply most of the wheat domestically and a majority of the exports. However, Region 1, Himachal Pradesh, also exports a small amount of wheat in the Base-18 model. In both models, India exports wheat to North Africa, and thus its exports originate from its western port.

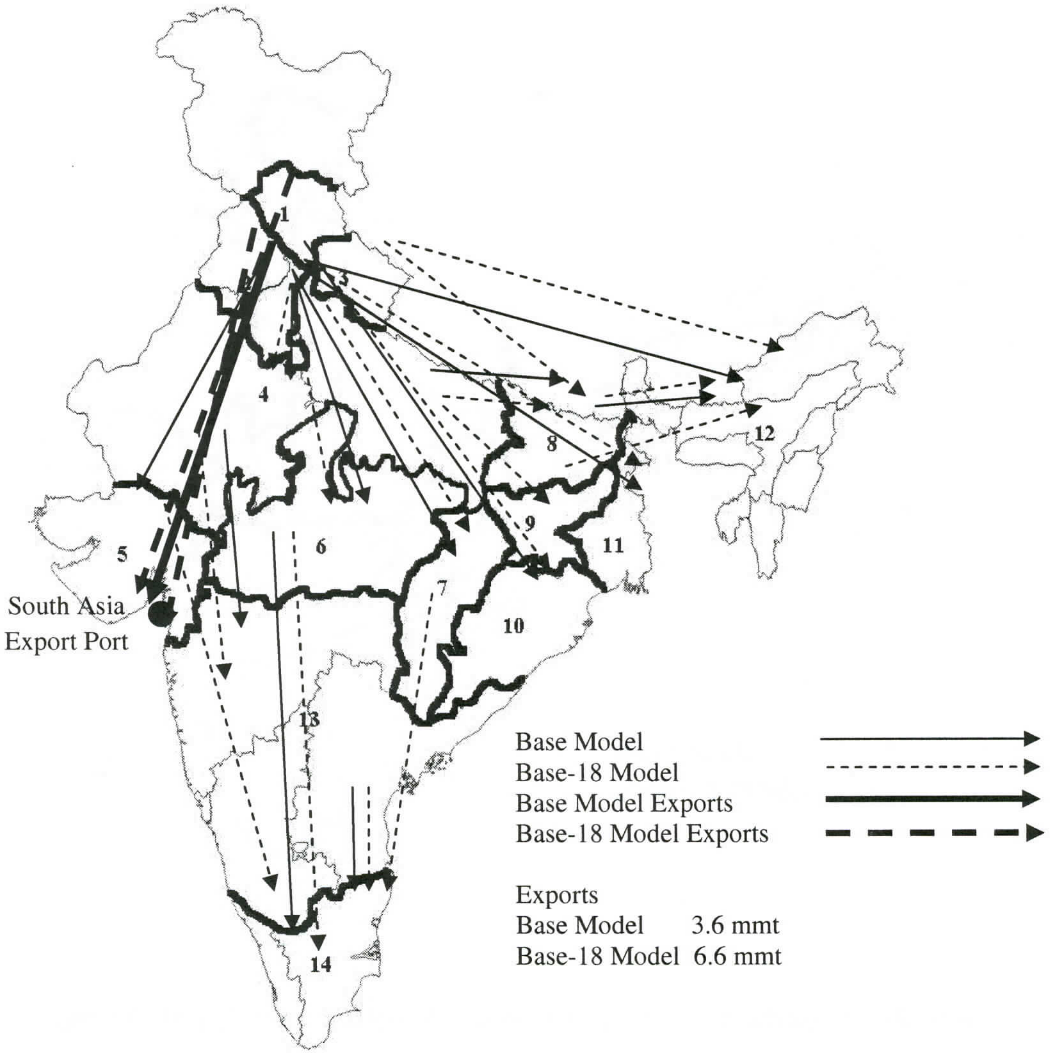


Figure 5.5. India's Wheat Domestic Flows and Exports for the Base and Base-18 Models

Figure 5.6 shows the domestic flows of corn in the Base and Base-18 models. In both models, India is able to stay self-sufficient in corn. The largest producing region is Region 13, made up of Maharashtra, Andhra Pradesh, Karnataka, followed by Region 4, made up of Rajasthan and Uttar Pradesh. Regions 6 and 8 are also substantial corn producers, which includes the states of Madhya Pradesh and Bihar, respectively. Domestic trade flows are similar in both models.

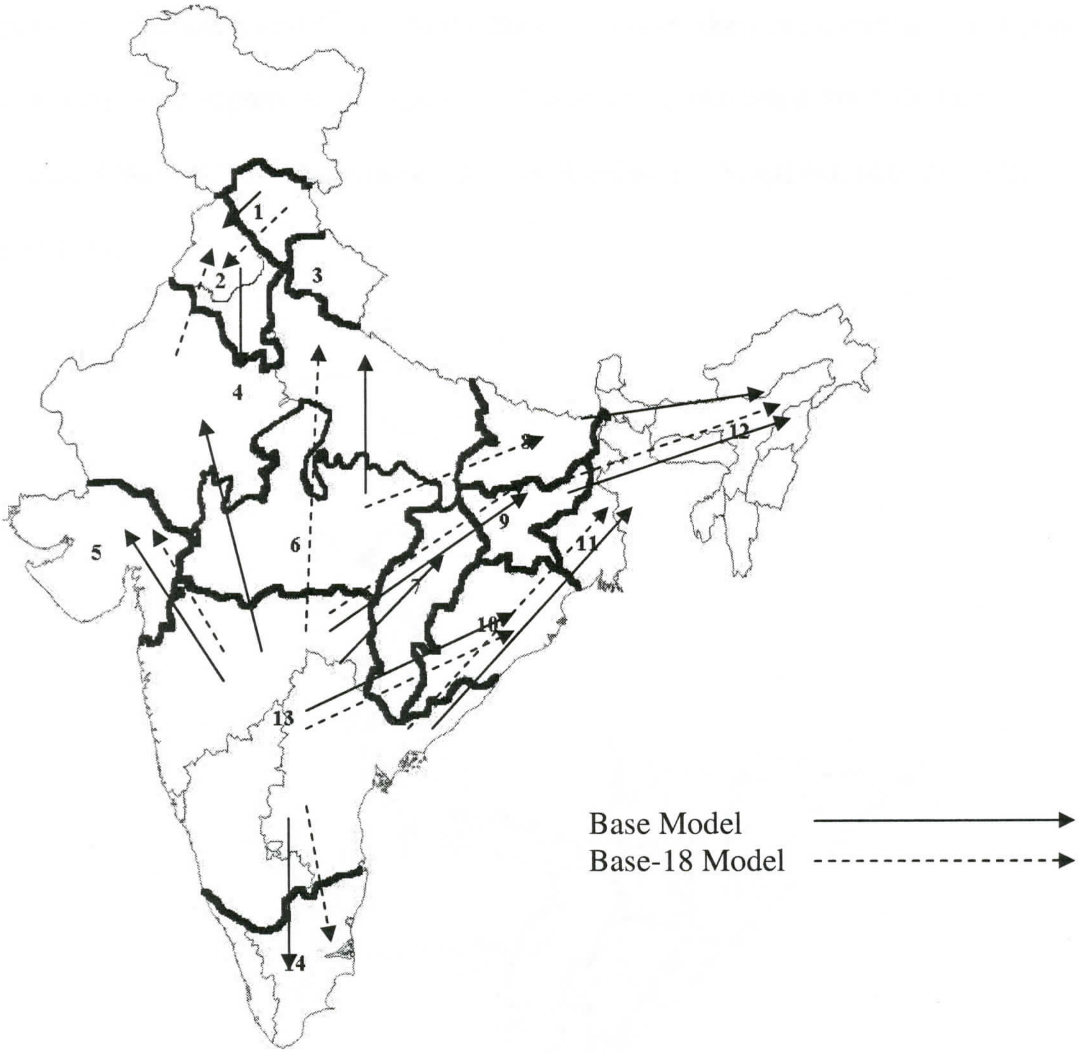


Figure 5.6. India's Corn Domestic Flows for the Base and Base-18 Models

Figure 5.7 depicts the domestic flows of soybeans and the flow of soybean imports from importing port to consumption regions. In both models, Regions 6 and 13 are the largest producers of soybeans, which include the states of Maharashtra, Andhra Pradesh, Karnataka and Madhya Pradesh. In the Base model, soybean imports are needed to fulfill domestic consumption, with imports coming from Brazil. Internally, these imports go to

Regions 1, 2, 10, 11, 12, and 14, or Himachal Pradesh, Punjab, Haryana, Orissa, West Bengal, Sikkim, Arunachal Pradesh, Assam, Meghalaya, Nagaland, Manipur, Mizoram, Tripura, Kerala, and Tamil Nadu. In the Base-18 model, there is an increase in imports from Brazil. The imports go to Regions 1, 2, and 12, or Himachal Pradesh, Punjab, Haryana, Sikkim, Arunachal Pradesh, Assam, Meghalaya, Nagaland, Manipur, Mizoram, and Tripura.

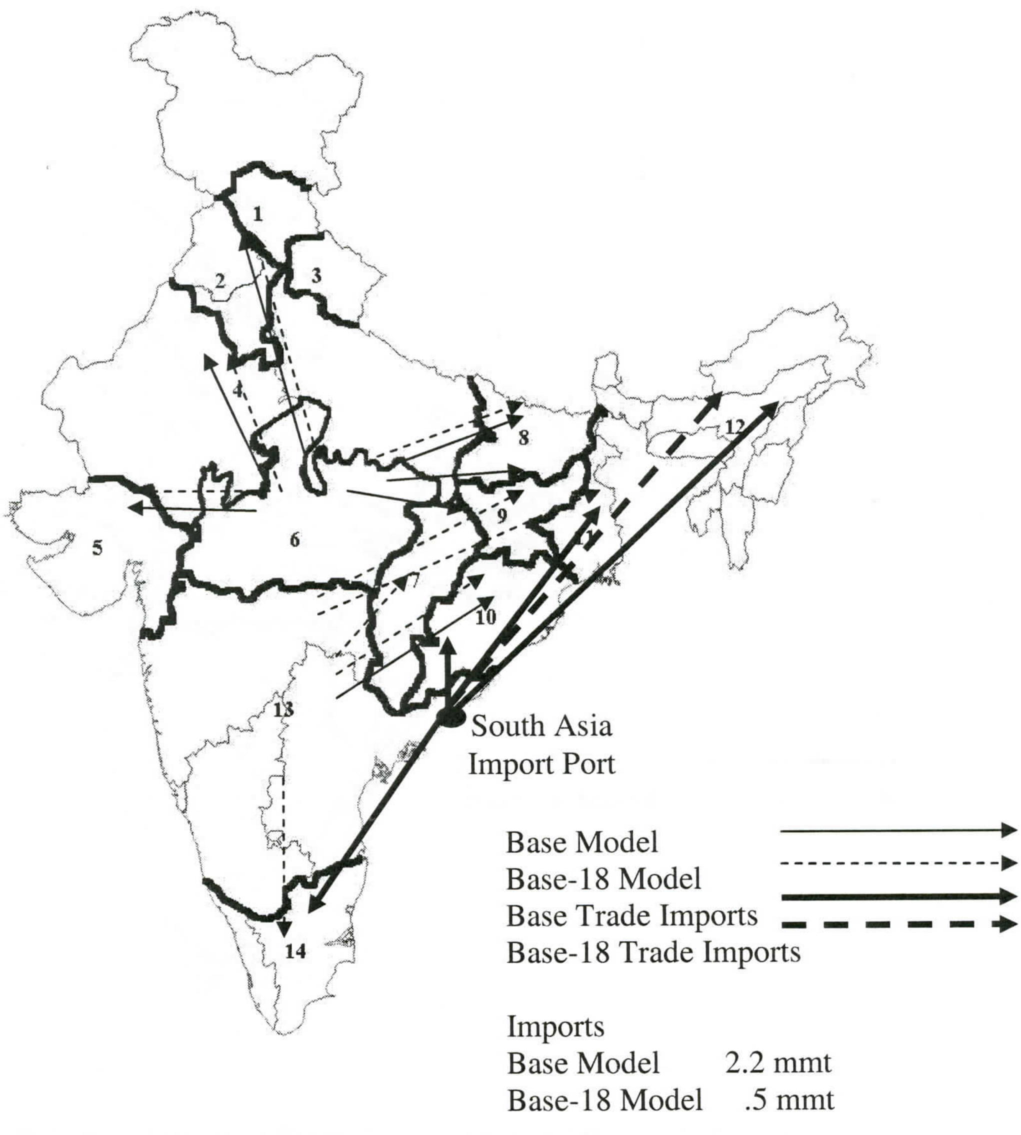


Figure 5.7. India's Soybean Domestic Flows and Imports for the Base and Base-18 Models

Figure 5.8 demonstrates the domestic flows of rice, in which India remains self sufficient in both models. The largest producing regions in the Base model are Regions 2, 4, 11, and 13, which is comprised of Punjab, Haryana, Rajasthan, Uttar Pradesh, West Bengal, Maharashtra, Andhra Pradesh, and Karnataka. In the Base-18 model all of these regions remain primary rice producing regions, and in addition Region 7, the state of Chhattisgarh becomes a large rice producer.

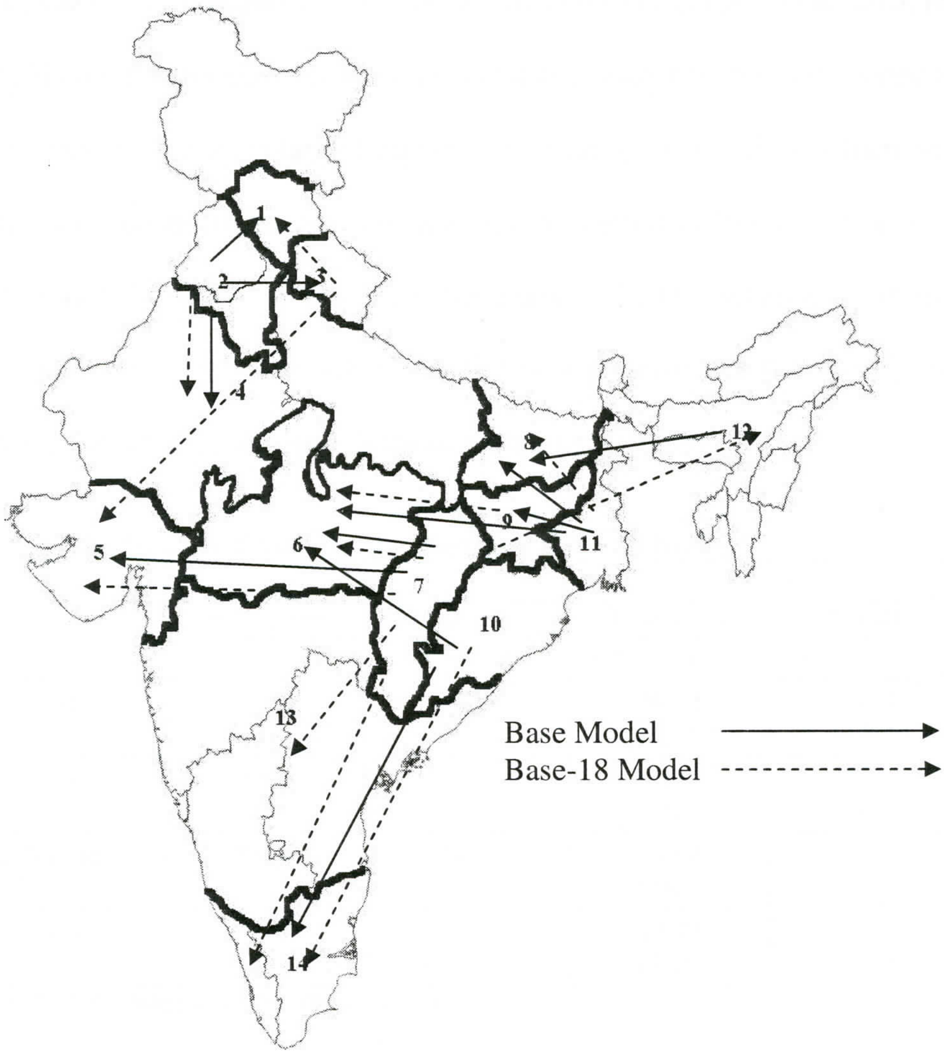


Figure 5.8. India's Rice Domestic Flows for the Base and Base-18 Models

Production and Trade in the United States and Canada

Changes in production and consumption conditions over the time period also have an impact on the U.S. and Canada, since they are both major exporting countries. Because of the increase in global demand, both nations increase in efficiency of production, and changes in land allocation over the time period, production increases in the 2018 over the base year.

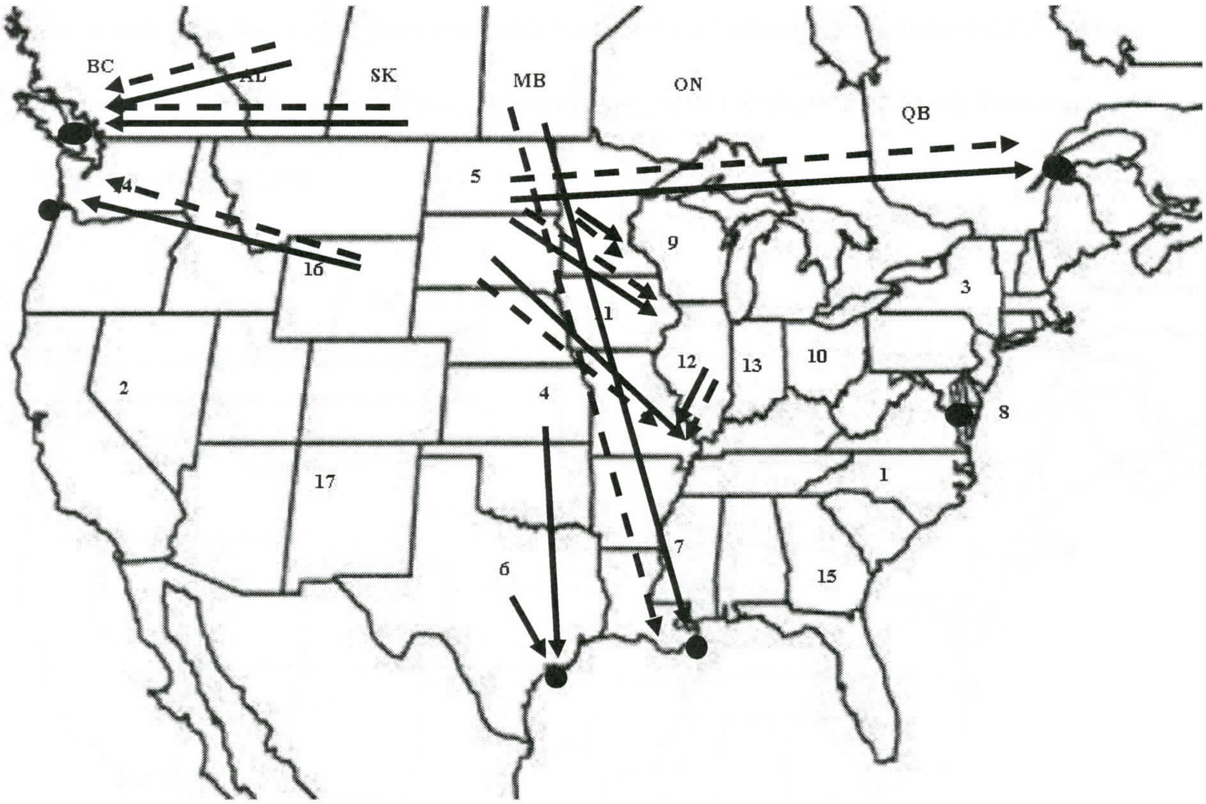
Table 5.3 presents changes in production of the four crops for the United States. U.S. wheat production increases by 23.9 percent from the current period to 2018. However, in 2018 the United States decreases its exports and as a result becomes the second largest exporter. Canada becomes the largest exporter of wheat in the world. The increase in U.S. production must account for the growing domestic consumption. Figure 5.9 shows the trade flows for U.S. and Canadian exports. In the Base model, the U.S. wheat exports are originating primarily from North Dakota, South Dakota, Minnesota, Wisconsin, Michigan, Illinois, Texas, Oklahoma, Missouri, Kansas, Nebraska, Colorado, Montana, and Idaho.

Table 5.3. U.S. Production in the Base and Base-18 Models

	Base		Base-18	
	Production	Exports	Production	Exports
	-------------------------million metric tons--------------------			
Wheat	53.99	28.74	66.92 (23.9)	22.06 (-30.3)
Corn	285.12	32.4	345.25 (21.1)	32.85 (1.4)
Soybean	74.94	27.28	99.67 (33.0)	38.09 (39.6)
Rice	9.66	5.74	13.79 (42.8)	8.30 (44.6)

( ) is the percentage change over the period

Canadian wheat exports are mainly from Saskatchewan, Alberta, and Manitoba. These trade flows remain the same in the Base-18 model, except Texas, Oklahoma, Kansas, Nebraska, and Missouri are no longer exporting wheat, which is shown in the reduction in U.S. exports from the Gulf ports. Canadian wheat exports increase, primarily from Saskatchewan and Alberta.



Canadian Pacific Wheat Exports

Base Model 13.5 million metric tons

Base-18 Model 16.6 million metric tons

Canadian Eastern Wheat Exports

Base Model 2.7 million metric tons

Base-18 Model 2.7 million metric tons

U.S. Pacific Northwest Wheat Exports

Base Model 7.9 million metric tons

Base-18 Model 7.6 million metric tons

U.S. Gulf Wheat Exports

Base Model 18.3 million metric tons

Base-18 Model 11.6 million metric tons

Figure 5.9. U.S. and Canadian Wheat Exports in the Base and Base-18 Models

Corn production increases by 21.1 percent in the United States; however, corn exports increase by only 1.4 percent, meaning that much of the increased production is consumed domestically. Figure 5.10 shows the export flows for the United States and

Canada. Canadian exports in both models originate from Quebec, which increases its production from the base year as a result of an increase in yields. In the Base model, U.S. exports of corn come from Illinois, Ohio, Minnesota, Wisconsin, Michigan, North Dakota, and South Dakota. In the Base-18 model exports continue to come from Illinois, Ohio, Minnesota, Wisconsin, and Michigan; however, North Dakota and South Dakota are no longer exporting corn.

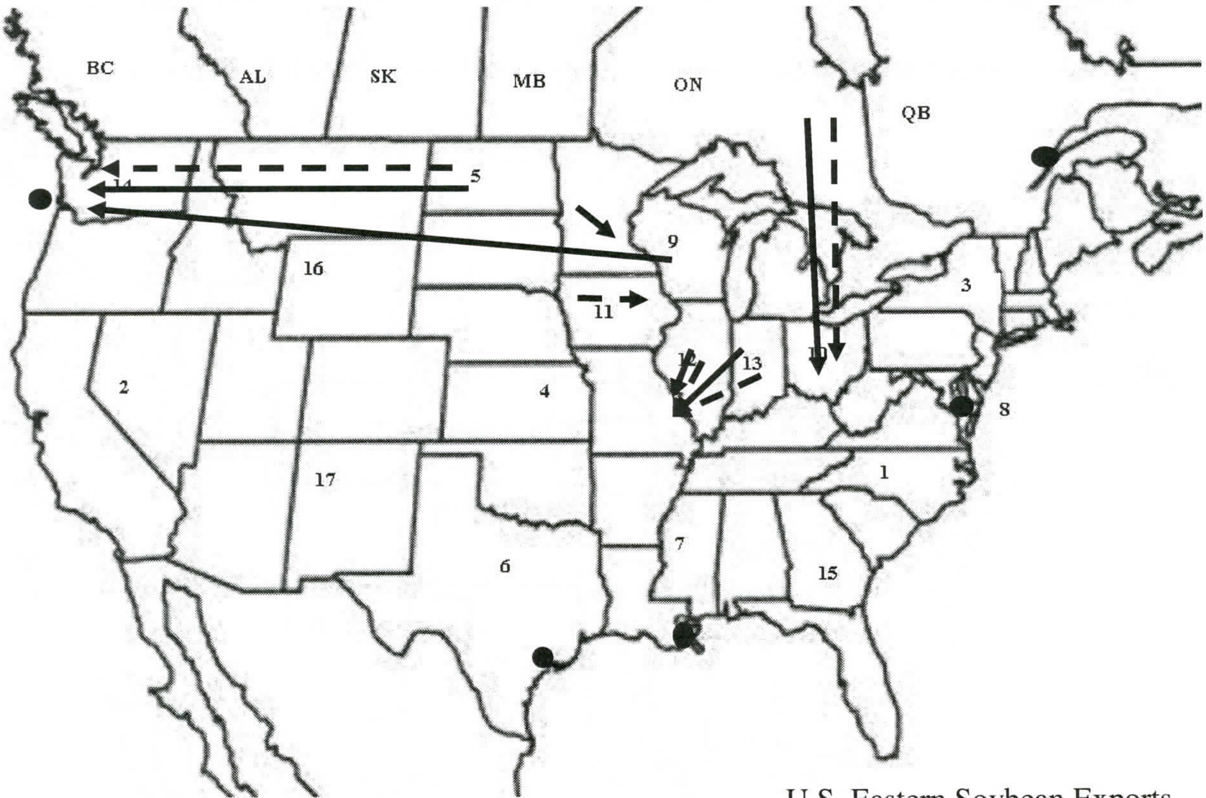
Canadian Northeast Corn Exports
Base Model 4.2 million metric tons
Base-18 Model 7.8 million metric tons

U.S. Pacific Northwest Corn Exports
Base Model 2.3 million metric tons

U.S. Gulf Corn Exports
Base Model 28.7 million metric tons
Base-18 Model 32.8 million metric tons

Figure 5.10. U.S. and Canadian Corn Exports in the Base and Base-18 Models

The increase in U.S. production in 2018 is most significant in soybeans, mainly due to growing global demand. Over the period, the United States increases its exports by nearly 40 percent, primarily to fulfill the growing demand in China. While exports account for 36.4 percent of domestic production in the base year, it accounts for 38 percent of domestic production in 2018. Figure 5.11 depicts the trade flows for U.S. exports in both models. The primary regions exporting soybeans in the Base model are North Dakota, South Dakota, Minnesota, Wisconsin, Michigan, Indiana, and Illinois, with some additional soybeans coming from Ontario to the eastern U.S. port for export. The increase in soybean exports in the Base-18 model is due to increased exports from North Dakota, South Dakota, Illinois, Indiana, and Iowa. Additionally, the exports from Ontario increase.



U.S. Eastern Soybean Exports
Base Model 2.1 million metric tons
Base-18 Model 3.8 million metric tons

U.S. Pacific Northwest Soybean Exports
Base Model 6.3 million metric tons
Base-18 Model 5.7 million metric tons

U.S. Gulf Soybean Exports
Base Model 15.3 million metric tons
Base-18 Model 23.7 million metric tons

Figure 5.11. U.S. and Canadian Soybean Exports in the Base and Base-18 Models

While the United States experiences the largest percentage increase in rice production over the period, the amount of rice produced in the country is relatively small and does not play a major role in global rice trade. The increase in production is due primarily to advances in farming technology as only a few regions of the United States produce rice. While the United States exports rice in both models, the trading partners in 2018 are different than in the base year. In both models, the United States exports rice by truck and rail to Mexico and Canada. However in the base year, the U.S. exports to Europe, China, and a small amount to South Africa. In 2018, the United States is exporting rice primarily to South Africa and the Former Soviet Union-Middle East. Figure 5.12 shows the flows of rice from producing regions to export ports in the United States.

U.S. Pacific Northwest Rice Exports		U.S. Gulf Rice Exports	
Base Model	.02 million metric tons	Base Model	5.0 million metric tons
Base-18 Model	1.9 million metric tons	Base-18 Model	6.0 million metric tons

Figure 5.12. U.S. Rice Exports in the Base and Base-18 Models

World Trade of Agriculture Commodities

Trade flows for all producing and consuming regions illustrate how changes in production and consumption patterns affect world agriculture. This is evident by comparing imports and exports in the base year to those in 2018. Tables 5.4 and 5.5 demonstrate the role and importance of each exporting and importing countries on the world market for each of the four grains. Exports in 2018 have increased for three of the four grains, and most significantly in soybeans with an increase of 28 percent in the volume of total soybean trade since the base year. Rice is the only grain to exhibit a decrease with global rice trade decreasing by 20.8 percent since the base year. This indicates a change in consumption patterns as consumers are demanding less rice and more soybeans globally.

Corn trade increases by 0.8 percent in volume from the base year to 2018. Primary exporting countries in both models are the United States, Argentina, and Brazil. However in the Base-18 model, the United States gains only a small share in the world market, while Argentina's share increases and Brazil's share decreases. The percentage of world corn exports for each exporting country indicates that the United States has a comparative advantage over other countries in exporting corn. Argentina exports about 28 percent of total corn trade in 2018 demonstrates that it also has a comparative advantage in exporting corn. Other shifts come from growth in Canadian exports, as well as the emergence of the EU-27 and South Asia as small exporting countries. Southeast Asia exports a small amount in the Base model, but shifts to become a net importer of corn in the Base-18 model. Exhibiting that Southeast Asia has a comparative advantage in the base year but has a comparative disadvantage in 2018, as it is not able to continue to provide for its growing domestic consumption.

The largest corn importing country in the Base-model is Japan, followed by the EU-27, Mexico, South Korea, and North Africa. In the Base-18 model, Mexico becomes the largest importer accounting for 26 percent of all imports. The EU-27 shifts to export a small amount of corn and China shifts to become an importing country in the Base-18 model.

Wheat exports in 2018, compared to the base year, indicate an increase in the volume of wheat traded by 6.9 percent. The primary exporting countries in both models are the United States, Canada, Argentina, and Australia. The two largest exporting countries are the United States and Canada. U.S. and Canadian exports account for 36.9 and 24.6 percent, respectively, of the world wheat trade in the base year, and 26.5 and 26.8 percent, respectively, in 2018. Over this period, the fact that United States decreases its exports and Canada increases its exports. This indicates that Canada has a comparative advantage in producing and exporting wheat over the United States and the other exporting countries in 2018. As a result, Canada becomes the largest exporter of wheat in 2018. All exporting countries increase exports in 2018, compared to the base year, with the exception of the United States.

In the Base model, North Africa, South Africa, and Southeast Asia are the largest importing regions of wheat. In 2018, South Africa is the largest importer accounting for nearly a third of all wheat imports. Southeast Asia has increased its imports, and North Africa, while still a large importer, has decreased its imports compared to the base year.

China, Japan, and South Korea decrease their wheat imports in the Base-18 model, indicating a decrease in consumption.

Soybean trade, as mentioned, increases the most significantly in Base-18 model. The largest exporting countries are the United States and Brazil. Both countries expand their exports and account for a larger share of total world exports in 2018. Argentina is also a large exporting country in 2018. However, Argentina shifts to produces more corn, and as a result, it has less of a presence in the world soybean market. This exhibits that Argentina has a comparative advantage in producing corn rather than soybeans. Soybean imports in both models demonstrate the large presence of China in global soybean trade.

While in the Base model China accounts for 45.3 percent of all soybean imports by volume, in the Base-18 model it is importing more than half of the global soybean trade. In 2018, China will import 53 percent of soybean imports, which is a growth of 53 percent in its imports during the period. Another large importing country is the EU-27, which increases its imports between the two periods; however in 2018, its imports account for a lesser share of the total soybean trade. Between the two periods, all importing countries increase their imports, except India, Japan, and South Africa, which reduce their imports due to advances in farming technology.

Rice trade in 2018 demonstrates the change in global consumption patterns, as the volume of rice traded decreases by one-fifth between the two periods. The largest exporting region is Southeast Asia accounting for 62.4 and 68.4 percent of global rice trade in the Base and Base-18 models, respectively. The second largest exporter in the Base model is Latin America; however, in the Base-18 model it decreases its exports by 78 percent as it shifts more acres to the production of soybeans. The United States is also an exporter of rice, accounting for nearly 21 percent of global rice trade in 2018. Australia and Brazil export a small amount of rice in the base year; however, Australia shifts to import rice in 2018.

The largest rice importer is South Africa, though it does reduce its imports between the two periods by 18.4 percent. Other importing countries increase their imports over the period by a small amount. China imports rice in the base year, but shifts to be a small net exporter in 2018.

Alternative Scenarios for China

This section compares the results of the alternative scenarios to those of the Base-18 model, which is summarized in Table 5.6. The alternative scenarios indicate what will happen to Chinese production, consumption and trade as a result of changing technology and increased demand. Scenario 2 explains the resulting conditions if crop yields were to increase by 20 percent above what has been forecasted for 2018. Scenario 4 explains the resulting conditions if crop yields were to be 20 percent lower than the forecast for 2018. Scenario 6 indicates the resulting conditions if domestic consumption in China were to be 5 percent higher than the forecast for 2018.

In Scenario 2 where yields are increased by 20 percent, China produces the same amount of wheat and rice as in the Base-18 model. However, it shifts more acres to corn and soybeans to increase its production to meet the demands of its growing livestock industry. As a result, China produces 2.6 percent more corn and 23.7 percent more soybeans compared to the Base-18 model. Because domestic consumption remains constant and its production increases, China is now able to decrease its soybean imports by 9.6 percent and become self-sufficient in corn.

Table 5.4. Exports in the Base and Base-18 Models

	Exporter	Base		Base-18	
	---------------------------------million metric ton----------------------------------				
Corn		Actual	Percentage	Actual	Percentage
	Argentina	17.39	24.4	20.25	28.2
	Brazil	17.07	24.0	10.39	14.5
	Canada	4.19	5.9	7.89	11.0
	EU-27	-	-	0.07	0.1
	South Asia	-	-	0.42	0.6
	Southeast Asia	0.19	0.3	-	-
	United States	32.40	45.5	32.85	45.7
	Total	71.24		71.86	
Wheat					
	Argentina	14.44	18.6	17.68	21.3
	Australia	11.28	14.5	13.46	16.2
	Canada	19.17	24.6	22.27	26.8
	Former Soviet Union /Middle East	0.54	0.70	1.06	1.3
	India	3.62	4.7	6.63	8.0
	United States	28.74	36.9	22.06	26.5
	Total	77.80		83.17	
Soybean					
	Argentina	14.00	21.7	4.14	5.0
	Brazil	19.50	30.4	31.52	38.3
	Canada	0.26	0.4	0.45	0.6
	Latin America	3.23	5.0	8.16	9.9
	United States	27.28	42.5	38.09	46.2
	Total	64.24		82.36	
Rice					
	Argentina	0.54	1.0	0.53	1.3
	Australia	0.06	0.1	-	-
	Brazil	0.03	0.06	-	-
	China	-	-	1.12	2.8
	Latin America	11.71	24.4	2.61	6.6
	Southeast Asia	29.96	62.4	27.23	68.4
	United States	5.74	12.0	8.30	20.9
	Total	48.04		39.80	

Table 5.5. Imports in the Base and Base-18 Models

	Importer	Base		Base-18	
--------------------------------million metric ton----------------------------------					
Corn		Actual	Percentage	Actual	Percentage
	China	-	-	4.58	6.4
	EU-27	14.84	20.8	-	-
	Former Soviet Union /Middle East	3.78	5.3	-	-
	Japan	16.60	23.3	16.42	22.8
	Latin America	7.01	9.8	7.87	11.0
	Mexico	12.41	17.4	18.65	26.0
	North Africa	8.07	11.3	10.84	15.1
	Southeast Asia	-	-	2.31	3.2
	South Korea	8.54	12.0	11.18	15.6
	Total	71.24		71.85	
Wheat					
	Brazil	5.98	7.7	6.94	8.3
	China	0.76	1.0	-	-
	EU-27	2.66	3.4	2.66	3.2
	Japan	5.21	6.7	4.81	5.8
	Latin America	5.11	6.6	5.75	6.9
	Mexico	2.53	3.2	2.86	3.4
	North Africa	16.65	21.4	13.87	16.7
	South Africa	22.09	28.4	26.47	31.8
	Southeast Asia	10.82	13.9	14.14	17.0
	South Korea	2.99	3.8	2.67	3.2
	United States	3.00	3.9	3.00	3.6
	Total	77.80		83.17	
Soybean					
	China	29.02	45.2	44.40	53.9
	EU-27	14.86	23.1	16.24	19.7
	Former Soviet Union /Middle East	3.35	5.2	4.39	5.3
	India	2.23	3.5	0.56	0.7
	Japan	4.02	6.3	3.55	4.3
	Mexico	3.61	5.6	4.96	6.0
	North Africa	1.53	2.4	1.53	1.9
	South Africa	0.47	0.7	0.22	0.3
	South Asia	0.07	0.1	0.17	0.2
	Southeast Asia	3.76	5.9	4.98	6.0
	South Korea	1.21	1.9	1.35	1.6

Table 5.5. (Continued)

	Total	64.24		82.33	
Rice					
	Australia	-	-	0.03	0.1
	Canada	0.32	0.6	0.49	1.2
	China	3.63	7.6	-	-
	EU-27	1.12	2.3	1.85	4.7
	Former Soviet Union /Middle East	4.10	8.5	5.11	12.8
	Japan	0.99	2.0	1.12	2.8
	Mexico	0.59	1.2	0.76	1.9
	South Africa	37.29	77.6	30.44	76.5
	Total	48.04		39.80	

Trade flows change as a result of China producing more corn and soybeans. Argentina and Canada export less corn and soybeans compared to the Base-18 model. Since China is no longer a net importer of corn, Argentina is able to export 12.8 percent more corn to Japan. The United States reduces its exports to Japan, and increases its exports to South Korea. Canada reduces its exports by nearly 28 percent. In the Base-18 model, Canada is exporting a small amount of corn to North Africa; however, in Scenario 2, North Africa is importing corn from Brazil. Brazil has extra corn, because it is exporting less to South Korea, as the United States is now exporting more to that country.

World soybean trade decreases because of the reduction in China's imports under this scenario, with overall flows of soybeans from exporting countries to importing countries changing as a result of an increase in soybean production in China. Argentina's exports to Southeast Asia are reduced by 71 percent. Southeast Asia is now importing more from Brazil, as Brazil is now exporting less to China. Brazil also has increased its exports to South Asia by a small amount. Thus, the amount of soybeans Brazil is exporting remains the same. U.S. exports of soybeans have decreased by 3 percent under this scenario.

In Scenario 4, yields are decreased by 20 percent from the 2018 projection in China resulting in China being a net importer of all four crops. Production of wheat, corn, soybeans, and rice decreases by 9.2, 23.2, 28.8, and 18.4 percent, respectively. As a result, China now imports 8.4 percent of its domestic consumption of wheat, 20.9 percent of its domestic consumption of corn, 77.6 percent of its domestic consumption of soybeans, and 14.8 percent of its domestic consumption of rice. The impact of the changes in China's imports on world agriculture trade is significant.

China imports corn from Argentina, Brazil, the Former Soviet Union-Middle East, and the United States in this scenario. Because of the increased demand for corn globally, Southeast Asia and North Africa have reduced their imports by 13 and 0.5 percent, respectively. While other importing regions maintain the quantity of imports, the amount arriving from the individual exporting ports has changed. Southeast Asia was importing all of its corn from Argentina, but in this scenario this amount is reduced. Argentina is exporting more corn to fill the increased demand in China and is no longer exporting to Australia and Japan. Brazil has increased its exports of corn, mostly to China though it also exports a larger amount to South Korea. In this scenario, Brazil no longer exports corn to North Africa. Canadian exports of corn are small in the Base-18 model at 7.89 million metric tons; however in Scenario 4, Canada has increased its exports to 9.72 million metric tons with this corn going to North Africa. In addition, the Former Soviet Union-Middle East becomes a net exporter of corn with this corn being exported to China and a small amount to North Africa.

Table 5.6. Production, Consumption and Trade for China in the Base-18 and Alternative Scenarios

	Base-18	Scenario 2	Scenario 4	Scenario 6
	------------------------------million metric tons--------------------------------			
Production				
Wheat	106.00	106.00 (0.0)	97.08 (-9.2)	111.31 (5.0)
Corn	176.77	181.35 (2.6)	143.43 (-23.2)	179.44 (1.5)
Soybean	17.96	22.21 (23.7)	13.94 (-28.8)	18.20 (1.3)
Rice	128.58	128.58 (0.0)	108.60 (-18.4)	134.95 (5.0)
Consumption				
Wheat	106.00	106.00	106.00	111.31 (5.0)
Corn	181.35	181.35	181.35	190.42 (5.0)
Soybean	62.36	62.36	62.36	65.47 (5.0)
Rice	127.45	127.45	127.45	133.82 (5.0)
Imports				
Wheat	-	-	8.91	-
Corn	4.58	-	37.92	10.98
Soybean	44.40	40.15	48.42	47.27
Rice	-	-	18.85	-
Exports				
Rice	1.13	1.13	-	1.13

( ) the percentage increase/decrease over the Base-18 model results

The United States is the most affected in Scenario 4, as it increases its corn exports by nearly 50 percent. This increase affects Iowa, Illinois, and Indiana, since they are now producing 9, 10, and 15 percent more corn, respectively, for export. The majority of the increase in U.S. exports is to fill the import demand for corn in China; however, it is also exporting more to Japan, as Japan is no longer receiving imports from Argentina. The

United States does reduce its exports to South Korea, as it is now importing more from Brazil.

Soybean trade volume has also increased, with Argentina almost doubling its exports of soybeans and with a slight increase from the United States. In actuality the increase in exports needed to fulfill China's import demand is coming primarily from Brazil, which increases its exports to China by 4.6 percent. Argentina shifts its exports as it begins to send soybeans to China, which accounts for its increase in exports. The slight increase in U.S. soybean exports is due to more exports going to the EU-27. In fact, in this scenario the United States actually decreases its exports to China, though only by one percent. The increase in U.S. exports impacts Regions 3, 8, and 10, which includes Maine, Massachusetts, New Hampshire, New York, Pennsylvania, Vermont, Connecticut, Delaware, Maryland, New Jersey, Rhode Island, and Ohio, as these three regions each increase their production of soybeans by 0.7 percent.

Wheat trade has increased to accommodate the growing demand in China and is met by increased exports in Argentina, Canada, South Asia, and the United States. Because China was not an importer previously, this scenario shows which country/region would export wheat to China should the demand arise. The country that supplies China with a significant portion of its wheat is Canada, though the United States also exports a small amount to them. Increases in Argentina's exports are to satisfy the import demand previously fulfilled by Canada, primarily in the South Africa region. South Asia increases its exports to North Africa, which previously imported wheat from the United States and Canada. The increased Canadian exports have implications for all of the 6 Canadian regions, with each region increasing its production of wheat by 0.7 percent. In the United

States the ability to export more is the result of most wheat producing regions increasing their wheat production by 0.7 percent.

Rice trade has shifted to increase exports from Latin America and Southeast Asia. China, who previously was a small net exporting country, is now importing 18.85 million metric tons. Southeast Asia is exporting nearly 55 percent more than it is in the Base-18 model, with the majority of its exports going to China. Latin America has increased its exports, though this is to fulfill the demand in South Africa, which was previously satisfied by Southeast Asia.

Scenario 6 indicates the impact of a 5 percent increase in consumption in China compared to the Base-18 model. In this scenario, China increases its production of rice and wheat by 5 percent to satisfy domestic demand, showing its comparative advantage in producing these two crops. Imports of corn and soybeans increase, because even though China has expanded its production of these two crops by 1.5 and 1.3 percent, respectively, it was not enough to satisfy domestic demand. As a result, China's imports of corn more than double and soybean imports increase by 6.5 percent. Because China is only increasing its imports of corn and soybeans, only the trade of these two commodities is affected.

The net result on global corn trade is that Canada, the Former Soviet Union-Middle East, and United States increase their exports. The increase in import demand from China is being satisfied by exports from Argentina. However, in order to satisfy this demand Argentina must export less to Japan, its other major export destination from the Base-18 model. Thus, Japan now imports three times more from the United States compared to the Base-18 model and as a result, the United States reduces its exports to South Korea. The increase in corn exports from the United States is due to Iowa increasing its production by

8 percent. South Korea now increases its imports from Brazil. The slight increase in Canadian exports and the emergence of the Former Soviet Union-Middle East as a net exporting country is due to the need to satisfy the import demand in North Africa. This is needed because Brazil has decreased its exports to North Africa in order to increase its exports to South Korea.

Soybean trade in Scenario 6 indicates that as Chinese demand for soybeans increases as a result of rising domestic consumption, soybean exports in Argentina increase. Argentina exports soybeans to China and it increases its exports to Southeast Asia. Brazil increases its exports to China by 3.6 percent, but as a result reduces exports to Southeast Asia.

The analysis confirms China's large role in the global soybean trade, as its imports are likely to increase substantially in 2018. China's growing livestock population, to serve growing consumer demand, is also likely to need more corn than what China can produce. China is a large producer of corn, but the analysis shows that it will likely become a small net importing country of corn in 2018. China also produces a large amount of wheat, which is consumed internally. Since Chinese consumers are consuming less wheat per capita in 2018, it is able to stay self-sufficient in all but Scenario 4. Rice is similar to wheat, with China having a comparative advantage in rice production. This allows for a small amount to be exported in all but one scenario, meaning China will also most likely remain self-sufficient in rice.

Alternative Scenarios for India

The other primary country of focus in this study is India, and the remaining alternative scenarios examine the same situations as those explored for China but in relation to production and consumption conditions in India. Table 5.7 compares the results of the alternative scenarios to those of the Base-18 model.

Alternative Scenario 1 determines the impact of increased technology on domestic production and trade in India. As a result of increasing yields by 20 percent above those in the Base-18 model, production of wheat, corn, and soybeans increase by 12.4, 18.1, and 14.2 percent, respectively. Rice production remains the same as in the Base-18 model. Consumption remains constant, and thus India now exports 17.8 percent of its total wheat production, 15.3 percent of domestically produced corn, and 8 percent of domestically produced soybeans.

Trade flows also change as India increases its role as an exporter. Global corn trade alters as India now exports its surplus production to North Africa. As a result, Brazil and Canada export less corn to North Africa. Brazil increases its exports to South Korea. The United States decreases its exports to South Korea but increases its exports to Japan, as Argentina has now reduced its exports to Japan. The net result is a reduction in corn exports from Argentina and Canada.

In the Base-18 model, India imports soybeans; however as yields increase in Scenario 1, India is able to export soybeans. India now exports soybeans to North Africa, who can now import less from Latin America. The EU-27 increases its imports from Latin America and reduces its imports from the United States. The United States can now export more to China, allowing Brazil to export less to China and more to Southeast Asia. Argentina can reduce its exports to Southeast Asia, and thus achieves the net result for this scenario of reducing its soybean exports by 37 percent.

Table 5.7. Production, Consumption and Trade for India in the Base-18 and Alternative Scenarios

	Base-18	Scenario 1	Scenario 3	Scenario 5
------------------------------million metric tons-------------------------------				
Production				
Wheat	92.00	103.41 (12.4)	80.53 (-12.5)	96.27 (4.6)
Corn	19.62	23.18 (18.1)	19.56 (-.3)	20.60 (5.0)
Soybean	10.87	12.41 (14.2)	8.29 (-23.8)	10.87 (0.0)
Rice	108.46	108.46 (0.0)	108.46 (0.0)	113.88 (5.0)
Consumption				
Wheat	85.37	85.37	85.37	89.64 (5.0)
Corn	19.62	19.62	19.62	20.60 (5.0)
Soybean	11.42	11.42	11.42	12.00 (5.0)
Rice	108.46	108.46	108.46	113.88 (5.0)
Imports				
Wheat	0.00	0.00	4.84	0.00
Corn	0.00	0.00	0.06	0.00
Soybean	0.56	0.00	3.14	1.13
Rice	0.00	0.00	0.00	0.00
Exports				
Wheat	6.63	18.04	0.00	6.63
Corn	0.00	3.56	0.00	0.00
Soybean	0.00	0.99	0.00	0.00

( ) the percentage decrease/increase over the Base-18 model results

Global wheat trade has also changed, since exports from India have nearly tripled. The net effect is that Canada and the United States have reduced their wheat exports. On the importer side, as a result of India's wheat exports, Brazil and North Africa are now importing more wheat. The reduction of wheat exports in Canada is due to Canada exporting less to South Africa. As a result, Argentina has increased it exports to South Africa and reduced its exports to Brazil. Brazil is now importing some wheat from the United States and the United States has significantly reduced its exports to North Africa. North Africa is now importing its wheat from India.

In Scenario 3 crop yields in India are decreased by 20 percent from the Base-18 model. The resulting change in production is that India now produces 12.5 percent less wheat, 0.3 percent less corn, and 23.8 percent less soybeans, while rice production remains constant. Consumption remains the same as in the Base-18 model, and thus India now imports more soybeans, a small amount of corn, and now imports wheat. The increased imports impact primarily the global trade of soybeans and wheat.

The net result on soybean trade is that Argentina increases its soybean exports by 62 percent. This is due to Argentina's increased exports to Southeast Asia and China. Brazil, whose overall exports remain the same, is now exporting less to China and is now exporting to India. Net changes in wheat trade are experienced in Australia, Canada, and the United States as each increases their exports. Argentina's exports remain the same; however, it has reduced its exports to Brazil. Brazil is now importing less wheat, and thus Argentina has increased its exports to South Africa. Australia has expanded its exports by 61 percent, as it now exports more wheat to Southeast Asia and is now exporting to India and South Africa. Canadian exports have increased by 2.8 percent, as it is now exporting to North Africa. North Africa was previously receiving wheat imports from India. Canada has also reduced its exports to South Africa, who is now importing wheat from Argentina. Wheat exports from the United States have increased by 7.8 percent, as it has increased its exports to North Africa and Japan. The increase in U.S. exports impacts production in Regions 4 and 6, Kansas, Nebraska, Missouri, Oklahoma, and Texas, with increases of nearly 15 percent. Rice trade remains constant, as India is able to stay self-sufficient in its rice consumption.

Scenario 5 demonstrates the resulting production, consumption and trade flows if India's consumption increases 5 percent above the Base-18 model. Production in this alternative scenario reveals that India will expand its production of wheat by 4.6 percent, corn by 5 percent, soybeans will remain constant, and rice production will increase by 5 percent. The result is that India is able to stay self-sufficient in rice and is able to maintain its exports of wheat from the Base-18 model. However, soybean imports increase to meet the increase in domestic demand. The impact on global trade for this scenario is minimal as only soybean trade is impacted. The net result is that Argentina increases its soybean exports by 13.9 percent, with this increase allowing them to increase its exports to Southeast Asia. Brazil reduces its exports to Southeast Asia, and instead exports to India.

By evaluating the alternative scenarios for India it is evident that the country is able to stay relatively self-sufficient in 2018, other than in the scenario in which its yields are reduced. India is able to stay self-sufficient in rice for all four scenarios, due to its comparative advantage in rice production. It also has a comparative advantage in wheat production, and thus is able to maintain exports in all but Scenario 3. India has a comparative disadvantage in producing corn and soybeans in all scenarios but Scenario 1 in which yields are increased. However, India does not consume a large amount of either crop in 2018. The analysis shows that while India will most likely have a role as an exporter in wheat and a small importer of soybeans, it is able to stay relatively self-sufficient in 2018.

CHAPTER VI. SUMMARY AND CONCLUSIONS

China and India have both experienced economic growth over the past twenty years, which is resulting in changes in domestic consumption. These changes are expected to alter China and India's trade of agricultural commodities. While both countries have tried to maintain self-sufficiency through policies and the practices of retaining grain stocks, they may be unable to continue these practices in the future and thus will become large importing countries of agricultural commodities. The impact on global agriculture could be substantial as major exporting countries would have to increase production to meet growing global demand.

The objective of this study is to examine the expected changes in China and India's import and export demand of corn, wheat, rice, and soybeans and the impact of these changes on the United States and other major importing and exporting countries. The following are specific objective of this study:

1. To determine the optimal production and trade flows of wheat, corn, rice, and soybeans in China and India based on their resource endowments.
2. To predict Chinese and Indian crop production and trade flows and their impacts on world agriculture under different scenarios.
3. To evaluate the competiveness of the United States and other major exporting countries in exporting grains to China, India, and other major importing countries.

A spatial equilibrium model, based on a mathematical programming algorithm, was developed to conduct the research. The model optimizes production in China and India and other major producing regions and trade flows are determined based on comparative advantage.

Summary

China in the Base model produces 99.31, 136.33, 123.47, and 15.52 million metric tons of wheat, corn, rice, and soybeans, respectively. As a result, China must import 0.76 million metric tons of wheat, 29.02 million metric tons of soybeans, and 3.63 million metric tons of corn to satisfy its domestic consumption. However, in the Base-18 model China produces 106, 181.35, 127.45, and 62.36 million metric tons of wheat, corn, rice, and soybeans, respectively. To satisfy its domestic consumption it must import 4.58 million metric tons of corn and 44.4 million metric tons of soybeans; however, it is now able to export 1.12 million metric tons of rice. This indicates that China will likely be able to satisfy its domestic consumption of rice and wheat through its domestic production in 2018. Therefore, increases in technology allow China to stay self-sufficient in these cereal grains. However, the results also indicate that despite increased production due to increasing yields, China will have to increase its imports of corn and soybeans in 2018 to satisfy domestic demand.

The alternative scenarios indicate that in most scenarios China is able to maintain its self-sufficiency in wheat and rice. China imports these commodities in the scenario in which yields are decreased by 20 percent from the Base-18 model. In all scenarios, China imports soybeans, indicating that China has a comparative disadvantage in soybean production over other crops. China imports corn in most scenarios; however the quantity imported remains relatively small in all but the reduced yield scenario. Thus, China's impact on global agriculture will be most significant in soybeans, with China importing nearly 54 percent of global soybean exports in 2018.

In the Base model, India produces 80.02, 14.29, 91.05, and 7.23 million metric tons of wheat, corn, rice, and soybeans, respectively. Thus, domestic production is enough to allow India to be self-sufficient in corn and rice and export 3.62 million metric tons of wheat. India does have to import 2.23 million metric tons of soybeans to satisfy domestic consumption. In the Base-18 model India produces 85.37, 19.62, 108.42, and 11.42 million metric tons of wheat, corn, rice, and soybeans, respectively. Therefore, it is able to increase its exports of wheat to 6.63 million metric tons, but must import .56 million metric tons of soybeans to meet growing domestic demand. Increased production in 2018, due to advancements in farming technology, allows for India to remain self-sufficient in rice and corn, expand its wheat exports, and reduce its soybean imports.

The alternative scenarios confirm the conclusions from the Base-18 model. India is not a large importer of any of the four crops and consistently exports wheat and remains self-sufficient in rice and corn in all but the alternative scenario in which yields are decreased 20 percent from the Base-18 model projections. This indicates that India will likely be able to remain self-sufficient in most crops in 2018.

Global agriculture in 2018 reveals an increase in production in order to meet rising global demand. The United States exports the most corn and soybeans in the Base and Base-18 models, as it increases its production in the Base and Base-18 models by 21.1 and 33 percent, respectively. The United States exports the most wheat in the Base model; however, in 2018 Canada surpasses the United States to become the largest supplier in the global wheat market as it exports 22.27 million metric tons of wheat compared to the U.S.

exports of 22.06 million metric tons. From the current period to 2018, Argentina becomes a large producer of corn and increases its corn exports substantially. As a result, it decreases its soybean production and exports, showing its comparative advantage in producing corn. Brazil increases its soybean production in 2018 and as a result becomes the second largest exporting country of soybeans in the world. Southeast Asia is the largest rice producer and exports the most rice in both the Base and Base-18 models. While other countries/regions also contribute to global grain trade, the United States, Canada, Brazil, Argentina, and Southeast Asia play the largest role in supplying the world with these four staple crops.

Conclusions

The following conclusions are drawn based on the discussions above:

1. China is likely to be able to stay self-sufficient in wheat and rice in 2018, but will import soybeans and corn. This is due to changes in consumption patterns in which Chinese consumers are consuming less wheat and rice, crops that China has a comparative advantage in producing, and consuming more corn and soybeans. While China will be able to produce much of its needed corn, it has a comparative disadvantage in soybean production and will become the world's largest soybean importing country.
2. India will likely remain self-sufficient in wheat, rice, and corn. However, India will import a small amount of soybeans to satisfy its domestic consumption. It is expected that technology increases will allow India to produce enough wheat, rice, and corn to fulfill its growing domestic demand and allow it to continue to export

wheat. India will import soybeans, though not as much China as its structural changes in demand are not as pronounced.

3. The United States has an advantage in exporting soybeans to China; however, India and China will both import soybeans from Brazil. In 2018, the United States will remain the largest corn exporter, though Argentina will increase its exports to meet rising demand in China. Canada will surpass the United States in wheat exports, though both will remain large wheat exporting countries. The United States will increase its rice exports, though exports of rice are not large comparatively. Southeast Asia will still produce and export the most rice in the world.

Need for Further Study

This study evaluates the impact of structural changes in demand of wheat, corn, rice, and soybeans on world agriculture and global grain trade. However, there are cultural differences between China and India that affect dietary preferences and thus conducting the analysis with different agricultural commodities could produce different results. In addition, few studies have evaluated structural changes in demand in India. Thus, there is limited information about its changing consumption resulting from its increasing income.

Another area that would warrant further study would include the by-products of these four primary crops. The model determines consumption, production, and trade of soybeans; however, it does not take into account soy oil and soybean meal which are both by-products of soybeans and will affect global soybean production, consumption, and trade. Biofuels are another area for additional research, as this model does not take into account corn-based ethanol or bio-diesel, which uses corn and soybeans, respectively, and would affect the production, consumption, and trade in the future.

REFERENCES

Agricultural Marketing Service. Grain Transportation Reports. Transportation and Marketing, Agricultural Marketing Service, United States Department of Agriculture. Jan. 2002, Sept. 2003.

Carter, C. and F. Zhong. (2001). China's Past and Future Role in the Grain Trade. Economic Development and Cultural Change, 39(04), 791-814.

The Center for Agricultural Policy and Trade Studies database (2008). North Dakota State University, Fargo, ND.

China the Beautiful. (2005). www.chinapage.com/amp/province-english.jpg.

China National Bureau of Statistics, China Statistical Yearbook (2008).

Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India. (2009). State Wise Area Production and Yield Statistics (1996-97 to 2005-06). http://dacnet.nic.in/eands/APY_96_To_06.htm Date accessed July 2009.

Economic Research Service. (ERS). Agricultural Baseline Projections 2018. Economic Research Service, United States Department of Agriculture. Date accessed July 2009.

EPW Research Foundation. (2009, April). Domestic Product of States of India 1960-61 to 2006-07. Mumbai, India.

Fabiosa, J.F. (2006). Westernization of the Asian Diet: The Case of Rising Wheat Consumption in Indonesia. Iowa State University, Center for Agricultural and Rural Development, Working Paper 422.

Food and Agricultural Policy Research Institute. (FAPRI). FAPRI U.S. and World Agricultural Outlook. Food and Agricultural Research Institute. Ames, IA. January 2009.

Foreign Agricultural Service. (FAS). The Production, Supply, and Distribution (PS&D) online database (1980-2007).

Gale, F., B. Lohmar, and F. Tuan. (2009). How Tightly Has China Embraced Market Reforms in Agriculture? Amber Waves. 7(2).

Global Insights. (2004). The Cost of Producing Crops Around the World. Philadelphia, December.

Haq, Z. and K. Mielke. (2009). The Role of Income Growth in Emerging Markets and the BRICS in Agrifood Trade. Canadian Agricultural Trade Policy Research Network Working Paper 2008-02. February 2009.

Henan University of Technology, Economics and Trade School. (2006) Database of China's Grain. March.

Koo, W.W. and R.D. Taylor. (2009). Expected Changes in China's Grain and Oilseed Industries and Implications for the U.S. and World Agriculture. North Dakota State University, Agribusiness and Applied Economics Report 640.

Landes, Price and Seeley. (2000). Developing Countries' Economies Key to U.S. Agriculture. Economic Research Service Agriculture Baseline Projections, Recommended Readings. http://www.ers.usda.gov/Briefing/baseline/research.htm Date Accessed May 2009.

Lu, W. and L. Kersten. (2006). Prospects of Chinese Grain Supply and Demand in 2010: A Regionalized Multi market Model Simulation and Policy Implication. International Association of Agricultural Economists, Annual Meeting, August 12-18, Queensland, Australia.

Maritime Research Inc. (2004) Ocean Shipping Rates for Grains. 1994-2004.

Mohanty, S., N., Alexandros, and J. Bruinsma. (1998). The Long-Term Food Outlook for India. Iowa State University, Center for Agricultural and Rural Development Technical Report 98-TR 38.

National Agricultural Statistics Service. (2009). Quick Stats online database. http://www.nass.usda.gov/QuickStats/Create_Federal_All.jsp Date accessed July 2009.

National Agricultural Statistical Service. Crops online database. National Agricultural Statistics Service, United States Department of Agriculture. Date Accessed August 12, 2009.

Population Division Department of Economic and Social Affairs, United Nations. *India Becomes a Billionaire*. http://huwu.org/esa/population/pubsarchive /india/india.htm Date Accessed April 2009.

ProExporter. (2004) Grain Transportation Digest. ProExporter, Olathe, KS, GTB-04-04 April 8.

Spreen, T.H. (2006). Price Endogenous Mathematical Programming Models and Trade Analysis. Journal of Agricultural and Applied Economics, 38 (02), 249-253.

Statistics Canada. (2009). Canada's population estimates online database. http://www.statcan.gc.ca/daily-quotidien/090929/dq090929b-eng.htm Date Accessed Aug 2009.

Surface Transportation Board. (2002) Public Waybill Data. Washington D.C.

Takayama, T. (1967). International Trade and Mathematical Programming. Australian Journal of Agricultural Economics, 11 (01), 36-48.

United Nations Food and Agriculture Organization (FAO). (2008). The state of food and agriculture in Asia and the Pacific region 2008. RAP Publication 2008/03.

United Nations Food and Agriculture Organization (FAO). (2003). World agriculture towards 2015/2030. Earthscan Publications. London, UK.

United Nations Food and Agriculture Organization (FAO). (2006). Rapid growth in selected Asian economies: Lessons and implications for agriculture and food security in China and India. RAP Publication 2006/05.

U.S Census Bureau. (2009). Population Finder online database. http://factfinder.census.gov/servlet/SAFFPopulation?_submenuId=population_0&_sse=on Date Accessed Aug 2009.

Von Witzke, H., S. Noleppa, and G. Schwarz. (2008). Global Agricultural Market Trends and their Impacts on European Union Agriculture. Humboldt University Berlin, Institute for Agricultural Economics and Social Sciences, Working Paper 84.

Wang, L. and J. Davis. (1998). Can China Feed Its People into the Next Millennium: Projections for China's Grain Supply and Demand in 2010. International Review of Applied Economics. 12 (01), 53-67.

Wilson, W.W., W.W. Koo, R.D. Taylor, and B.L. Dahl. (2005). Fundamental Factors Affecting World Grain Trade in the Next Two Decades. North Dakota State University, Agribusiness and Applied Economics Report No. 555.

The World Bank Group. (2009). *World Development Indicators Quick Query.* http://ddpext.worldbank.org/ext/DDPQQ/member.do?method=getMembers&userid=1&queryId=135 Date accessed June 2009.

The World Factbook. (2009). https://www.cia.gov/library/publications/the-world-factbook/ Date accessed: May 2009.

World Trade Organization and International Trade Centre. (2008) World Tariff Profiles 2008. Geneva, Switzerland.

Zhuang, R. and W.W. Koo. (2007). Implications of Growth in China for the U.S. and Other Countries. Selected Paper for Western Agricultural Economics Association Annual Meeting, July 29-August 1, Portland, Oregon.

APPENDIX

Table A.1. Domestic Consumption Estimates for 2018

	FAPRI	USDA	AR(1)
	----------------------------------1000 metric tons----------------------------------		
Corn			
ARG	10,580	9,230	8,521
AUS	488	0	433
BZL	61,551	55,176	52,511
CAN	15,434	13,513	17,580
EU	70,609	62,827	58,955
FSU-ME	50,852	31,813	118,377
IND	21,406	22,814	19,616
JAP	18,795	16,502	16,418
KOR	9,358	8492	11,295
LAT	30,498	18715	86882
MEX	40,763	38,718	41,570
NAF	16,864	18,834	90,397
SA	1,619	0	3,960
SAF	12,009	54595	54270
SEA	39,405	31,246	299,062
US	346,198	312,396	286,586
Wheat			
ARG	6,752	5384	5,158
AUS	13,358	6956	8,252
BZL	13,181	12545	11,894
CAN	18,440	8411	7,609
EU	156,640	135345	134,580
FSU-ME	202,529	143,844	569,207
IND	98,705	84436	85,368
JAP	7,934	5928	5,517
KOR	5,725	3851	2,682
LAT	17,104	10405	51,472
MEX	8,148	7827	6,155
NAF	52,945	41,278	178,755
SA	29,162	29420	19,059
SAF	0	3200	20,427
SEA	29,890	29675	124,053
US	53,768	36779	45,450
Soybean			
ARG	72,701	56,546	56,586

Table A.1. (continued)

AUS	0	0	48
BZL	59,305	47,858	55,905
CAN	2,360	1,981	2,603
EU	15,615	12,808	17,340
FSU-ME	1,517	6,473	32,110
IND	13,096	11,422	3,401
JAP	4,113	4,382	3,913
KOR	1,501	1,454	1,575
LAT	2276	3791	22869
MEX	3,868	4,805	5,099
NAF	0	1582	8,921
SA	0	0	159
SAF	0	0	1660
SEA	0	6,383	66,652
US	69,347	51,588	65,348
Rice			
ARG	548	374	505
AUS	479	343	563
BZL	10,857	9,448	8,690
CAN	488	404	489
EU	3,661	2,910	3,773
FSU-ME	10,121	9,299	52,564
IND	121,573	108,455	94,645
JAP	9,395	7,779	6,699
KOR	5,566	4,295	3,738
LAT	279	5691	26820
MEX	1,232	1,037	941
NAF	4,952	4,307	19,833
SA	40,405	40,640	22,825
SAF	10,113	21,158	25,160
SEA	138,367	125,676	975,026
US	5,810	6,633	5,488

Table A.2. Corn Production in Base and Base-18 Models

	Base Model			Base-18 Model		
	Harvested	Yield	Production	Harvested	Yield	Production
	------------------------------------1000 metric tons--					
ARG	3490	6.99	24393	3487	8.25	28770
AUS	62	5.2	320	70	6.13	430
BRZ1	9465	3.13	29625	7002	3.69	25837
BRZ2	7975	3.63	28950	8659	4.28	37061
CAL	4	7.43	27	0	0	0
CBC	0	0	0	4	8.77	32
CMB	64	6.5	415	91	7.67	697
CON	1113	9.27	10316	1523	10.93	16644
CQB	559	8.2	4583	837	9.67	8094
CSK	0	0	0	0	0	0
EUR	7832	6.2	48557	8074	7.31	59020
FSU-ME	5676	4.04	22931	7143	4.76	34000
IND1	275	2.18	600	273	2.58	704
IND2	203	2.77	563	186	3.27	609
IND3	32	1.43	46	83	1.68	139
IND4	1739	1.42	2469	1605	1.68	2696
IND5	433	1.25	541	551	1.47	810
IND6	800	1.63	1304	833	1.93	1607
IND7	88	1.27	112	229	1.5	343
IND8	564	2.29	1292	401	2.7	1081
IND9	167	1.47	246	429	1.74	747
IND10	55	1.55	85	63	1.83	115
IND11	62	2.59	160	88	3.06	271
IND12	158	1.74	276	187	2.06	386
IND13	2246	2.83	6357	2857	3.34	9542
IND14	166	1.44	238	336	1.69	567
JAP	1	1	1	1	1.18	1
LAT	2592	3.23	8372	2847	3.81	10846
MEX	6404	3.06	19595	6348	3.61	22915
NAF	1176	6.46	7598	1048	7.63	7995
SAF	31121	1.57	48860	29335	1.85	54270
SA	2207	2.39	5274	2018	2.82	5690
KOR	18	4.82	87	20	5.68	114
SEA	10031	2.86	28688	11007	3.37	37093
US1	1268	7.77	9852	1200	9.17	11002
US2	60	10.86	651	294	12.82	3766
US3	612	7.79	4769	567	9.2	5216
US4	5366	9.06	48614	6176	10.69	66019
US5	2015	7.15	14408	2562	8.44	21626
US6	730	7.97	5817	779	9.4	7318

Table A.2. (continued)

US7	551	8.73	4812	807	10.3	8313
US8	279	7.93	2214	270	9.36	2528
US9	4471	9.54	42655	4716	11.26	53102
US10	1193	9.46	11281	1137	11.16	12686
US11	5406	10.67	57679	5105	12.59	64276
US12	5043	10.07	50780	4719	11.88	56058
US13	2444	9.73	23778	2156	11.48	24745
US14	50	12.63	627	52	14.91	768
US15	361	6.76	2440	222	7.97	1766
US16	64	9.62	617	76	11.36	867
US17	437	9.44	4130	466	11.14	5190
ANHUI	829	5.06	4197	852	5.97	5089
BEIJIN	146	4.85	707	144	5.72	825
CHONGQIN	371	4.43	1643	402	5.23	2104
FUJIAN	28	3.39	95	28	4	112
GANSU	387	5.08	1966	409	5.99	2448
GUANGDON	140	4.51	629	131	5.32	694
GUANGXI	444	3.39	1504	483	4	1933
GUIZHOU	542	5.29	2866	575	6.24	3589
HAINAN	14	3.25	44	13	3.84	48
HEBEI	2244	4.5	10099	3648	5.31	19370
HENAN	1975	5.48	10825	2115	6.47	13685
HLJ	3977	4.93	19609	4062	5.82	23642
HUBEI	356	5.73	2039	360	6.76	2432
HUNAN	211	5.04	1061	213	5.95	1269
JIANGSU	776	6.28	4871	640	7.41	4743
JIANGXI	18	3.77	68	18	4.45	80
JILIN	2236	5.07	11334	2472	5.98	14784
LIAONING	1492	4.34	6476	1464	5.12	7497
NEIMONG	1089	5.44	5926	1134	6.42	7280
NINGXIA	262	7.01	1834	263	8.27	2174
QINGHAI	5	6.41	33	5	7.56	39
SHAANXI	821	4.39	3603	755	5.18	3911
SHANDONG	4294	6.82	29285	4654	8.05	37464
SHANGHAI	10	7.99	83	10	9.43	97
SHANXI	615	5.02	3086	545	5.92	3229
SICHUAN	1008	4.97	5010	1123	5.86	6582
TIANJIN	117	3.5	410	116	4.13	479
XINGJIANG	372	7.88	2929	461	9.3	4285
XIZHANG	5	5.03	26	5	5.94	31
YUNNAN	838	4.7	3938	1202	5.55	6673
ZHEJIANG	36	4.37	157	34	5.16	176

Table A.3. Wheat Production in Base and Base-18 Models

	Base Model			Base-18 Model		
	Harvested	Yield	Production	Harvested	Yield	Production
	----------1000 metric tons----------					
ARG	6568	2.98	19572	6679	3.42	22843
AUS	13045	1.34	17481	14098	1.54	21710
BRZ1	1271	1.7	2160	968	1.96	1896
BRZ2	1221	1.92	2344	1384	2.21	3059
CAL	2674	2.9	7756	2491	3.34	8321
CBC	19	2.27	42	19	2.61	48
CMB	1340	2.97	3981	1056	3.41	3599
CON	474	5	2368	697	5.75	4007
CQB	57	2.93	167	83	3.37	279
CSK	5484	2.1	11517	5466	2.42	13228
EUR	22640	5.03	113877	22824	5.78	131921
FSU-ME	60344	1.95	117671	60338	2.25	135760
IND1	325	1.72	559	312	1.98	618
IND2	6991	4.08	28525	8524	4.69	39976
IND3	356	1.85	658	928	2.13	1976
IND4	13533	2.67	36132	11042	3.07	33898
IND5	969	2.62	2539	1394	3.01	4195
IND6	3576	1.72	6150	2665	1.97	5250
IND7	92	0.92	84	237	1.06	251
IND8	1832	1.67	3060	1754	1.92	3368
IND9	59	1.76	103	150	2.03	305
IND10	4	1.36	5	3	1.57	4
IND11	482	2.18	1050	405	2.5	1013
IND12	0	0	0	32	1.39	44
IND13	72	1.21	87	836	1.32	1104
IND14	931	1.15	1070	0	0	0
JAP	193	4.09	788	150	4.7	706
LAT	1329	2.64	3507	1530	3.04	4652
MEX	553	5.38	2973	532	6.19	3292
NAF	8405	2.29	19247	10421	2.63	27408
SAF	3355	1.99	6677	3727	2.29	8534
SA	14197	2.36	33505	12201	2.71	33065
KOR	2	3.67	9	4	4.22	17
SEA	120	1.5	180	88	1.73	153
US1	470	3.85	1808	425	4.42	1877
US2	148	5.17	765	261	5.94	1549
US3	101	3.81	386	83	4.38	366
US4	4876	2.47	12044	4289	2.84	12182
US5	4824	2.35	11337	4118	2.71	11161
US6	2664	1.99	5301	1616	2.29	3699

Table A.3. (continued)

US7	288	3.51	1009	162	4.04	654
US8	91	4.41	401	61	5.07	308
US9	1063	3.54	3764	1014	4.08	4138
US10	352	4.48	1575	243	5.16	1255
US11	8	3.68	30	8	4.23	35
US12	335	4.1	1374	297	4.72	1401
US13	163	4.39	717	112	5.05	567
US14	1275	3.99	5088	1013	4.59	4647
US15	154	3.12	481	123	3.59	440
US16	2722	2.69	7322	2442	3.1	7569
US17	954	0.62	591	1011	0.71	718
ANHUI	1143	3.63	4148	1026	4.17	4278
BEIJIN	188	5.98	1126	163	6.88	1121
CHONGQI	203	2.37	480	220	2.73	600
FUJIAN	19	3.1	59	20	3.57	71
GANSU	557	2.43	1354	590	2.79	1645
GUANGDO	6	3.11	20	5	3.58	19
GUANGXI	0	0	0	9	1.73	16
GUIZHOU	8	1.5	12	261	2.28	595
HAINAN	246	1.98	486	0	0	0
HEBEI	2388	4.92	11749	3389	5.66	19179
HENAN	5619	4.95	27813	5252	5.69	29886
HLJ	571	1.77	1010	509	2.04	1037
HUBEI	475	3.02	1434	419	3.47	1452
HUNAN	50	2.14	106	50	2.46	122
JIANGSU	2023	4.44	8982	1459	5.11	7455
JIANGXI	24	1.68	41	24	1.93	47
JILIN	32	2.3	75	36	2.65	95
LIAONING	2139	3.31	7079	1826	3.81	6957
NEIMONG	328	3.22	1055	341	3.7	1262
NINGXIA	127	2.78	353	128	3.2	409
QINGHAI	83	2.89	239	83	3.32	275
SHAANXI	642	2.97	1906	653	3.42	2235
SHANDON	2694	5.41	14575	2549	6.22	15854
SHANGHA	204	4.72	962	176	5.43	958
SHANXI	424	2.63	1115	376	3.02	1136
SICHUAN	688	3.62	2489	766	4.16	3186
TIANJIN	305	5.33	1626	262	6.13	1605
XINGJIAN	1112	5.19	5770	1202	5.97	7173
XIZHANG	347	6.45	2241	308	7.42	2284
YUNNAN	279	2.57	717	401	2.96	1185
ZHEJIANG	100	3.38	339	83	3.89	322

Table A.4. Soybean Production in Base and Base-18 Models

	Base Model			Base-18 Model		
	Harvested	Yield	Production	Harvested	Yield	Production
	--1000 metric tons--					
ARG	17839	2.81	50127	18919	3.21	60731
AUS	16	2.32	38	6	2.64	17
BRZ1	11398	2.58	29406	14695	2.94	43204
BRZ2	7920	3.02	23918	12855	3.44	44220
CAL	0	0	0	0	0	0
CBC	0	0	0	0	0	0
CMB	120	2.1	252	155	2.39	370
CON	1181	2.73	3224	1714	3.12	5346
CQB	264	2.69	709	360	3.07	1105
CSK	0	0	0	0	0	0
EUR	500	2.5	1249	388	2.85	1105
FSU-ME	1281	1.2	1537	1533	1.36	2084
IND1	1	1.11	1	1	1.27	1
IND2	0	0	0	0	0	0
IND3	15	1.18	18	39	1.34	52
IND4	756	1.32	998	961	1.5	1441
IND5	23	0.71	16	49	0.81	39
IND6	3886	1	3886	3782	1.14	4311
IND7	29	0.93	27	74	1.06	78
IND8	0	0	0	0	0	0
IND9	0	0	0	0	0	0
IND10	0	0	0	0	0	0
IND11	0	0	0	0	0	0
IND12	46	1.3	60	95	1.48	141
IND13	2000	1.11	2220	3783	1.27	4804
IND14	0	0	0	0	0	0
JAP	124	1.63	202	196	1.86	365
LAT	3424	2.09	7155	5020	2.38	11948
MEX	60	1.63	98	76	1.86	141
NAF	17	2.44	41	19	2.78	52
SAF	771	1.18	910	1070	1.35	1445
SA	2	1	2	2	1.14	2
KOR	109	1.66	181	121	1.89	228
SEA	1013	1.32	1337	929	1.51	1402
US1	1544	2.15	3319	2092	2.45	5124
US2	0	0	0	0	0	0
US3	260	2.77	719	371	3.16	1173
US4	4461	2.79	12447	5586	3.18	17764
US5	2522	2.4	6052	3901	2.74	10688
US6	204	1.7	347	204	1.94	396

Table A.4. (continued)

US7	1925	2.36	4543	1520	2.69	4089
US8	293	2.07	606	237	2.36	560
US9	3729	2.92	10888	4757	3.33	15839
US10	1862	3.12	5808	2081	3.55	7388
US11	3488	3.48	12140	3947	3.96	15632
US12	3372	3.09	10420	3494	3.53	12333
US13	2211	3.25	7186	2183	3.71	8097
US14	0	0	0	0	0	0
US15	286	1.64	469	314	1.87	587
US16	0	0	0	0	0	0
US17	0	0	0	0	0	0
ANHUI	432	1.42	613	446	1.62	722
BEIJIN	11	2.27	26	11	2.59	29
CHONGQI	43	1.17	51	47	1.33	62
FUJIAN	178	2.07	368	180	2.36	426
GANSU	124	1.6	199	131	1.82	238
GUANGDO	158	2.05	324	147	2.34	345
GUANGXI	167	1.37	228	182	1.56	284
GUIZHOU	86	1.36	116	90	1.55	140
HAINAN	14	1.85	27	14	2.11	30
HEBEI	243	1.58	384	396	1.8	713
HENAN	391	2.18	852	418	2.49	1042
HLJ	1723	1.67	2877	1766	1.9	3355
HUBEI	132	2.17	287	134	2.47	331
HUNAN	122	2.21	271	124	2.52	313
JIANGSU	383	2.86	1094	316	3.26	1032
JIANGXI	243	1.8	437	243	2.05	499
JILIN	597	2.37	1414	659	2.7	1779
LIAONING	166	1.69	280	162	1.93	313
NEIMONG	470	1.15	540	490	1.31	641
NINGXIA	32	0.71	23	32	0.81	26
QINGHAI	0	0	0	0	0	0
SHAANXI	1727	0.96	1658	1238	1.09	1349
SHANDON	734	2.42	1777	796	2.76	2196
SHANGHA	4	3.25	13	4	3.71	15
SHANXI	144	1.4	202	128	1.6	204
SICHUAN	251	2.34	588	279	2.67	746
TIANJIN	17	1.21	21	17	1.38	24
XINGJIAN	86	2.96	254	106	3.37	358
XIZHANG	1	5.75	6	1	6.56	7
YUNNAN	121	1.57	190	173	1.79	310
ZHEJIANG	170	2.34	398	161	2.67	430

Table A.5. Rice Production in Base and Base-18 Models

	Base Model			Base-18 Model		
	Harvested	Yield	Production	Harvested	Yield	Production
	----------1000 metric tons----------					
ARG	208	4.4	916	200	5.19	1037
AUS	50	8.22	408	55	9.7	533
BRZ1	1583	2.5	3958	1618	2.94	4756
BRZ2	1479	2.97	4392	1124	3.5	3935
CAL	0	0	0	0	0	0
CBC	0	0	0	0	0	0
CMB	0	0	0	0	0	0
CON	0	0	0	0	0	0
CQB	0	0	0	0	0	0
CSK	0	0	0	0	0	0
EUR	509	4.17	2124	390	4.93	1921
FSU-ME	1490	2.85	4245	1493	3.36	5016
IND1	73	1.47	107	69	1.73	120
IND2	4436	3.57	15836	5349	4.22	22573
IND3	270	1.92	518	700	2.27	1589
IND4	5153	1.98	10204	4818	2.34	11273
IND5	818	1.88	1538	612	2.22	1359
IND6	1499	0.91	1364	1499	1.08	1619
IND7	3397	1.32	4484	8825	1.56	13768
IND8	2986	1.13	3374	2986	1.33	3972
IND9	1201	1.38	1657	3132	1.63	5105
IND10	4036	1.49	6013	3992	1.76	7025
IND11	5960	2.53	15079	5137	2.98	15309
IND12	2975	1.6	4759	2894	1.89	5470
IND13	7451	2.68	19969	4597	3.16	14527
IND14	2490	2.47	6151	1625	2.92	4746
JAP	1520	4.73	7190	1193	5.58	6654
LAT	5830	2.92	17023	3816	3.45	13165
MEX	51	3.22	165	48	3.8	181
NAF	608	6.4	3894	721	7.56	5450
SAF	12799	1.61	20607	14504	1.9	27558
SA	15891	2.45	38934	15827	2.9	45899
KOR	973	4.8	4670	758	5.67	4295
SEA	54123	2.35	127190	59568	2.78	165599
US1	0	0	0	0	0	0
US2	220	8.69	1914	418	10.25	4280
US3	0	0	0	0	0	0
US4	85	7.44	631	121	8.78	1059
US5	0	0	0	0	0	0
US6	69	7.59	526	107	8.96	960

Table A.5. (continued)

US7	872	7.56	6591	841	8.91	7490
US8	0	0	0	0	0	0
US9	0	0	0	0	0	0
US10	0	0	0	0	0	0
US11	0	0	0	0	0	0
US12	0	0	0	0	0	0
US13	0	0	0	0	0	0
US14	0	0	0	0	0	0
US15	0	0	0	0	0	0
US16	0	0	0	0	0	0
US17	0	0	0	0	0	0
ANHUI	1688	3.65	6160	1516	4.31	6532
BEIJIN	11	4.45	48	11	5.25	57
CHONGQI	494	4.59	2268	536	5.42	2907
FUJIAN	826	3.46	2859	845	4.08	3448
GANSU	5	5.69	29	5	6.71	30
GUANGDO	1676	3.86	6469	1574	4.55	7162
GUANGXI	1499	3.57	5353	1632	4.21	6869
GUIZHOU	468	4.25	1989	497	5.02	2494
HAINAN	248	2.74	681	246	3.23	794
HEBEI	111	3.06	339	180	3.61	650
HENAN	343	4.64	1593	321	5.48	1761
HLJ	2527	4.34	10965	2254	5.12	11538
HUBEI	5884	5.02	29535	5193	5.92	30743
HUNAN	2462	4.11	10120	2485	4.85	12052
JIANGSU	2912	5.47	15930	2101	6.45	13549
JIANGXI	1879	3.53	6634	1885	4.17	7859
JILIN	388	4.29	1664	428	5.06	2168
LIAONING	375	5.15	1933	321	6.08	1954
NEIMONG	74	4.08	301	77	4.81	368
NINGXIA	58	5.44	315	50	6.42	324
QINGHAI	0	0	0	0	0	0
SHAANXI	101	4.37	443	59	5.16	307
SHANDON	122	4.19	513	133	4.94	658
SHANGHA	137	5.21	711	119	6.15	731
SHANXI	3	4.84	15	3	5.71	15
SICHUAN	1739	5.15	8958	1760	6.08	10703
TIANJIN	42	2.74	116	42	3.23	137
XINGJIAN	121	5.17	626	131	6.1	796
XIZHANG	1	3.65	3	1	4.31	4
YUNNAN	673	3.54	2383	967	4.18	4040
ZHEJIANG	1090	4.15	4523	1032	4.9	5058