Impacts of Climate Change on Maize Production in China and the U.S. and Possible Risk Mitigation Strategies

(気候変動による中国とアメリカのトウモロコシ生産への影響とリスク緩和戦略の研究)

Li Xiang

李　想

Ph.D. Thesis (2013)

平成 24 年度　博士論文

Impacts of Climate Change on Maize Production in China and the U.S. and Possible Risk Mitigation Strategies

(気候変動による中国とアメリカのトウモロコシ生産への影響とリスク緩和戦略の研究）

Laboratory of International Environmental Economics,
Graduate School of Agricultural and Life Sciences,
The University of Tokyo
(1-1-1, Yayoi, Bunkyo-ku, Tokyo, Japan, 113-8657)

東京大学大学院農学生命科学研究科

農学国際専攻　国際環境経済学研究室

東京大学
THE UNIVERSITY OF TOKYO

Xiang Li

李想

Preface

Industrial revolution in the 19th century and the fast economic growth thereafter have contributed to a higher standard of living and an extended life expectancy of our society. Over the past years, at a never seen pace in the history of the earth utile natural resources have been extracted and processed to be energies and materials at desirable formats to satisfy the desires and needs of human beings. Though such egocentric practices have brought about the improvement of the qualities of lives of a large number of people, the compensation on the environment is big, in extreme cases irretrievable.

Over the past years, the emissions of greenhouse gases have increased dramatically with economic development, contributing to the global greenhouse effects. Scientists in overall have agreed that the continuous emissions of global greenhouse gases accompanying with globalization and economic development will further alter the climate of the earth and accelerate climate change (Bolin et al., 1986; Brown and Rosenberg, 1999; Corbera et al., 2010; den Elzen et al., 2010; Esteve et al., 2010; Gabriele et al., 1996; Hegerl et al., 1996; IPCC, 2007; Li et al., 2011; Paeth et al., 1999; Stockle et al., 1992; Tubiello et al., 2002; Wigley, et al., 1996). Among all climate sensitive systems, agriculture, key to provide foods to people and to support the economy of our society, no doubt is a critically important sector in this century.

The global structure of food production and consumption in the world has been in a polarized style. Countries are either net importers or net exporters. Given the possibility that climate change, changes of age structure of overall labor force, and the increased bioethanol demand could put a further pressure on the balance of food supply and demand in the coming decades, the future impacts of climate change on agriculture sector would not simply be the problems of those countries that produce and export foods, but a world issue. Thus, food production definitely is a key issue in this century and people all over the world should not continuously hold a NIMBY (not-in-my-backyard) view in the future.

Among various agricultural crops, maize (*Zea mays* L) is an important crop in sustaining human lives in terms of its roles as a major grain commodity, a feed commodity, and a significant recyclable bioethanol energy source. Thus, this thesis focuses on this crop for analysis.

In the long-term perspective, understanding the environmental and social problems we are facing and will be facing, as well as proposing corresponding possible risk mitigation solutions are important strategies to coexist with nature and to preserve the natural heritage for the future generations. Thus, analyzing the interrelationships between climate change and maize production in China and the U.S. with a multidisciplinary approach, predicting the potential effects of climate change on maize production, and proposing alternative risk prevention and management policy solutions to reduce potential negative impacts of climate change are the purposes of this thesis.

This thesis covers the total of seven chapters. Three case studies are carefully examined and discussed. The first chapter provided information on the background and purposes of the thesis. Chapter two reviewed the past studies related to the analysis about climate change and crop production. Chapter three to chapter five covered three different research topics where each research's target, analysis method, and the findings are carefully examined and explained in each chapter. Chapter three did an analysis with a global view, where maize production in the Midwestern United States and Middle China (major maize producing countries) are analyzed with a regression model. Climate inputs, socioeconomic inputs in terms of real profits, and technology improvement are simultaneously incorporated in the model. Chapter four and five are about regional analyses. The effects of climate change on maize production in Northern and Southern China and the U.S are separately examined with Cobb-Douglas production functions and converted supply functions. The last two chapters separately described the limitations of models and concluded the thesis. Findings gained from this thesis can be used for policy makers and advanced risk mitigation and diversification programs. They are also expected to contribute to the stability of international crop market price and to prevent future risks in countries/regions beyond the scope of this study, such as Japan, to combat radioactive contamination issues.

Acknowledgements

I specially thank my supervisor professor Nobuhiro Suzuki to guide me throughout the whole research. I also greatly thank assistant professor Taro Takahashi who provided valuable advice. In addition, I also thank staff members working in different departments of the USDA and the National Development and Reform Commission for providing me valuable data and information. Completing this thesis would have been difficult without the advice and supports provided by my parents, relatives, classmates, great members in the same laboratory, and the true friendship provided by friends. I am indebted to them for their encouragement and great help.

Table of contents

論　文　の　内　容　の　要　旨

東京大学大学院農学生命科学研究科農学国際　専攻

平成２２年度博士課程　入学（進学）

氏　　　名　李想（リシャン）/LI XIANG (39-107104)

指導教員名　鈴木宣弘

論文題目　Impacts of Climate Change on Maize Production in China and the U.S. and Possible Risk Mitigation Strategies

(気候変動による中国とアメリカのトウモロコシ生産への影響とリスク緩和戦略の研究）

It has become increasingly clear among scientists that a continuous increase in atmospheric greenhouse emission is changing the climate of earth. Among various climate change sensitive ecosystem, agriculture is a key sector to support the sustainable economic development of our society in this century. Given the backdrop of the fact that the share of maize production in China and the U.S. is over 50% of total maize production amount in the world, this thesis analyzed the interrelationship between climate change and maize production in China and the U.S. with a multidisciplinary approach, predicted the potential effects of climate change on maize production, and proposed alternative risk mitigation strategies to reduce the whole-country risk of maize reduction.

This thesis did three case studies in China and the U.S., where climate inputs, socioeconomic inputs, and technology improvement (with and without) were taken into the consideration. While the first study analyzed the maize production in the Midwestern United States and Middle China with a semi-optimized supply function, the following two studies separately analyzed maize production responses in the North and the South of two countries with a regression function (Cobb-Douglas production function) and converted supply functions.

The major finding of the first case study is that climate change will not universally cause negative impacts of maize yields in the United States and China. The results of a simulation of climate change on maize yields over the period 2008–2030 showed that variation in regional climatic and economic conditions could make the impacts of climatic change on maize yields substantially different in different regions. Even with significant changes in climate conditions that alter the maize crop's growing environment and affect crop yields, a decrease in maize supply due to a decrease in maize yields would lead to an increase in the maize price, which in turn would induce farmers to add more investments in production inputs to raise yields. Thus, the decrease in actual yields may not be as dramatic as predicted in cases where only climate factor are considered.

The second study indicates that the impacts on maize production will likely be the opposite in the Northeast and the Southwest of China. The results indicate that a higher flexibility of production timing in the Southwest region allows farmers to better adapt to climate change than the Northeast region. Moreover, the gains in the Southeast may outweigh the potential reduction of maize production in the Northeast region. When a further reduction of agricultural labor population occurs, maize production decreases more in the Southwest region, even the substitution of more machinery for human labor is allowed. This result reflects that terraced, sloped lands in the Southwest region limit the effective use of machinery.

The third case study indicates that under the same climate change South region tends to respond oppositely relative to the North Central region in the U.S., implying that one region's losses could be partially offset by the other region's gains. The different responses imply that the South region could provide potential risk mitigation to climate change within the United States and could help the nation maintain its maize production balance.

All simulated results indicated that maize production could respond oppositely among different countries and regions through 2030. It has been noticed that advanced international and inter-regional contracts and cooperation as well as policies could mitigate the entire-country risk of reduced production and to stabilize regional agricultural labor force. Moreover, the gains in the Southeast may outweigh the potential reduction of maize production in the North region in China and the U.S.

The risk mitigation strategies provided in this thesis are expected to impact the stability of food production self-sufficiency in China and the U.S. and the price stability of the international commodity market, as well as to be applied to other countries like Japan.

Keywords**:** climate change, maize production, interrelationship, climate and socioeconomic inputs, risk, mitigation

1. Introduction

Accompanying with a rapid economic development since the industrial revolution in the 19th century, at a never seen pace in the history of the earth utile natural resources have been extracted and transformed to be desirable formats of energies and materials to satisfy the egocentric desires and needs of human beings. A large amount of anthropogenic greenhouse gases have been released to the atmosphere during this process, leading to various environmental problems such as greenhouse effects (Figure 1.1 and Figure 1.2). Over the past decades, scientists have widely accepted the view that a continuous emission of global greenhouse gases accompanying with globalization and economic development will further alter the climate of the earth and accelerate climate change (Bolin et al., 1986; Brown and Rosenberg, 1999; Corbera et al., 2010; den Elzen et al., 2010; Esteve et al., 2010; Gabriele et al., 1996; Hegerl et al., 1996; IPCC, 2007; Li et al., 2011; Paeth et al., 1999; Stockle et al., 1992; Tubiello et al., 2002; Wigley, et al., 1996). Global general circulation models (GCMs), which are the best tools for predicting future climates, indicate that the earth's surface temperature could rise by an average of 1.5˚C to 4.5˚C over the next 50 to 100 years due to increasing concentrations of greenhouse gases in the atmosphere (Intergovernmental Panel on Climate Change, 2007).

Any change in climate will have implications for climate-sensitive systems such as forestry, other natural resources, and agriculture. For the agriculture sector, climate change will have agronomic impacts on crop production and also generate economic effects on agricultural prices, production, demand, trade, regional comparative advantage, and producer and consumer welfare. These agronomic and economic impacts will depend principally on: (1) the magnitude of climatic change, and (2) the locale specific capacity to absorb the effects of climate change.

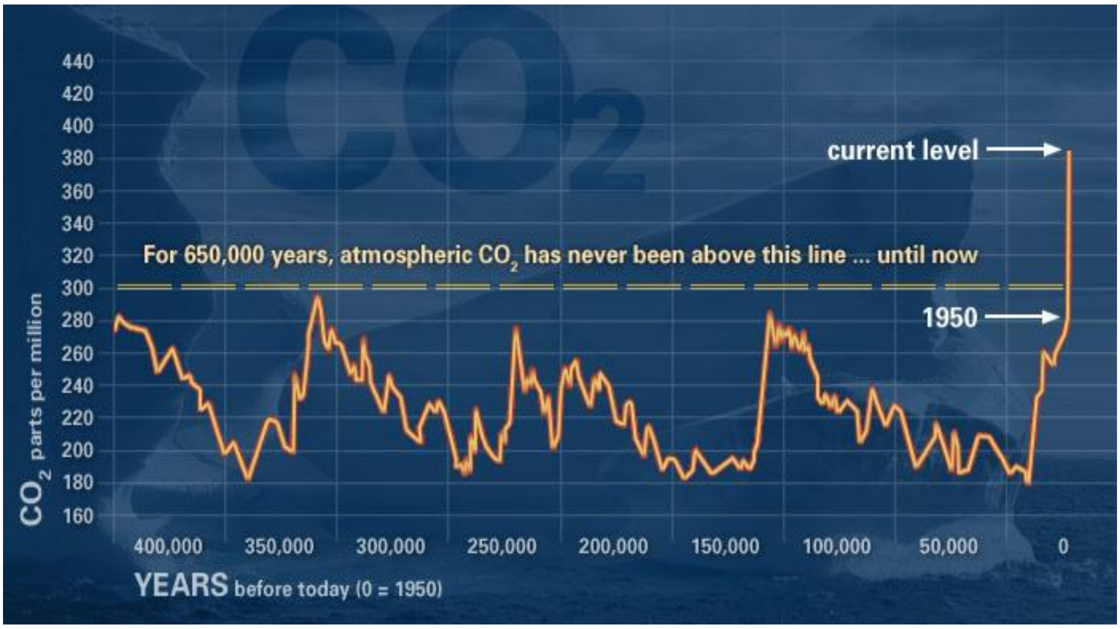


Figure 1.1 CO_2 concentration trend over time (Source: National Aeronautics and Space administration NSSA)

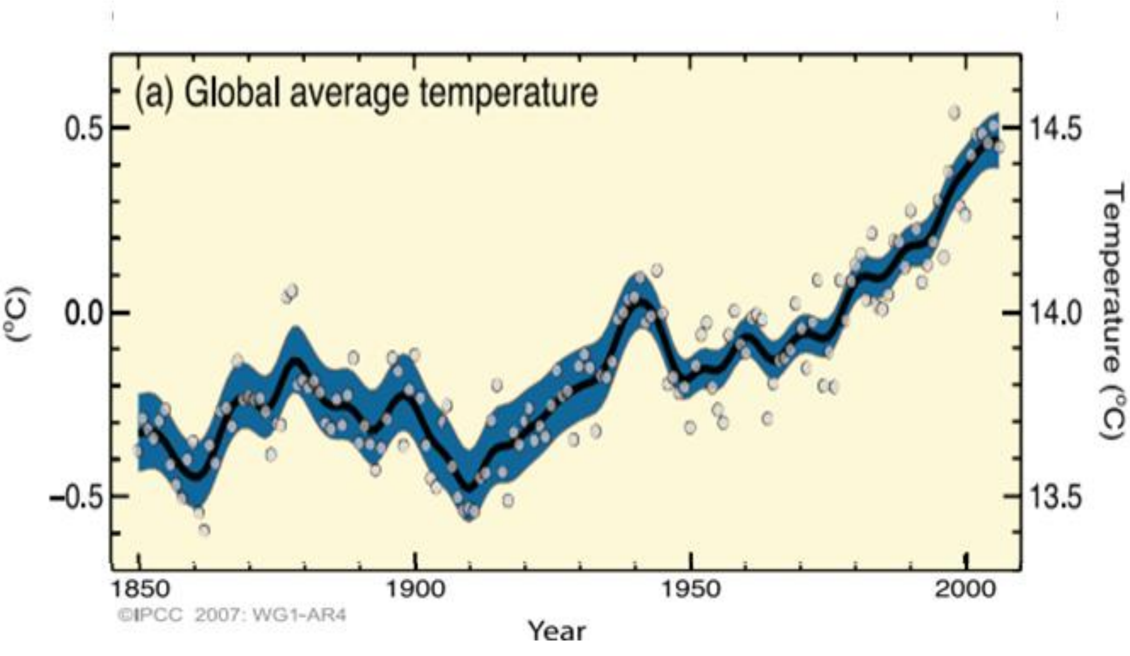


Figure 1.2. Global average temperature trend over time (Source: IPCC)

The global structure of food production and consumption in the world has been in a polarized style. Countries are either net importers or net exporters. Those that are capable of producing a large amount of agriculture products beyond their consumptive abilities and exporting them to other places in the world are limited to a few countries such as the U.S., Canada, Argentina, etc.

In addition to this above point, aging and unbalanced world food production and consumption structure could add additional risks to the agricultural sector. Since labor force is an important input in the crop production process, ensuring working population to be stable and the working age (workable age range between 15 and 64 years old) to be healthy are critically important for sustainable crop production. Based on the projection of the United Nations DESA (2012), the old-age dependency ratios (the ratio of persons aged 65 or over to those range between 15-64 years old) in six major areas of the world will experience significant growths over the period 2000 to 2050 (Figure 1.3). The ratios are predicted to grow 6 per hundred to 11 per hundred in Africa, 9 to 26 in Asia and Latin America and Caribbean, 19 to 35 in Northern America and 22 to 51 in the Europe (Figure 1.3). The projected results reflect the seriousness of world aging issue.

Among major crop producing countries, China in Asia and the U.S. in the Northern America are focused in this thesis, as these two countries can significantly impact the world crop market. While China has the largest population size in the world, the U.S. has the third largest population size (U.S Census Bureau 2012). Thus, it is interesting to know population trend of each country. At present, the age cohort of working labor force in China is between ages 40 to 44 (Figure 1.4). Natural aging and one-child policy combined together would put further pressure on the labor force's structure and size in the agricultural sector in the near future.

In the U.S., baby boom generation born between 1946 and 1964 period has started entering the ageing population group at present. In the near future, more people will enter this group. Though ageing is also a problematic issue in the U.S., immigration policies conducted over years has helped the country avoid shortage of labor force.

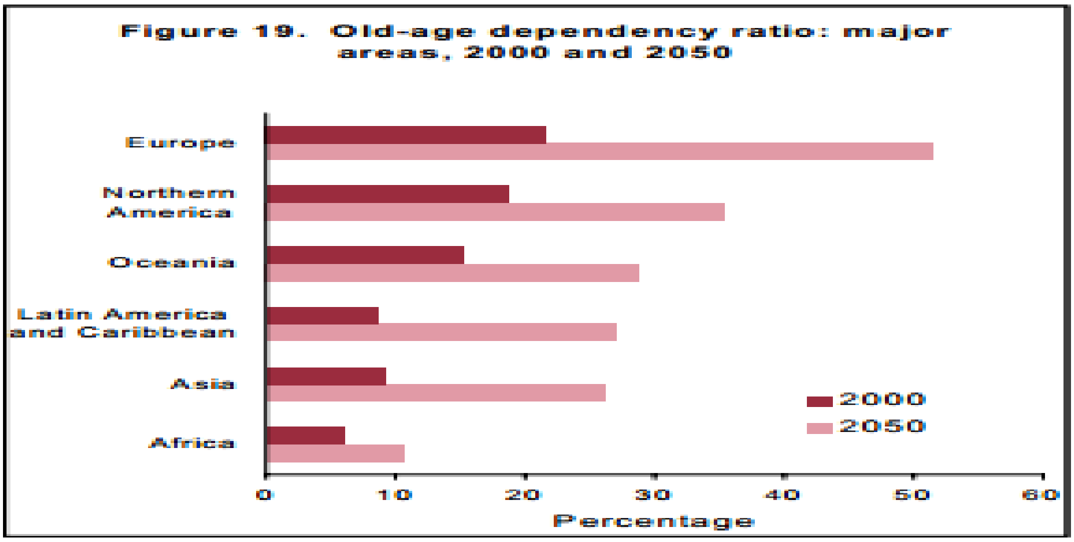


Figure 1.3 Old-age dependency ratio in the major areas of the world in year 2000 and 2050 (United Nations DESA)

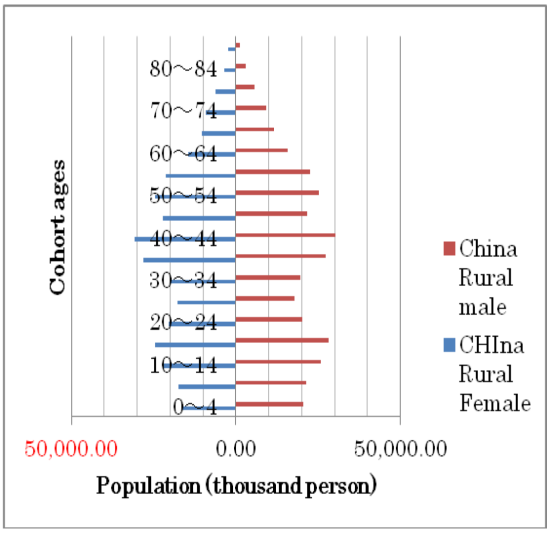
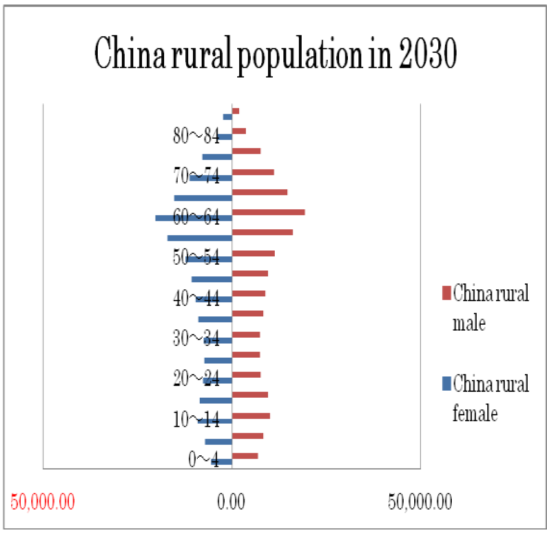
Year 2008	Year 2030
	

Figure 1.4 2008 and 2030 rural population structure in China (China labor statistical yearbook 2009)

Among crops, maize (*Zea mays* L) is focused and analyzed in this thesis for the following reasons. First, maize is a major grain commodity. Dietary customs in many countries are linked to this crop. Traditional customs to consume foods that are either directly or indirectly produced from maize, such as maize flour and meats, cannot be easily altered. Thus, any changes in maize supply would first affect maize-related food prices and force people to alter their customs. Secondly, maize is an important feed crop. In most cases, fluctuations of maize productions can quickly affect the feed prices, and the changes in feed prices in turn become the controlling factor in deciding the survival of livestock businesses and the meat prices offered in the market. Third, maize crop is a critically important renewable bioethanol energy source that could compete with food demand. Any reductions in maize production could put pressure on the maize prices.

Overall, the combined pressure of climate change, changes of age structure of labor force, and the increased demand of renewable energy (e.g., bioethanols) will put further pressure on the supply and demand balance of agricultural products in the coming decades. Given the background of these facts, the impacts of climate change on the agriculture sector will not simply be the problems of crop exporting countries, but a key world issue. People all over the world should not continuously hold the view that agricultural production is a NIMBY (not-in-my- backyard) issue in this century. Furthermore, understanding the potential impacts of climate change on maize production and proposing potential risk mitigation strategies in advance are necessary.

In this thesis, analyzing the interrelationship between climate change and maize productions in China and the U.S. with a multidisciplinary approach, predicting the potential effects of climate change on maize production, and proposing alternative risk prevention and management solutions that are applicable to China, the U.S, as well as other countries, such as Japan, to reduce the entire-country risk of crop reduction are the purposes of this thesis.

Chapter II. Review of previous findings

Previous studies examining the potential impacts of climate change on agriculture have used either biophysical crop analysis approach such as CERES-maize and EPIC models, statistical approach, mathematical programming methods, or input-output analysis approach to analyze the impacts of climate change on maize production (Chen et al., 2004, Carlton et al., 2012; Deschênes and Greenstone, 2007; Kane et al., 1989; Kaiser et el., 1993; Lobell and Burke, 2010; Mendelsohn, 1994; Phillips et al, 1996; Piao et al., 2010; Rosenzweig et al., 2002; Schlenker and Roberts, 2008; Tan and Shibasaki, 2003; Tao et al., 2008; Wang et al., 2009; Xiong et al., 2008; Yuan et al, 2011). Typically, CERES and EPIC are two representative models that are widely used among scientists to examine the biophysical relationships between weather and crop yields.

Among previous studies that examined the overall effects of climate change on maize production at the global or national levels (e.g., Deschênes and Greenstone, 2007; Li et al., 2011; Phillips et al, 1996; Rosenzweig et al, 2002; Schlenker and Roberts, 2008; Tan and Shibasaki, 2003; Yuan et al 2011), Tan and Shibasaki analyzed the impacts of climate change on crop productivity and yields at the global level with the GIS-based EPIC model. They indicated that climate change may bring negative impacts on crop yields in most countries in the world, implying that the adaptation is important to mitigate climate change damages. Phillips et al (1996) focused the analysis at the national level and analyzed the potential impacts of climate change and associated CO_2 increases on maize yields and soybean yields in the US Corn belt, pointing out the variations in temperature, precipitation, and atmospheric CO_2 concentration could bring either positive or negative effects on crop yields. Another representative study undergone by Rosenzweig et al (2002) used a CERES-maize model to examine the seriousness of maize crop damage in the American Midwest, the major grain production region in the U.S. They concluded that soil moisture at the current climate condition is already abundant and a further increase in excessive soil moisture caused by the climate change-induced excessive precipitation events could lead to the loss of the US maize production outputs double in the next thirty years.

Among statistical and mathematical programming methods, a representative focal point is on the impacts of climate change on the economic perspective of agriculture, such as land values, farm revenues, and crop price. Mendelsohn et al (1994) is one of those studies. They examined the impacts of climate factors on land productivity as measured by land price. This Ricardian approach examined the direct impacts of climate change on land values using cross sectional data for almost 3000 counties in the 48 contiguous states in the United States in 1982 (Mendelsohn 1994). They noticed the estimated negative impacts brought about by climate change on the US agriculture are lower than those predicted in the traditional crop-climate biophysical relationship models, and pointed out that climate change could have positive economic effects on agriculture. Kane et al (1989) on the other hand found a doubling of atmospheric CO_2 concentration could cause a decrease in the world crop production outputs, which in turn could lead to a significant increase in the market crop price.

For other studies, the links between climate change and crop yields are first examined with CERES models or EPIC models, and the results are then further processed in other models to analyze the cascading effects of climate change on the economic perspective of agriculture (Kaiser et el. 1993). Even so, the future yield itself is derived using biophysical factors only.

In terms of input-output analysis approach, the interrelationships between physical inputs and outputs are focused. The study undergone by Yuan et al (2011) used this approach and examined the direct effects of production inputs on final crop outputs.

All in all, while the crop yield simulation models analyzed crop yields with climatic, soils, and cultivar variables, Ricardian statistical model analyzed the land values, input-output production function on the other hand focused the effects of production inputs on final outcomes, they virtually ignore the importance that both climatic and economic variables, such as price or profitability, simultaneously affects the crop production. In addition, technology improvement is often ignored in these models.

In recent years, some scholars indicated that the relatively stable crop prices over the long term in the past inhibit yield-enhancing technology development, which in turn eliminates a further growth of maize yields. In reality, however, technology developments always exist despite the existence of climate change impacts on crop yields. To demonstrate that the past analytical points are discrepant from the reality, to accurately reflect how maize production outputs respond to climatic change, and to interpret the important role of farmers' gradual technological adaptation in maintaining or raising maize production over the medium to long term, the econometric model, Cobb-Douglas functions and converted supply functions in the following studies incorporated climatic and economic factors, as well as technological improvement factor.

The purposes of this thesis are to extract the true effects of climate change on maize production and to simulate the potential impacts of climate change on maize production. Analyses of climate change on maize production in case studies 1 to 3 differ from other studies in that they included the consideration of national and regional climatic, geographic, and socioeconomic differences in China and the U.S. By doing so, a clear vision of causality links can be captured and the possible policy solutions to mitigate potential climate change induced damages can then be proposed. Additionally, three studies in this thesis focused the relative national and regional advantages and characteristics in China and the United States. The potential differences in national and regional responses of maize production to climate change provide useful information on how China and United States may adapt to climate change through international cooperation and shifts in regional production.

Over the years, given the background of large population and progressive aging issues, many scholars consider that future food self-sufficiency in China is unsustainable and risky. The scholar Lester Brown (1995) is one of those scientists supporting this view. In his book "Who Will Feed China? Wake-Up Call for a Small Planet" (Worldwatch Environmental Alert Series), he pointed out that the fast growing population and loss of croplands will make food self-sufficiency in China unsustainable in the near future, which in turn will push the global food prices to rise as China will import a significant amount of agricultural products from the global market (Elizabeth 1995; Lester 1995).

In another study that analyzed Chinese food self-sufficiency, Gerhard et al (2000) focused the maximum grain production potential in China under both rain-fed and irrigated conditions. With the agroclimatic model, they found that China can produce some 492 million tons of grains under the current water use and technology condition. If the diet alters, some 672 million tons are required to meet the increased grain demands in 2025, more than the amount the current technology level can provide. They also pointed out that irrigation can help grain production meet the possible demand, and hence they concluded that water conservation is the key element to the Chinese agriculture.

In comparison with analysis results proposed by Gerhard et al (2000), Peng (2011) is more optimistic about the future Chinese agriculture and pointed out China can maintain its food self-sufficiency without the foreign help in the near future. He pointed out that the continuous urbanization accompanying with economic growth will reconstruct the residential land uses in rural areas, and these lands accompanying with the converted lands from the march and the flood lands added together will become new cropping lands, resolving the potential land shortage issues in China (Peng 2011). He also pointed out policy adjustments, investment, and education will continuously work together to combat against various agriculture problems, and the faster melting glaciers induced by climate change in the western regions of the country could become a new water resource for agricultural irrigation (Peng 2011).

Though land conversion is one of approaches that can be used to solve short-term agricultural land shortage problems, environmental repercussions of such a practice are large and irreversible. More environmental friendly practices and solutions are required to support the continuous economic growth of the country. Hence, this thesis also aims to provide alternative environmental friendly policy strategies to efficiently combat against climate change induced crop reduction problems and to support future risk mitigation programs.

Chapter III. CASE STUDY 1: The impacts of climate change on maize yields in the United States and China and the implications of international cooperation

3.1 Purposes and background of this study

The purposes of this case study are to extract the true effects of climate change on maize yields in the major maize production regions in the U.S. and China, to predict the potential impacts of climate change on maize yields in these regions, and to propose advanced risk mitigation strategies to solve potential climate change induced maize reduction.

Diverting from previous studies, the regression model used in this case study simulated the effects of climate change on maize yields with the consideration of the combined effects of climatic and economic inputs, as well as technology improvement. Geological and socioeconomic differences between different countries and regions are also considered in the analytical model.

3.2 Materials and Methods

3.2.1 Study Sites

Maize production in the United States and China accounts for over 50% of total world maize production. Thus, the potential impacts of climate change on maize yields in these two important maize producing countries are analyzed. While the distribution of maize production in the United States is clustered in the Midwest, maize production regions in China appear to be patchy (Table 3.1). Owing to the geological and climatic advantages, Middle China, where its maize production accounts for 38% of China's total, has been designated as an important production region, which is known as the "Summer Corn Belt" (Figure 3.1). The Midwest in the U.S., on the other hand, can produce 77% of total U.S maize and is known as the "Corn Belt" of the U.S. (Figure 3.2).

For both countries, maize is a critical crop in sustaining human lives in terms of its role as a major grain commodity, a feed commodity, and a significantly important renewable bioethanol energy source.

Thus, the impacts of climate change on maize yields in eight major maize producing states in the Midwestern United States (Iowa, Illinois, Ohio, Indiana, Nebraska, South Dakota, Wisconsin, and Minnesota), ranging from 37° to 48° north by latitude, 80° to 103° west by longitude, and five major maize producing provinces (Shandong, Hebei, Henan, Shanxi and Shaanxi) in middle China, ranging from 33° to 39° north by latitude, 108° to 119° east by longitude, are the focus of this research (Table 3.1, Figure 3.1, and Figure 3.2).

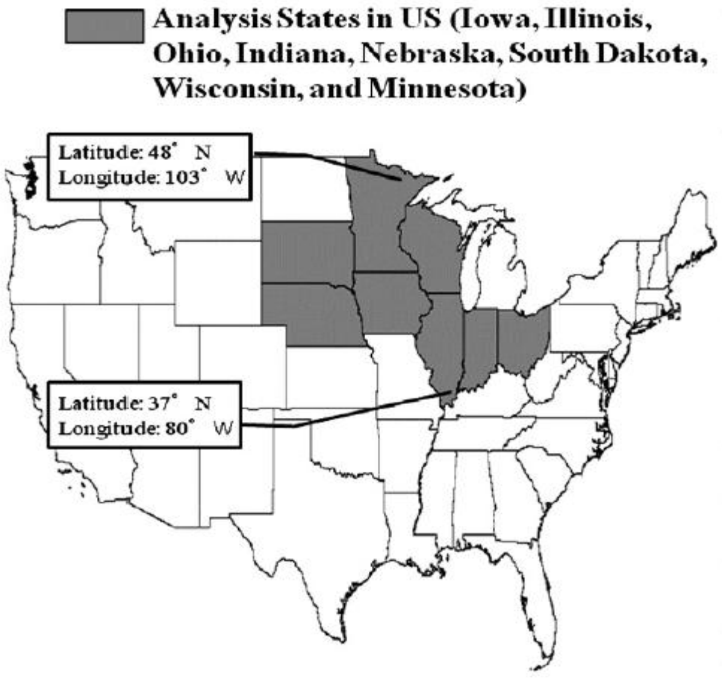
Table 3.1. Maize production regions in the Midwestern United State and Middle China

Country, Region (Plantation patterns)	**Geographic Position (Latitude)**	**Geographic Position (Longitude)**	**Regional Province/State (Description)**
U.S, The Midwestern region (the U.S. "Corn belt" (clustered)	37°N ~48 °N	80°W~103°W	<u>U.S Corn Belt</u> (8 states) 1. Iowa 2. Illinois 3. Nebraska 4. Minnesota 5. Indiana 6. Ohio 7. Wisconsin 8. South Dakota
China, Middle region, (patchy)	33°N~39°N	108°~1119°E	<u>Middle Region</u> (5 provinces) 1. Shandong, 2. Hebei, 3. Henan, 4. Shanxi, 5. Shaanxi

Provinces in China	% of maize production contribution each province has on China total (Ave1988-2007)
Shandong	12.54
Hebei	9.24
Henan	8.89
Shanxi	3.54
Shaanxi	3.36
Total	37.57

Fig. 2. Geographic range of maize production in Middle China.

Figure 3.1 Geographic range of maize production in Middle China



States in U.S.	% of maize production contribution each state has on US total (Ave1988-2007)
Iowa	18.64
Illinois	16.69
Nebraska	11.92
Minnesota	9.31
Indiana	8.24
Ohio	4.61
Wisconsin	3.88
South Dakota	3.53
Total	76.82

Figure 3.2 Geographic range of maize production in the Midwestern United State

3.2.2 Overall Structure of the model

Examining the impacts of climate change on maize yields with only climatic factors considered should overestimate the true effects of climate change on maize yields. Moreover, technology improvement over the long term may mitigate the negative impacts of climate change on maize yields. Thus, the model developed for this case study analysis differs from many previous models in that it accounted for national and regional climatic, geographic, and economic differences. This case study also differs from others in that the analysis included the consideration of the combined effects of climate variables, economic variables, and technology improvement variable on maize yields.

Linkages among climatic, economic, technology improvement and maize yield components in the model to analyze the impacts of climate change on maize yields and their relationships are illustrated in Figure 3.3. Temperature and precipitation as the two main climatic factors that are directly altered by climate change and correspond to the planting and developing time of maize crop are chosen for consideration in the model.

The ‘‘CO_2 fertilizer effect’’ which could possibly enhance maize yields with elevated atmospheric CO_2 concentration is a controversial topic among scientists, and how the interactions of this effect with other environmental factors work is also uncertain (Kaiser et al., 1993; Kaiser and Crosson, 1995). Furthermore, yield enhancement effects brought by an increased level of atmospheric CO_2 concentration are often examined under a controlled experimental environment where an extremely high concentration of CO_2 closes to the examined crop plants is released. Thus, under the current climate condition where the atmospheric CO_2 concentration is not extremely high, analyzing the links between CO_2 and maize yields is difficult. Based on these reasons, CO_2 fertilizer effect is assumed to have no enhancing effects on maize yields in this case study.

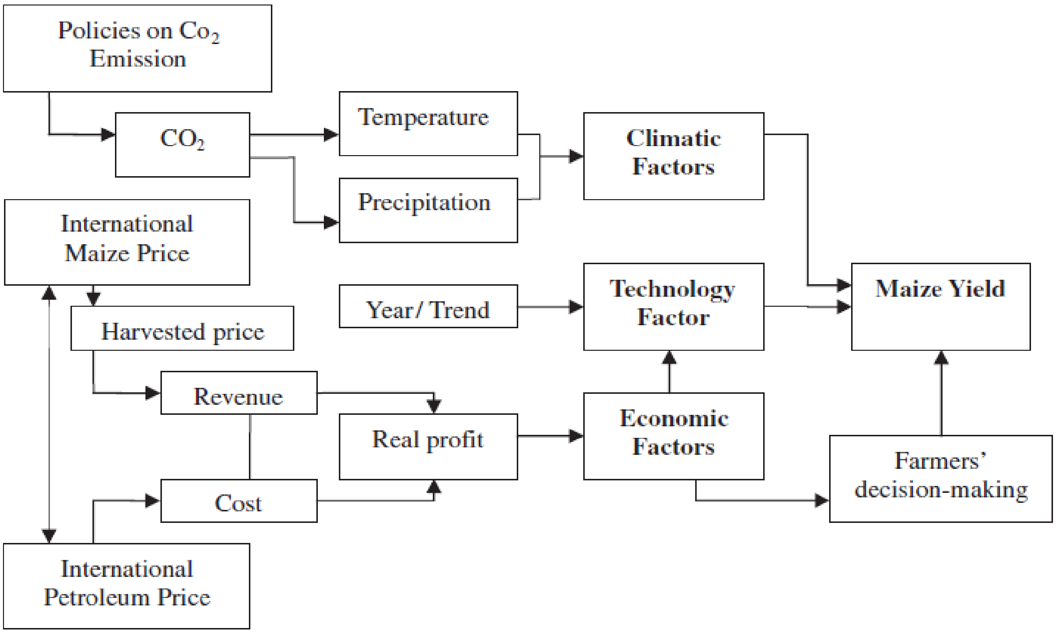


Figure 3.3 Empirical model structure in this study

3.3 Model Variables

3.3.1 Climate variables

Whether or not a good harvesting result can be obtained each year is greatly affected by the climate conditions in the planting season and growing season of that year. The planting season refers to the time when seeds sprout from the soil and the early-staged leaves emerge, and the growing season (vegetative stage, silking stage, and grain-filling stage) prior to the harvesting season refers to the time period when maize grows and develops. In specific, temperature and precipitation in the planting stage, silking stage, and grain-filling stage of maize can significant impact the final yields of maize. Thus, whether each year's maize yields are high or low are directly affected by climate conditions in these stages. Since the elevated atmospheric CO_2 concentration is assumed to have no enhancing effects on maize yields in this case study, instead of directly incorporating this factor into the models, CO_2 factor is indirectly implemented in the model through the IPCC's CO_2 projection scenarios and the corresponding variations in temperature over the period 2008-2030 (IPCC 2007).

For analyses about the U.S. and China, data on average monthly temperature and average monthly accumulated precipitation that correspond to maize's planting season and growing season (maize's vegetative stage, silking stage, and grain-filling stage) over the period of 1988-2007 are collected (Table 3.2).

Table 3.2 Months corresponding to the analysis period of the maize life cycle stages in the Midwestern United States and Middle China region

	US	China Middle
Planting	April May	June
Growth Vegetative stage	June	July
Growth Silking stage	July	July August
Growth Filling stage	August	August
Harvesting	September to October	September

Along with the progress of global warming, maize crop in the higher latitude may be forced to face a never experienced climate change challenge in the future. Given the background of such a possibility, temperature and precipitation in the colder provinces/ states in the higher latitude as well as the warmer provinces/ states in the lower latitudes are equally weighted in the model.

In the Midwestern United States, maize production schedule is earlier than middle China (Table 3.2). While April to May corresponds to the planting season; June to August corresponds to the growing season, September to October corresponds to the harvesting season of maize (Table 3.2). Over the growing stage of maize, June corresponds to the maize's vegetative stage; July and August correspond to the maize's silking stage and grain-filling stage.

In the U.S., each state is classified into one climate division and in most cases 8 to 10 districts compose one climate division (NOAA 2009). Data on average monthly temperature and average monthly accumulated precipitation at each state's district level is available. Thus, time series and cross sectional climate data in the 8 Midwestern United states, covering Iowa, Illinois, Nebraska, Minnesota, Indiana, Wisconsin, South Dakota, and Ohio in maize's planting and subsequent growing season were first collected (Table 3.3).

Table 3.3 Geographic ranges of analyzed states in the Midwestern United States

Country, Region	State	Geographic ranges
U.S, Midwest	Iowa	Latitude: 37°N ~ 48 °N; Longitude: 80°W ~103°W
U.S, Midwest	Illinois	Latitude: 37°N ~ 48 °N; Longitude: 80°W ~103°W
U.S, Midwest	Nebraska	Latitude: 37°N ~ 48 °N; Longitude: 80°W ~103°W
U.S, Midwest	Minnesota	Latitude: 37°N ~ 48 °N; Longitude: 80°W ~103°W
U.S, Midwest	Indiana	Latitude: 37°N ~ 48 °N; Longitude: 80°W ~103°W
U.S, Midwest	Ohio	Latitude: 37°N ~ 48 °N; Longitude: 80°W ~103°W
U.S, Midwest	Wisconsin	Latitude: 37°N ~ 48 °N; Longitude: 80°W ~103°W
U.S, Midwest	South Dakota	Latitude: 37°N ~ 48 °N; Longitude: 80°W ~103°W

In middle China, annual accumulated heating degrees over 10°C are between 4200-5500°C (Liu and Chen, 2005). Due to geographic, climatic, and cultural differences within the nation, crops in this region are planted more than once in a year. According to farmers' customs, maize is generally planted in June, following the winter wheat harvest (Liu and Chen, 2005). In middle China, July and August correspond to maize's vegetative stage, silking stage, and grain-filling stage (Table 3.4). Since winter wheat is harvested in June, farmers in this region usually plant early-ripening varieties of maize, known as summer maize in China, to ensure the stable supply of maize grains to the market (Liu and Chen, 2005).

Similar to the case in the Midwestern United States, data on average monthly temperature and average monthly accumulated precipitation are collected in the Middle China. Due to data access limitation in this region, climate data in only a limited number of weather stations are available. As a result, time series and cross sectional climate data in three climate stations that are the closest to the major maize producing sites in Middle China are chosen to collect the climate data (Table 3.4, China Meteorological Data Sharing Service System 2008).

Table 3.4 Climate stations chosen for analysis in Middle China

Country, Region	Climate Station	Climate station position by latitude and longitude
China, Shandong	Jinan 54823	36.40°N, 116.58°E
China, Shanxi	Taiyuan 53772	37.46°N, 112.32°E
China, Henan	Lushi 57067	34.05°N, 111.03°E

For both the Midwestern United States and Middle China, the collected data on average temperature and average accumulated precipitation in 8 states and 3 climate stations that correspond to the maize's planting season and growing season (vegetative stage, silking stage, and grain-filling stages) were separately pooled and averaged to estimate each of average temperature and average accumulated precipitation in maize's planting season and growing season in the Midwestern United States and the Middle China.

3.3.2 Economic variables

Based on the interviews with local farmers in the Midwestern United States and Middle China as well as the government researchers who are knowledgeable about agriculture and economics of two countries, it has been learnt that averages profits calculated from past years, among many factors that can affect farmers' decisions and actions, are important economic indicator for farmers. Since the time duration over the previous two-to-three years has key effects on farmers' decision-making, average real profit over the previous two-to-three years is used to be a key economic indicator in the models.

In this study, real profits, expressed in logarithm, are calculated from farmers' real revenues and real costs. To remove the effects of inflation, profit is deflated by the Consumer Price Index for all items in both countries and is therefore expressed in real terms.

In the US, prior to 1995 states with similar production styles were grouped in the same regions (USDA, 2009) and therefore data on revenues ($/planted acre) and costs ($/planted acre) in each state are collected from either the Plains States region or the North Central regions based on the old production region definition. Considering the diversities of farm activities, the US Farm Resource Region system is utilized from 1996 on (USDA, 2009). Thus, revenues (dollars/acre) and costs (dollars/acre) starting from 1996 are collected from Northern Great Plains, Heartland, or Prairie Gateway based on the new defined ERS US Farm Resource Regions system. Time series real profit data in each state are then derived from revenues and costs, and the results are pooled and averaged for the average real profits.

In China, each province is considered to be one unit and revenues (Yuan/acre) and costs (Yuan/acre) for each province is available. Time series profit data in five provinces are derived, pooled and averaged for the Middle China average real profits.

In terms of subsidy issue, it is treated differently in the U.S. and China. Based on WTO's rules and international treaties about crop subsidies, governments across countries agreed to decouple subsidies from agricultural production (USDA 2009). For that reason, subsidies in the U.S. are not officially added to the calculation of farmer's revenues in USDA's revenue statistics (USDA 2009). Thus, farmers' revenues, excluding subsidies, are used in the Midwestern United States maize yield analysis model in this case study.

Unlike the design of statistics in the U.S., subsidies are included in the calculation of farmers' revenues in China's national statistics (China Statistics Yearbook 1988-2007). Through the field survey in China, it has been learnt that subsidies only account for 2-3% of total farmers' revenue (He 2009). It has also been learnt that in China significant socioeconomic differences exist among provinces (He 2009). Due to these differences, people living in poorer provinces tend to move to richer provinces. Thus, subsidy provision, though the amount offered to farmers is small, has been a method used by the government to maintain the population structure among regions and to control large population movements within the nation (He 2009). Thus, the value differences between revenue that includes the subsidy in the calculation and the revenue that does not include the subsidy in the calculation are negligible. Based on above reasons, farmers' revenue data provided by the national statistics centre of China that include subsidies in their calculation are used in the Middle China maize yield analysis model in this case study.

3.3.3 Maize crop variable

For both the Midwestern United States and Middle China, annual maize production and planted area data in eight Midwestern states and five provinces were collected from the major maize producing states and provinces over the 1988-2007 period (Figure 3.1 and Figure 3.2, USDA, 2009; China Statistics Yearbook 2008).

Yields in states and provinces were estimated by having annual total production divided by planted area. The estimated yields in eight states in the U.S. and five provinces in China were separately pooled, averaged, and used in the models (expression: logarithm ln). Over the estimating process, instead of using harvested areas, data on planted areas were rather utilized to better catch the impact magnitudes of climate change on maize yields.

3.3.4 Technology Adaptation variable

A continuous adaption of technology has played a key role in reducing the negative impacts of climate change on maize yields in the real world. The technology adaptation will continue to help farmers maintain or increase crop yields in the future.

Usually, farmers adjust their agricultural practice styles and management methods, such as changing crop varieties for plantation or planting schedules, to combat climate change. Such a practice in turn ensures revenue stability. To catch the positive effects of farmers' gradual adaptation in mitigating the negative effects of climate change on maize yields in the reality, technology adaptation variable is purposely taken into the models. As a proxy for technology improvement over time, a linear time trend is included in the model (e.g., year 2007 is 2007). The use of the linear time trend term assumes that changes in technology improvement occur at a constant rate over time. Inclusion of this variable also allows simulating what would happen to maize yields with technology improvement in the future.

3.4 Empirical model

In both the Midwestern United States and Middle China, the following semi-optimized supply equation is estimated:

$$\ln(Y) = \beta_0 + d\text{TECH} + \beta_1 \ln(\Pi) + \beta_2 \text{wmT} + \beta_3 \text{wmT}^2 + \beta_4 \text{wmP} + \beta_5 \text{wmP}^2 \qquad (1)$$

where Y is the maize yields expressed as bushel/acre. β_0-β_5 are estimated coefficients. TECH is technology improvement. Π is average real profit in previous years. wmT is the weighted mean temperature in the key seasons of maize's life, including planting stage and growing stage (vegetative stage, silking stage, and grain-filling stage). wmP is the weighted mean precipitation in the key seasons of maize's life, including planting stage and growing stage (vegetative stage, silking stage, and grain-filling stage).

Eq. (1) is estimated with time series and cross sectional data from the 8 regions in the Midwestern United States and 5 regions in the Middle China over the time 1988 to 2007. In the models, temperature and precipitation variable are partitioned into two seasons: (1) planting and (2) growing, and each are equally weighted in terms of influencing maize yields. A linear time trend as a proxy for technology improvement over time, assuming that changes in technology adaptation occurs at a constant rate over time, is included in the model to simulate what would happen to maize yields in the future with the technology improvement consideration.

3.5 Methods for Future Projections

To examine the potential effects of climate change on maize yields in the Midwestern United State and Middle China over the period 2008–2030, nine climate scenarios are simulated: (1) no change at the 2000 level, (2) mild change with adaptation, (3) moderate change with adaptation, (4) substantial change with adaptation, (5) extreme change with adaption (Table 3.5, Table 3.6, Table 3.7).

The consensus estimate of climatologists has been that the increase in atmospheric CO_2 concentrations will lead to an increase in the mean global temperature. Illustrated in the Table 5, the further future climate varies from the current level, the further climate scenario is to the right on the horizontal axis of the table. In Eq. (1), future changes of temperature over the period 2008–2030 are set corresponding to the projected changes in the Fourth Assessment Report of the Intergovernmental Panel of Climate Change (IPCC, 2007) (Table 3.5, Table 3.6, Table 3.7). Atmospheric CO_2 concentrations in different scenarios are processed accordingly with temperature scenarios (Table 3.7). Based on these projections, temperature changes in the simulation period 2008-2030 increase by 0.46°C (optimistic scenarios), 0.86°C (moderate scenarios), and 1.46°C (pessimistic and the extreme scenarios) above 2000 levels.

As for the precipitation projections, the relationships between temperature and precipitation are not as clear as those between temperature and CO_2 concentration. Though temperature can affect precipitation patterns, the complicated climate systems make predictions difficult (Stern 2008). Furthermore, a common agreement on future precipitation changes has not been formally set (IPCC, 2007). Accordingly, a sensitivity analysis on the effects of precipitation variation on maize yields is conducted in the simulation by increasing and decreasing each climate change scenario by 2.5% (mild scenario), 5% (moderate scenario), 10% (substantial scenario), 30% (extreme scenario) above/below 2000 levels (Table 3.8).

Table 3.5 Projected climate change scenarios

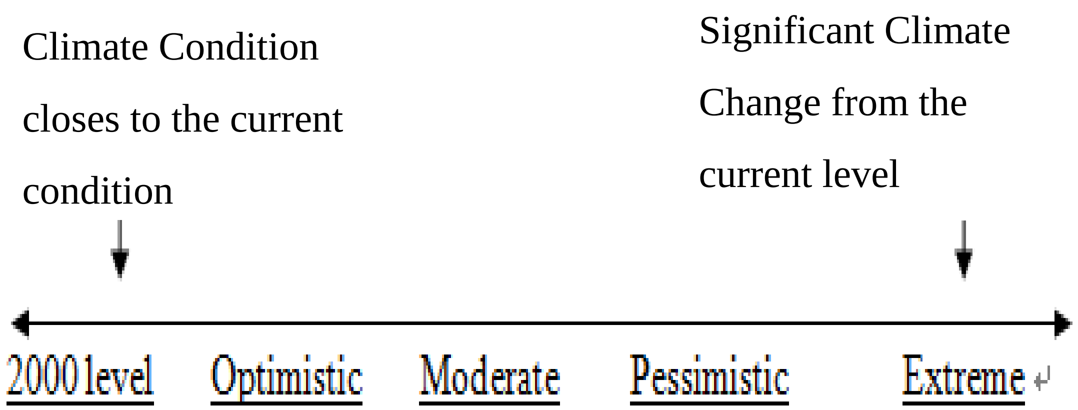


Table 3.6 Projected temperature changes corresponding to different levels of atmospheric CO_2 concentrations over the period 2008-2030 (IPCC, 2007)

Scenarios	CO_2 concentration in ppm (IPCC scenario)	Temperature changes (°C)
Staying at 2000 level	368 (IPCC A1 scenario)	No change
Optimistic	420 (IPCC A2 scenario)	0.46 °C increase
Moderate	462.5 (IPCC B scenario)	0.86 °C increase
Pessimistic and extreme	527.5 (IPCC C scenario)	1.46 °C increase

Table 3.7 Atmospheric CO_2 concentration and the corresponding temperature changes over the period of 2008-2030 (IPCC 2007)

Optimistic scenarios	**Optimistic Scenarios**	**Optimistic temperature**
IPCC A2 Scenario (year 2008-2030) Co2 concentration (ppm)	IPCC A2 Scenario Co2-eq (ppm)	IPCC A2 Scenario Global mean temperature (°C)
350-400	445-490	2.0-2.4
400-440	490-535	2.4-2.8
The corresponding temperature changes over the period of 2030-2000	(2.6°C -2.14°C =0.46°C)	0.46 degree Celsius increase
Moderate Scenarios	**Moderate Scenarios**	**Moderate temperature**
IPCC B Scenario (year 2008-2030) Co2 concentration (ppm)	IPCC B Scenario Co2-eq (ppm)	IPCC B Scenario Global mean temperature (°C)
350-400	445-490	2.0-2.4
440-485	539-590	2.8-3.2
The corresponding temperature changes over the period of 2030-2000	(3°C -2.14°C =0.86°C)	0.86 degree Celsius increase
Pessimistic Scenarios and Extreme Scenarios	**Pessimistic Scenarios and Extreme Scenarios**	**Pessimistic Temperature Extreme Temperature**
IPCC C Scenario (year 2008-2030) Co2 concentration (ppm)	IPCC C Scenario Co2-eq (ppm)	IPCC C Scenario Global mean temperature (°C)
350-400	445-490	2.0-2.4
485-570	590-710	3.2-4.0
The corresponding temperature changes over the period of 2030-2000	(3.6°C -2.14°C =1.46°C)	1.46 degree Celsius increase

Table 3.8 Description of 9 scenarios applied to the future projections

Staying at 2000 level Scenario1. Staying at 368 ppm CO_2 concentration level in 2030 (2000 level)	For future prediction, -2000 level temperature (average of 1988-2002) -2000 level precipitation (average of 1988-2002) - Economic component stays at exactly current level (2007 level) - Technology improvement (e.g., year 2007= 2007)
Optimistic Scenario2 (increase)/ Scenario3 (decrease). Staying at 420ppm CO_2 concentration level in 2030	For future prediction, - 0.46°C temperature increases (above 2000 level)[7] - 2.5% precipitation increases/ decreases (above /below 2000 level) - Economic component stays at exactly current level (2007 level) - Technology improvement (e.g., year 2007= 2007)
Moderate Scenario4 (increase)/ Scenario5 (decrease). Staying at 462.5 CO_2 concentration level in 2030	For future prediction, - 0.86°C temperature increases (above 2000 level) [7] - 5% precipitation increases/ decreases (above/ below 2000 level) - Economic component stays at exactly current level (2007 level) - Technology improvement (e.g., year 2007= 2007)
Pessimistic Scenario6 (increase)/ Scenario7 (decrease). Staying at 527.5 ppm level in 2030	For future prediction, - 1.46°C temperature increases (above 2000 level) [7] - 10% precipitation increases/ decreases (above/ below 2000 level) - Economic component stays at exactly current level (2007 level) - Technology improvement (e.g., year 2007= 2007)
Extreme Scenario8 (increase)/ Scenario9 (decrease). Staying at 527.5 ppm level in 2030	For future prediction, - 1.46 °C temperature increases (above 2000 level) [7] - 30% precipitation increases/decreases (above/ below 2000 level) - Economic component stays at exactly current level (2007 level) - Technology improvement(e.g., year 2007= 2007)

3.6 Results

For both the Midwestern United State and the Middle China, the same modeling method is applied and the estimation results are presented in Table 3.9. The results indicate that the climatic and economic variables in the two countries have different effects on maize yields.

Table 3.9 Regression results of the Midwestern United States and Middle China (data over 1988-2007 are used)

Explained variable, (yield)	The Midwestern United States	China Middle
Explanatory variables	Coefficients (t-value)	Coefficients (t-value)
Constant	-50.89 (-4.9)	-33.62 (-1.6)
TECH	1.87×10^{-2} (3.9)	6.89×10^{-3} (3.2)
In(π)	1.91×10^{-1} (2.1)	1.88×10^{-1} (2.3)
wmT	1.79 (1.8)	1.85 (1.1)
wmT^2	-5.40×10^{-2} (-1.8)	-3.86×10^{-2} (-1.1)
wmP	5.96×10^{-2} (1.9)	9.05×10^{-3} (2.4)
wmP^2	-3.37×10^{-4} (-2.2)	-4.00×10^{-5} (-2.1)
R squared	0.85	0.80
Adjusted R squared	0.76	0.69
D.W.	2.91	2.10

Data source: NOAA, 2009; China Meteorological Data Sharing Service System, 2008; USDA, 2009; China Statistics Yearbook, 1988-2007

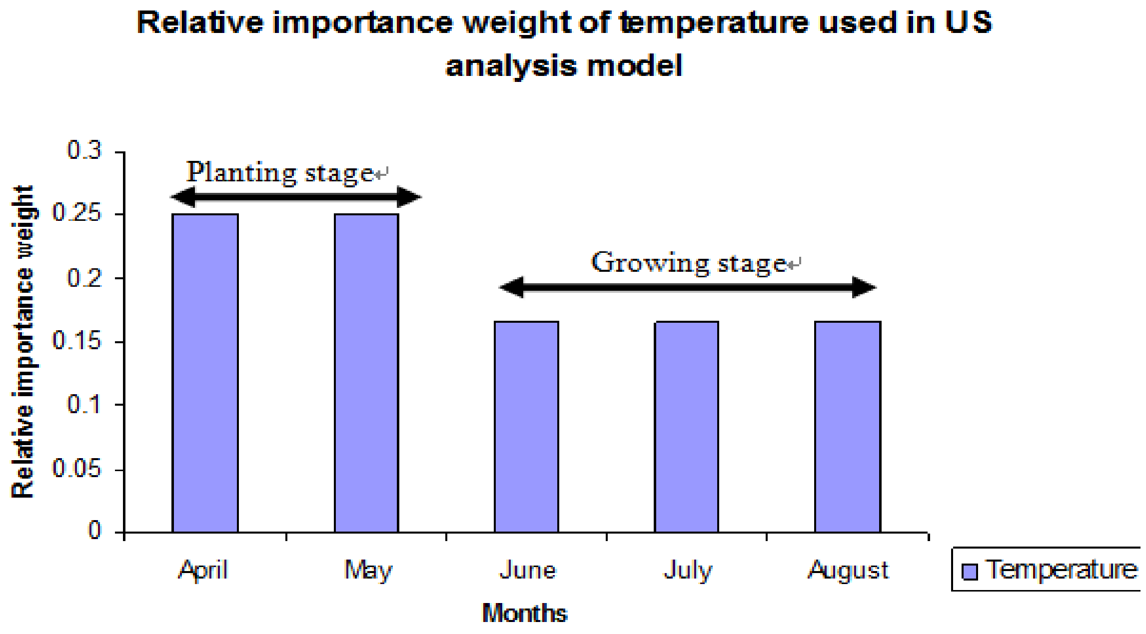
3.6.1 Midwestern United States

In the Midwestern United States, due to its geographic latitude range, maize is planted starting from April (Table 3.2). While April to May corresponds to the planting season, June to August corresponds to the growing season (vegetative stage, silking stage and grain-filling stage), September to November corresponds to the harvesting season of maize (Table 3.2). Since climate condition in maize's planting season decides the number of seed sprouts, and climate conditions in maize's growing season decides the successful development of maize, 50% weight is separately assigned to each of climate variables in these two seasons (Table 3.9, Figure 3.4). In the Midwestern Untied States, average annual precipitation at the 2000 level is slightly high (834.46mm). Thus, water is not a limiting factor in this region (Rosenzweig et al., 2002).

Based on the interviews with local farmers and government researchers, it has been learned that average real profit over the previous 3 years is an important economic indicator (Table 3.9). The confirmation of profit trend over the past years allows farmers to understand the overall cost and benefit balance of maize production in the past years, and to estimate the potential costs and benefits in the future. Average real profit in the past years helps farmers to minimize the risks of having a large crop reduction.

The modeling result showed that a 1% increase in average profits in the previous 3 years in the Midwestern United States could increase maize yields by 0.191% (Table 3.9). While inelastic in magnitude, the positive relationship between profit and maize yield indicates that a higher profit links to a higher economic incentive of farmers to increase yields.

The coefficient of technology variable is also higher in the Midwestern United State (Table 3.9). Since the United States is a leading country in the R&D of agriculture sector, new technology can be applied to the reality in a relatively shorter term to increase maize yields. Thus, it is reasonable that the annual growth rate of technological progress appears to be 1.9% in the Midwestern United States.



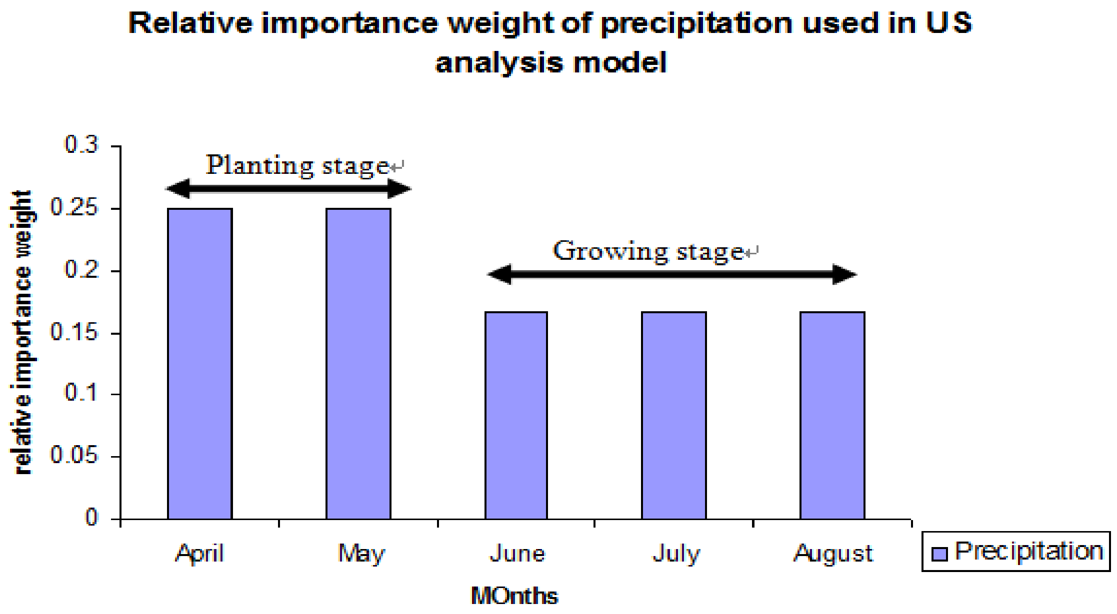


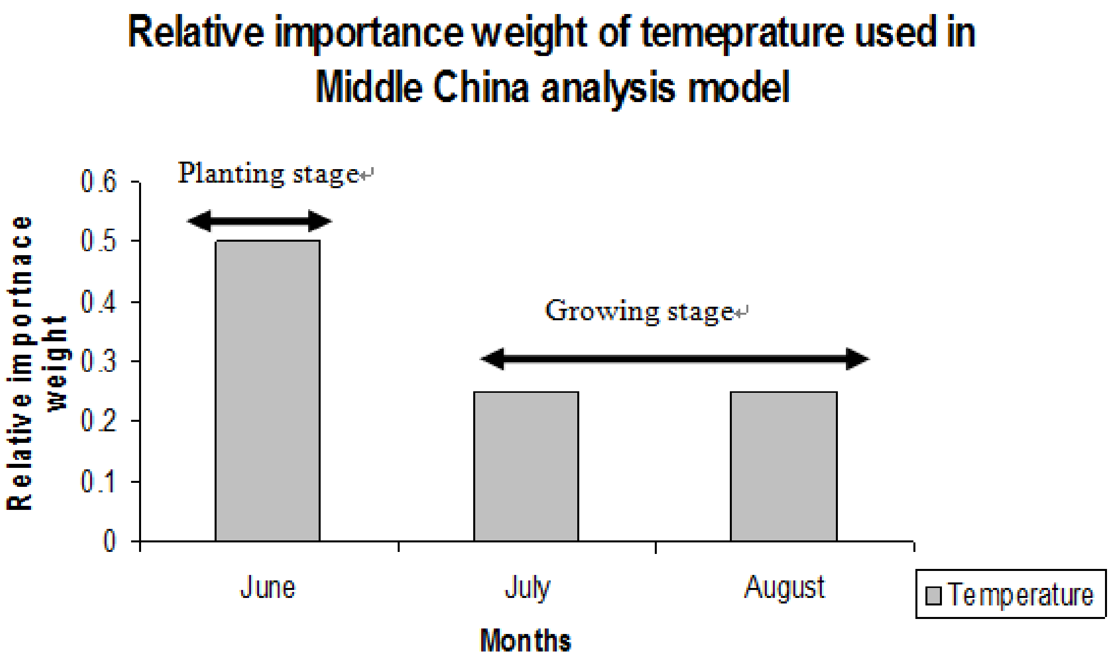
Figure 3.4 Relative importance weights of temperature and precipitation used in the Midwestern United States maize yield analysis model

3.6.2 Middle China

Middle China is located in lower latitude. Comparatively, annual accumulated heating degrees over 10°C are between 4200 and 5500 °C (Liu and Chen, 2005). Thus, multiple-crops can be planted more than once each year in this region. Because of warmer annual temperature, in June, following the winter wheat harvest, the planting season for maize begins in this region (Table 3.9 and Figure 3.5). While June corresponds to the planting season, July to August corresponds to the growing season of the maize (Figure 3.5). To ensure a good harvest of maize within a relatively shorter growing time period, farmers in Middle China often choose early-yielding varieties, known as "summer maize", for plantation (Liu and Chen, 2005). Similarly, 50% importance is separately assigned to each of climate variables in both the planting and growing seasons (Figure 3.5).

In the Middle China, average real profit calculated from the previous 2 years is found to be a significantly important factor affecting maize yield results. A 1% increase in average profits in the previous 2 years is found to increase maize yields by 0.188%, closes to the result of the Midwestern United States. The positive coefficient value indicates a positive relationship between the profit and maize yield.

Comparatively, the annual growth rate of technological progress is much lower (0.7%), as the mechanization level is still low compared to that in the Midwestern United States.



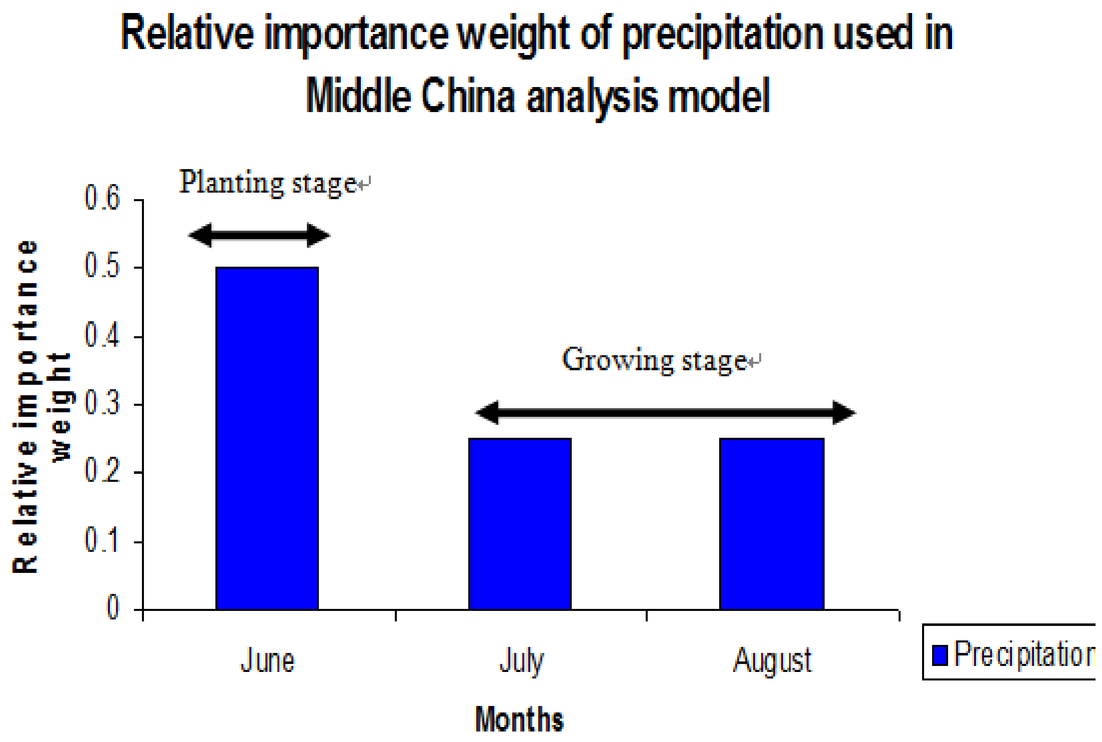


Figure 3.5 Relative importance weights of temperature and precipitation in Middle China regional maize yield analysis model

3.7 Simulation outcomes

When the impacts of climate change on maize yields are analyzed with the consideration of technology improvement over the period 2008–2030, the simulation results are quite different in the Midwestern United States and Middle China. Under the same climate change scenario, an increase in both temperature and precipitation is found to have larger negative impacts on maize yields in the Midwestern United States; however, an increase in temperature with a decrease in precipitation instead is found to have larger negative impacts on maize yields in Middle China.

3.7.1 Midwestern United States

To examine the biophysical relationship between average temperature and the corresponding maize yields, economic and technology improvement factor are first controlled at the 2007 level. The estimated result shows that the average temperature over the analysis period of maize's key life stages (planting season and growing season of maize) at 2000 level (17.18°C) is slightly over the optimal maize's average temperature level (16.53°C) (Figure 3.7). The result indicates that if technology level is unchanged over 2030, a further increase in temperature could eliminate a further growth of maize yields. As stated earlier in this chapter, precipitation and soil moisture at the 2000 level in the Midwestern United States are already abundant. A further decrease in precipitation rather than a further increase in precipitation is better for maize growth in this region. Illustrated in Figure 3.6, extreme precipitation decreased scenario has a better effect on maize yield than extreme precipitation increased scenario.

When the links between average temperature (x-axis: maize silking stage, July, is focused) and the corresponding yields are analyzed with different combinations of temperature and precipitation, similar results is obtained (Figure 3.7). Under the same temperature changed scenario, an increase in precipitation has a worse effect on maize yields than a decrease in precipitation. For example, in an extreme situation where precipitation increases 30% above the 2000 level, maize yield is projected to reduce more than 30% precipitation decreased scenario under the same temperature. Given the background of abundant soil moisture contents, a further increase in precipitation could bring waterlogging problems to the land and causes damages to the crops. The result corresponds to the previous findings done by Rosenzweig et al (2002). Thus, it can be said that the reduced precipitation in the Midwestern United States is better for maize growth (Figure 3.7).

Though agronomists might argue that an increase in CO_2 level in the atmosphere could increase crop yields, obvious interrelationships between CO_2 changes and maize yields are not observed with analysis of past data. The results indicate that the effect of CO_2 changes on maize yields is small. Furthermore, impacts of CO_2 on maize yields are usually analyzed in a controlled environment where a high concentration of CO_2 is released to examine the responses of crop.

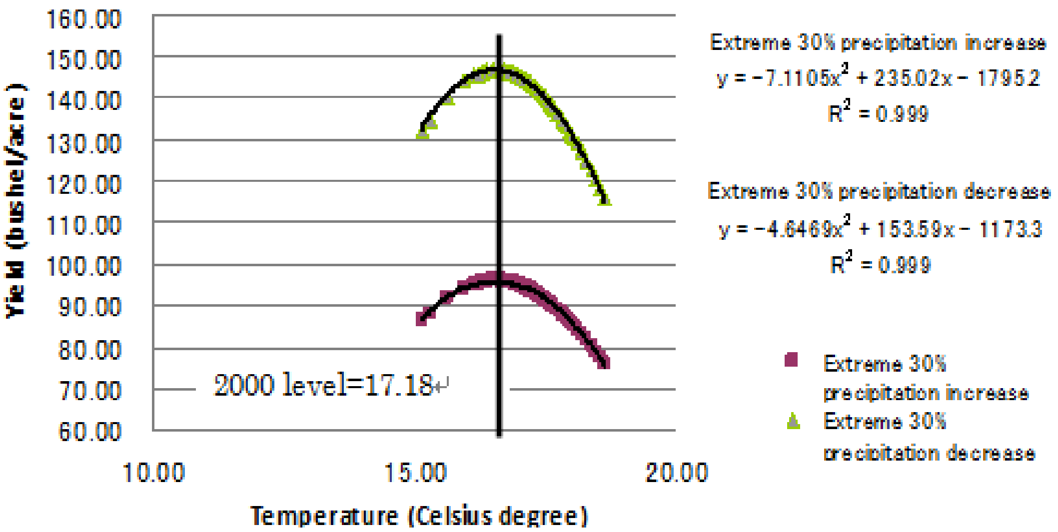


Figure 3.6 Relationship between average temperature and maize yields in the Midwestern United States (x-axis: average temperature over the maize's analysis period: planting season and growing season)

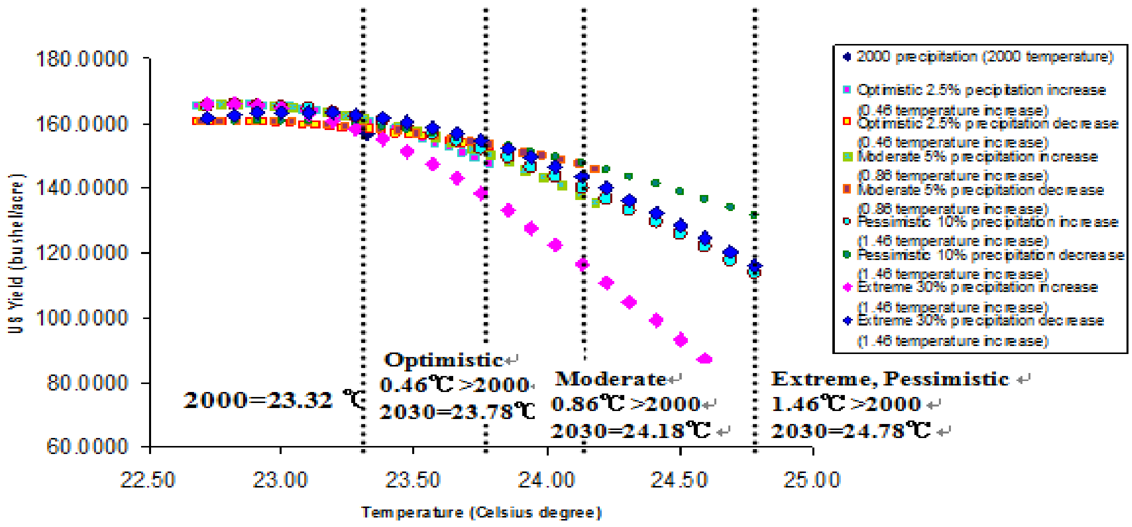
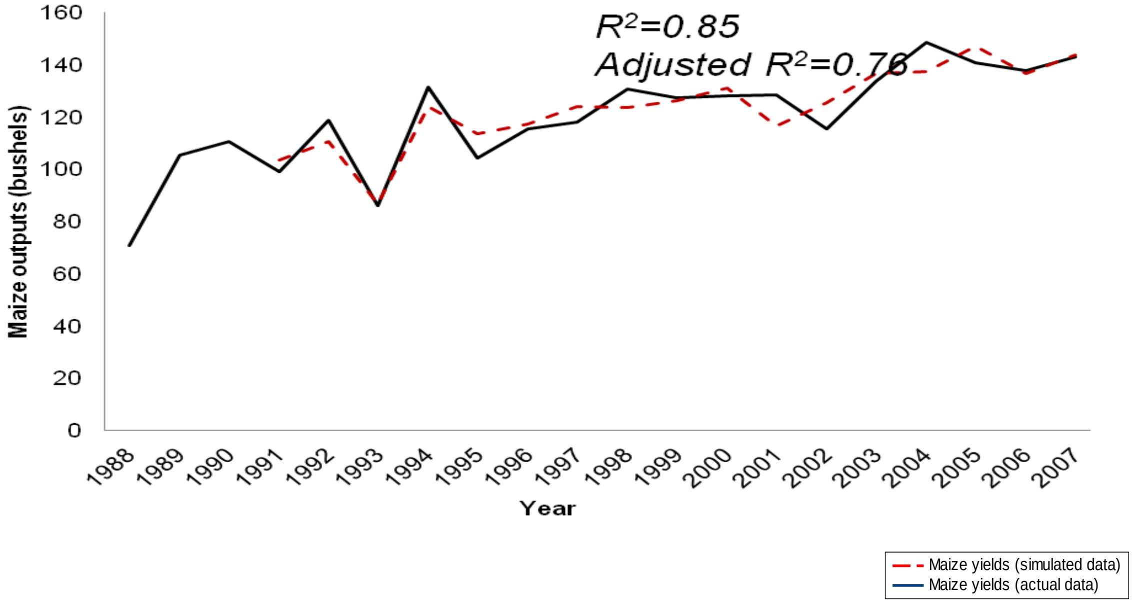


Figure 3.7 Variations of maize yields in the Midwestern United States with different combinations of temperature and precipitation

The projected results of maize yields under 9 climate scenarios in the Midwestern United States are presented in Figure 3.8.b Since water is not a limiting factor in this region, a further increase in precipitation rather than a further decrease in precipitation in the near future has a worse effect on maize yields. Alternatively speaking, the magnitude of the negative climate change impacts on maize yields can be mitigated when a decrease in precipitation accompanies an increase in temperature occurs. Over the projection period of 2008 to 2030, under the extreme scenario where temperature increases by 1.46 °C and precipitation increases by 30% above the 2000 level with technology improvement consideration, maize yields drop 7.44% from 125.99 bushels/acre in 2000 level to 116.62 bushels/acre in 2030 (Figure 3.8b). Under another extreme scenario where temperature increases 1.46°C and precipitation decreases 30% below 2000 level with technology improvement considered, maize yields increase 41.63% from 125.99 bushels/acre in 2000 level to 178.44 bushels/acre in 2030 (Figure 3.8).

a. Actual and simulated maize yields

(red line: simulated maize yields; black line: actual maize yields)



b. Nine simulated maize yield results in the Midwestern United States over the period 2008–2030

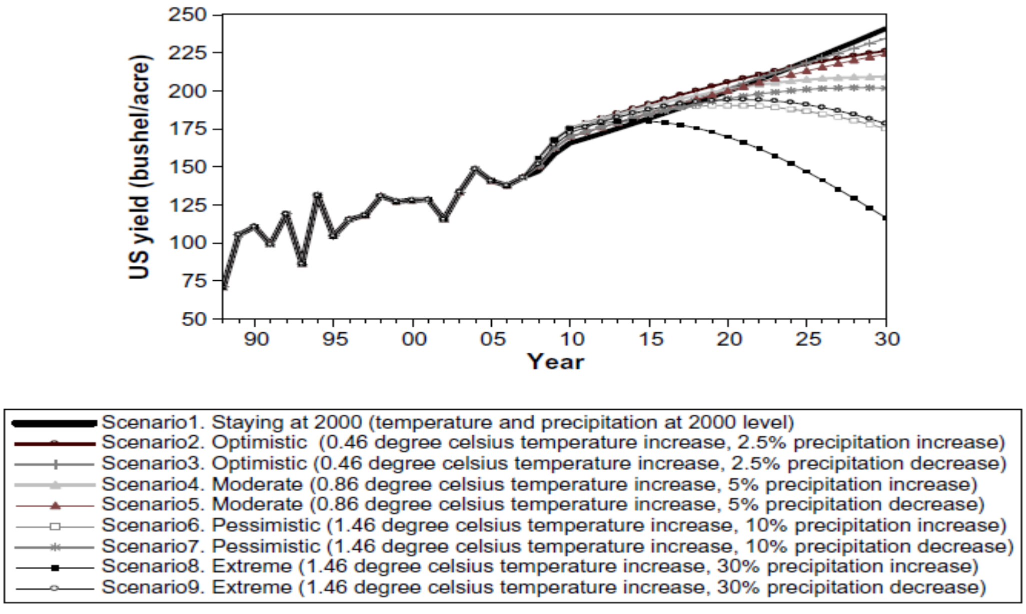


Figure 3.8 Comparison between actual and simulated maize yields and simulated nine maize yield results in the Midwestern United States over the period 2008–2030.

3.7.2 Middle China

In Middle China, the biophysical relationship between average temperature over the analysis period of the life stages of maize (the planting season and growing season of maize) and the corresponding maize yields are also examined under a condition where the economic factor and technology improvement factor are controlled at the 2007 level. The results are illustrated in Figure 3.9.

It has been noticed that average temperature over the analysis period at the 2000 level (average temperature=24.56°C) in this region is slightly over the optimal regional maize temperature level (23.97°C) (Figure 3.9). It has also been noticed that the modeling results are opposite to that in the Midwestern United States. An increase in precipitation instead of a decrease in precipitation shows a better effect on maize yields in Middle China. The result can be explained by regional precipitation's water deficiency cancelling effects.

In general, agricultural style in Middle China is highly weather dependent. The source of water for agricultural use mainly comes from precipitation. When future technology is unchanged from the current level, an increase in precipitation rather than a decrease in precipitation with an increase in temperature would increase maize yields in Middle China (Figure 3.9). When the relationships between average temperatures (x-axis, maize's silking stage, is focused) in July and the corresponding yields are analyzed with different combinations of temperature and precipitation, the same modeling results can be observed (Figure 3.10).

In middle China, over the entire growing season of maize in the summer, an increase in temperature can lead to a higher soil water evaporation rate. When water (e.g., precipitation) is not adequately provided under such a condition, water deficiency will become a problem and starts to affect maize production (He 2009). Since the water source for maize production in this region mainly relies on precipitation rather than irrigation, precipitation during the hot summer is the key in determining the results of maize production. Comparatively, an increase in both temperature and precipitation in Middle China has a significantly better effect on maize yield compared with the Midwestern United States. Under the same extreme climate change scenario where temperature increases 1.46°C and precipitation increases 30% above 2000 levels, maize yields in Middle China increase by 22.82% from 74.67 bushels/acre in 2000 level to 91.71 bushels/acre. Under another extreme climate change scenario where temperature increases 1.46°C and precipitation decreases 30%, maize yields in Middle China increase 10.70% from 74.67 bushels/acre in 2000 level to 82.66 bushels/acre in 2030 (Figure 3.11b).

The modeling results show that maize yields in different regions can vary significantly under the same climate change scenarios. Past studies analyzed the impacts of climate change on crop yields with regression models where climate variables are mainly considered, leading to low R squared of 0.54 (Lobell and Burke, 2010). In reality, other variables such as economic profit and technology improvement also play roles in mitigating the negative impacts of climate change. Thus, models without considering these elements might be deficient in extracting and capturing the overall climate change effect compared to our study where the R squared is 0.85 and 0.8 for the US and China. The previous study by Rosenzweig (2002) analyzed the impacts of climate change on maize yield with the CERES-maize model pointed out that the probability of crop damages due to excess precipitation on climate change could be 90% greater in 2030 compared to the 2002 level. Our results with climate variables, technology variable, and economic variables considered found that under extreme precipitation scenarios where 30% increase above 2000 level is estimated, the United States yields decrease 7.44% at a maximum; Middle China yields increase 22.82% (Figure 3.8 and Figure 3.11b).

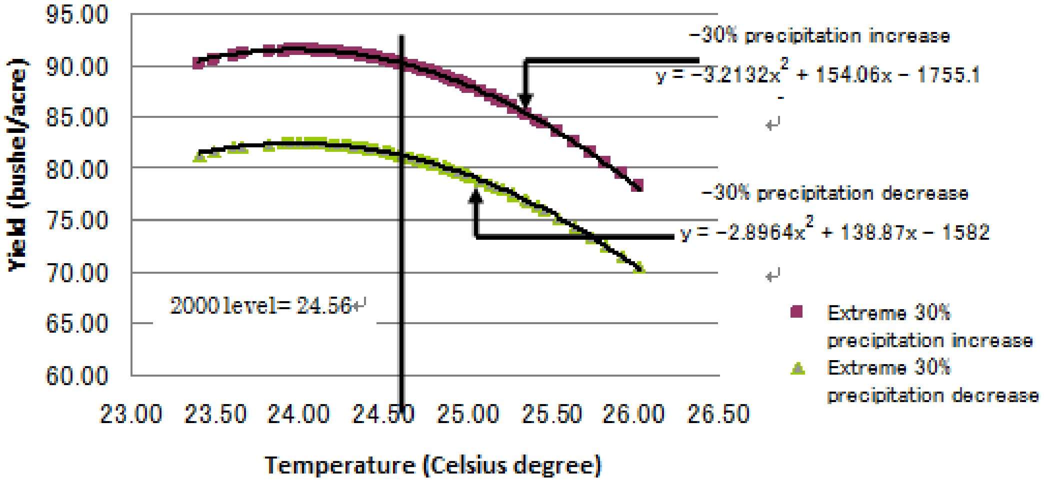


Figure 3.9 Relationships between average temperature and maize yields in the Middle China (x-axis: average temperature over the maize yield's analysis period: planting season and growing season)

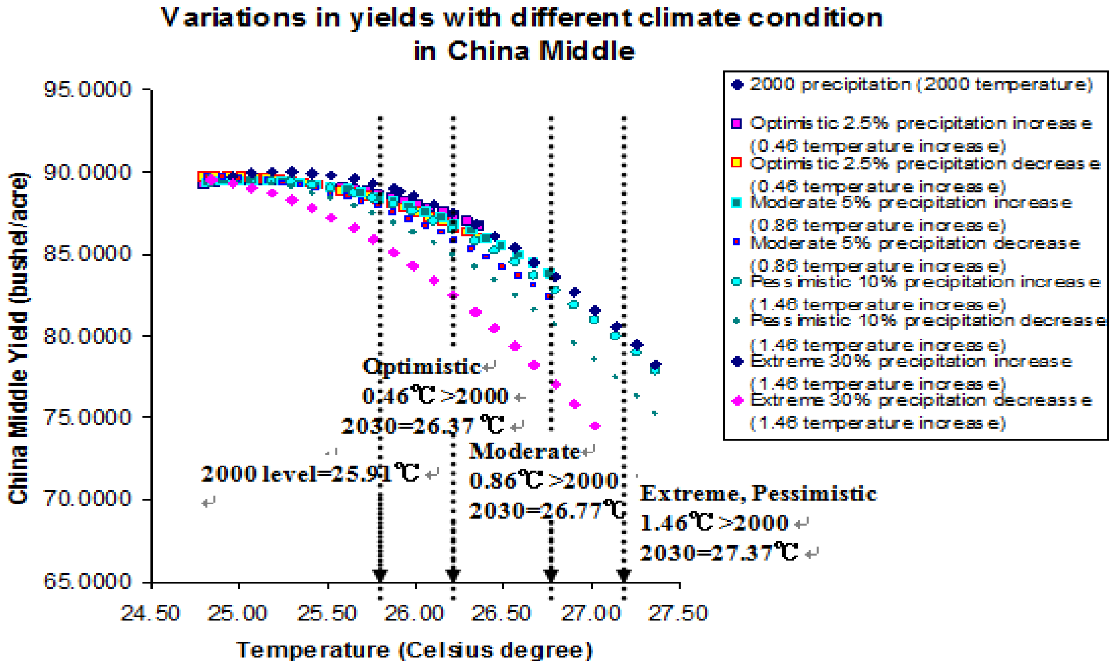
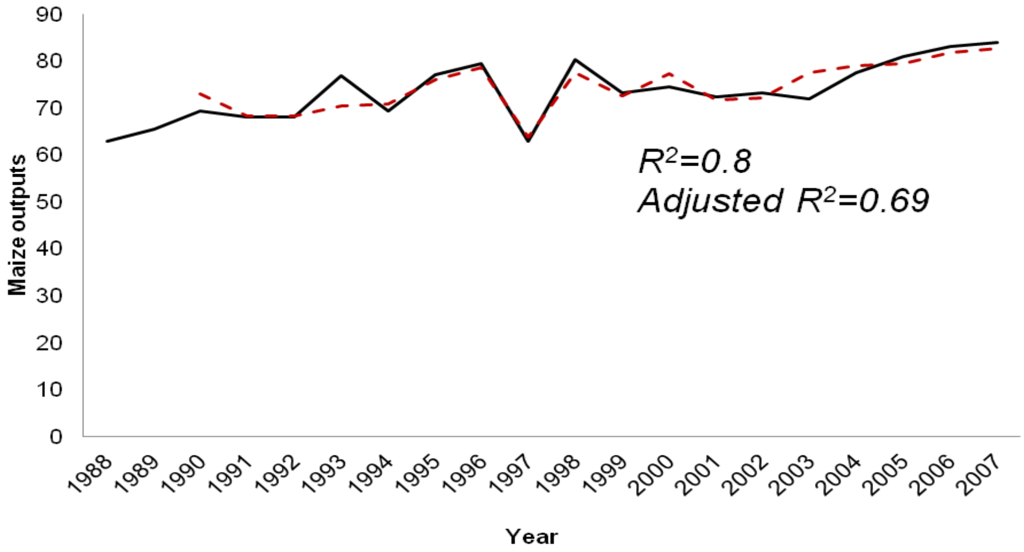


Figure3.10 Relationships between temperature and maize yields in different temperature scenarios in Middle China

a. Actual and Simulated data

(red line: Simulated maize yields; black line: Actual maize yields)



b. Nine simulated maize yield results in Middle China over the period 2008–2030

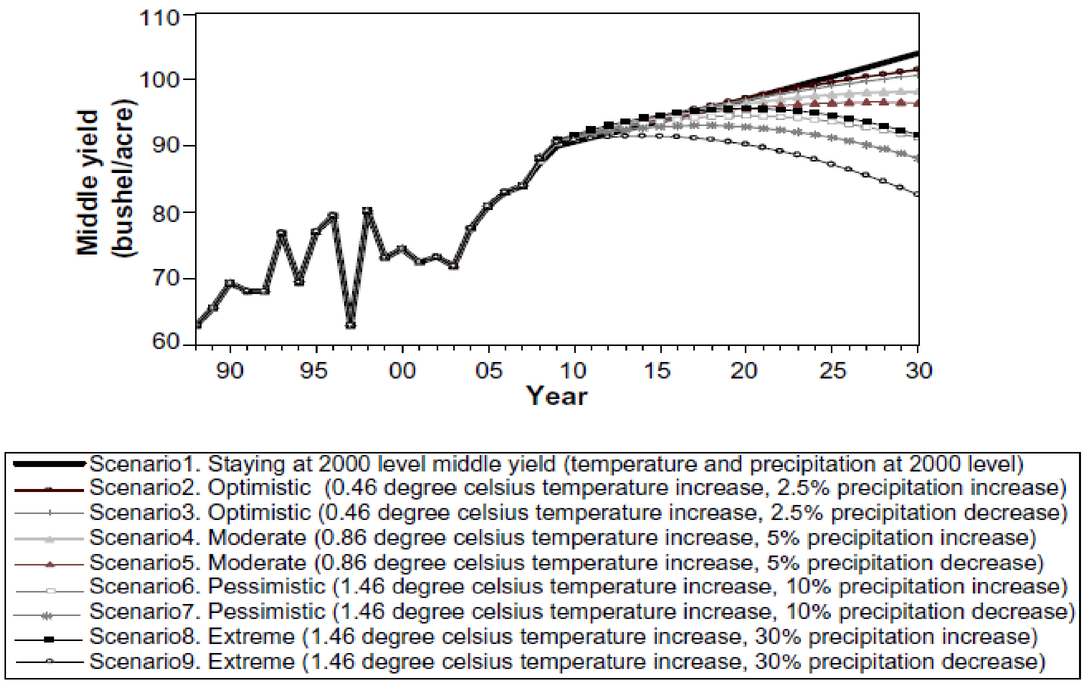


Figure 3.11 Comparison between actual and simulated maize yields and simulated nine maize yield results in Middle China over the period 2008–2030.

3.8. Implications

The simulation results indicate that the responses of maize are not uniform to the same climate change scenario in different parts of the world. Under the same climate change scenario, maize yields in China could increases, while maize yields in the United States could decrease. Such an opposite response suggests that freer trade in agriculture could be an important adaptation strategy to combat climate change. Further, if climate change substantially alters the relative comparative advantage of major maize-producing regions like the United States and China, greater specialization in maize production in the region benefited by climate change will also mitigate some of the negative effects of climate change on global maize production although the total supply of the two countries would stay more or less at the same level whether climate change results in increased precipitation or decreased precipitation.

To sustain overall maize production in the world and to reduce the possible maize shortage problems, the United State and China might want to establish a negotiated relationship regarding maize and maize-related products in a FTA format, where special duties or no duties should be imposed to maize crop and maize-related products imported and exported between two countries in order to avoid the risks of losing the countries' maize supply to an extreme degree. By establishing such a prior negotiation, the two countries could help stabilize the world maize supply.

Chapter VI. CASE STUDY 2: Impacts of climate change on maize production in Northeast and Southwest China and possible risk mitigation strategies

4.1 Purposes and background of this study

The effects of accelerated climate change on future Chinese agriculture have been predicted to be negative and fairly dramatic in the past studies. Variations in geographic, climatic, and socioeconomic conditions within the large country imply, however, that such effects may be significantly different across domestic regions. As the world's second largest producer (20%), second largest consumer (20%), and fifth largest importer (5%) of maize, China's production potential will have important implications for the global landscape of the agricultural industry. When the stability of maize production in major maize-producing countries like China becomes questionable under the combined pressure of climate change, structural changes of labor force, and the increased demand of renewable bioethanol energy, agricultural issues will not simply be concerns of a single country, but rather a world-wide issue.

Thus, the purposes of this case study are to analyze the effects of climate change, structural changes of labor force, and progressing mechanization on maize production in two important maize producing regions: the Northeast region and Southwest region and to project the potential future impacts with a regression model (Cobb-Douglas production function) and converted supply functions in the profit maximizing condition. This case study also aims to propose cost-efficient risk mitigation and management strategies to combat potential reduction in maize production to contribute to the stability of international market price in agricultural commodity.

4.2 Materials and Methods

4.2.1 Study Sites

Diverting from the study examined in the last chapter, this case study analyzes the effects of climate change on maize production in another two important Chinese

Farming Systems defined maize production regions in China: the Northeast region and the Southwest region (Table 4.1, Figure 4.1, Figure 4.2, Figure 4.3, Liu *et el*., 2005). Presented in Figure 4.1, the distribution of maize production in China is patchy. While the Northeast region is comprised of Liaoning, Jilin and Heilongjiang provinces, the Southwest region is comprised of Sichuan and Yunnan provinces. Though the Inner Mongolia also belongs to the Northern region, its lands size for maize production is limited to the eastern side of the province. Agricultural classification system in China also defines that the Northeast region is comprised of Liaoning, Jilin and Heilongjiang provinces, not Inner Mongolia (Liu and Chen, 2005). Furthermore, incorporation of Inner Mongolia data into the model appears to show no obvious interrelationships. Therefore, analysis of maize production in this case study is conducted without the consideration of Inner Mongolia province.

In this case study, the arguing point is that for a large country like China, the climate change effects on crop production can be significantly different across domestic regions due to variations in geographic, climatic, and socioeconomic conditions, and therefore the whole-country approach undertaken by the previous studies may have overlooked the possibility of inter-regional production cooperation strategies that could largely mitigate the negative outcome.

In Northeast region, agricultural lands in overall are flat and black soils are fertile. Thus, environment condition in this region is optimal for farmers to grow crops. Ranging from 40° to 47° north by latitude and 119° to 132°east by longitude, three provinces added together in this region are known to be the Chinese Corn Belt (Table 4.1, Figure 4.2). The effects of climate change and the structural changes of inputs such as population change on maize production in the Northeast region are analyzed with data collected from these 3 provinces.

Given the background of the optimal regional crop growing environment, maize production share in the Northeast region reaches to the 30% of total maize production amount in China, next to the level of middle China (maize production share is 37.57%) (Figure 2.1 and Figure 4.2). While Jilin produces 13.25% of total maize amount in the whole country, Heilongjiang province produces 9.28%, and Liaoning province produces 7.63% (Table 4.1, Figure 4.2).

Southwest region also plays an important role in maize production (Figure 4.3). Tracing back the facts of this region, it is noticed that Southeast region has an extremely high population density in China. Furthermore, arable land available to cultivate is limited. Because of a higher ratio of mountainous and basin land to flat land, transportation efficiency is lower in this region. To coexist with nature, update to the social needs, and to meet food demand, local farmers are forced to produce crops in both flat lands and terraced lands. In the Southwest, though rice is mainly consumed, maize is also largely produced as it is an important food crop and feed crop.

Ranging from 22° to 31° north by latitude, 101° to 108° east by longitude, the share of maize production in Southwest region is 8.69% of total national maize production in China (Table 4.1, Figure 4.3). While the maize production in Sichuan province accounts for 5.37% of total maize production amount of the whole country, maize production in Yunnan province is 3.32% (Figure 4.3).

Table 4.1 Maize production regions: Northeast China and Southwest China

Country, Region (Plantation patterns)	**Geographic Position**	**Geographic Position**	**Regional Province/State**
China, Northeast region, (patchy)	40°N ~47 °N	119°W~132°W	Northeast Region (3 provinces) 1. Liaoning, 2. Jilin, 3. Heilongjiang
China, Southwest region, (patchy)	22°N~31°N	101°~108°E	Southwest Region (2 provinces) 1. Sichuan, 2. 2. Yunnan

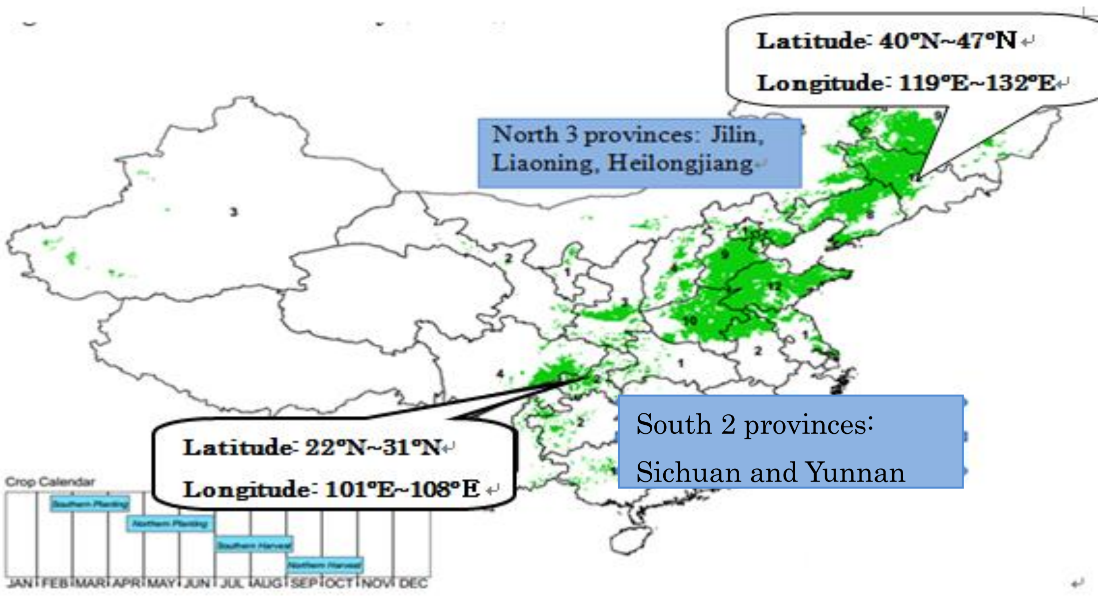
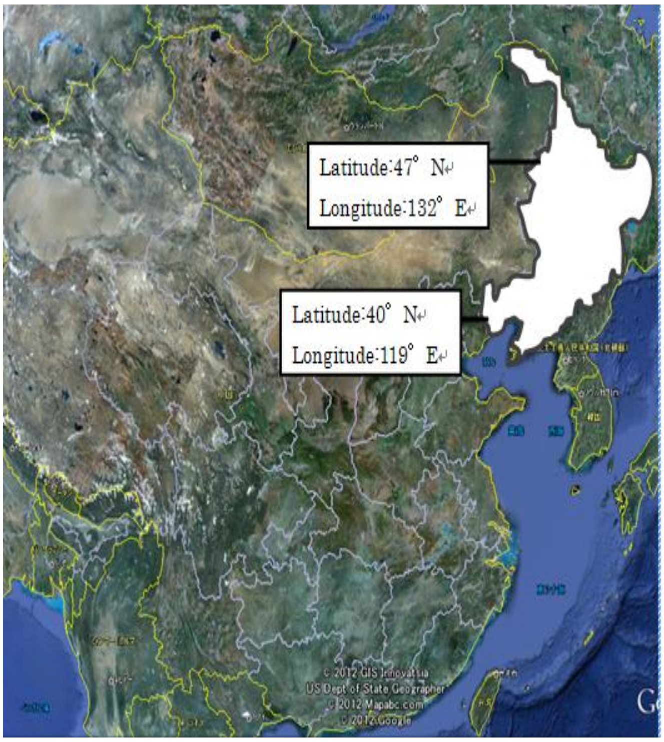
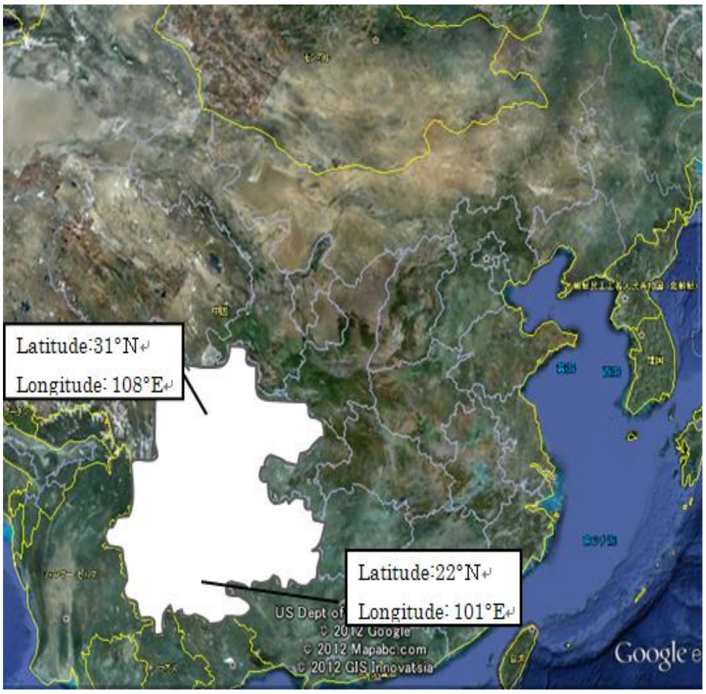


Figure 4.1 Geographic distribution of maize production in China (Source: USDA Agricultural Weather Assessments World Agricultural Outlook Board)



Provinces in China	% of maize production each province has on China Total (Ave 1988-2008)
Liaoning	7.63
Jilin	13.25
Heilongjiang	9.28
Total	30.16

Figure 4.2 Maize production in Northeast region of China (Source: Google Earth)



Provinces in China	% of maize production each province has on China Total (Ave 1988-2008)
Sichuan	5.37
Yunnan	3.32
Total	8.69

Figure 4.3 Maize productions in Southwest region of China (Source: Google Earth)

4.2.2 Overall Structure of the model

This case study analyzes the impacts of climate change, structural population changes, and progressing mechanization on maize production in the Northeast and the Southwest of China. In the first step, a regression function (Cobb-Douglas production function) is estimated. In the second step, the estimated function is converted to supply functions in the profit maximizing condition for analysis.

This case study extends the economic framework of production functions to incorporate climatic variables (temperature and precipitation) in addition to the traditionally included production inputs (land, labour, machinery, and chemical fertilisers). As seeds are mostly self-produced in both regions, this variable is omitted from the estimation. A conceptual overview of the model is summarised in Figure 4.4.

For climatic variables temperature and precipitation in the models, the most sensitive periods in plant and growth for maize are taken into the consideration. Similar to the first case study in the last chapter, the 'CO_2 fertiliser effect' is also assumed to have no enhancing effect on maize output in this case study (Kaiser and Crosson, 1995; Li et al., 2011). Other production inputs that directly control and affect maize outputs, covering land, labor, farm equipment, and fertilizer, are also included in the model (Figure 4.4).

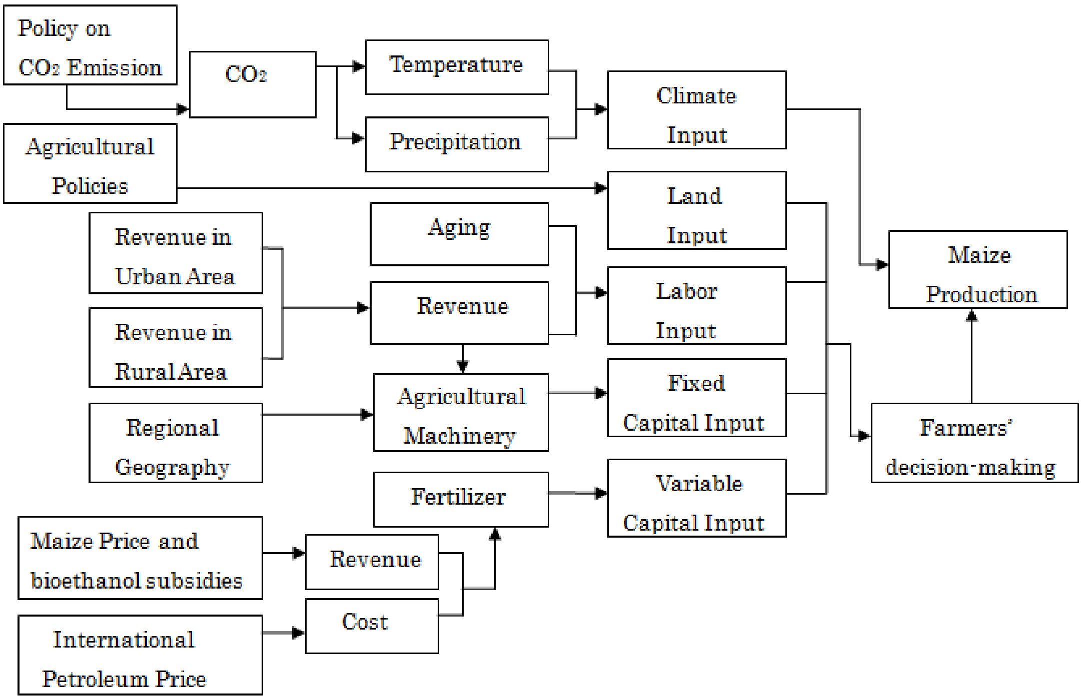


Figure 4.4 Model structure in this research

4.3 Model Variables

4.3.1 Climate variables

Good climate conditions in temperature and precipitation sensitive development stages of maize can lead to a successful maize production output result (Shi 2008). Thus, temperature and precipitation that correspond to maize's planting and growing season (vegetative stage and reproductive stage) can significantly affect the final result of maize production.

Monthly averages of temperature and precipitation for the months that correspond to the most sensitive periods in plant and growth for maize are used rather than simple annual averages in order to better capture the sensitivity of production to the environment (Li et al., 2011). These months correspond to the key planting and growing stages (vegetative and reproductive stage) of crop development, which fall in May, June and July in the Northeast region and March, April and August in the Southwest region (Table 4.2). The latter has two climate sensitive periods because of the double-cropping system.

Table 4.2 Months correspond to the temperature and precipitation sensitive stages of development of maize in Northeast China and Southwest China

	China Northeast	China Southwest
Planting and seedling Stage	May	March April
Growing (Vegetative Stage)	June	August
Growing (Reproductive Stage (Silking Stage))	June July	August

For climate data, historical average day temperature (Fahrenheit degree) and precipitation (inch) are available (CLIMVIS Global Summary of the Day, 2010). Due to data limitation, six climate stations in each province that are closest to the maize production sites and have consecutive data are collected. Since Northeast region has 3 provinces and Southwest region has 2 provinces, a total of 18 climate stations in Northeast region and 12 climate stations in Southwest region are used to collect climate data. Climate data in these climate stations over the time period of 1992-2008 are collected in this case study. Table 4.3 and Table 4.4 separately summarized information about climate stations.

For both the Northeast and the Southwest, collected data on average day temperature and average precipitation in each year's month are seperately summed and averaged to estimate the average monthly temperature and average monthly precipitation in each climate station over the time period of 1992-2008. Since each province has six climate stations, average monthly temperature and average monthly precipitation in these climate stations are summed, averaged, and converted to the provincial average monthly temperature (℃) and provincial average monthly precipitation (mm) for each province. Because of unavailability of consecutive data prior to 1992, 51 panel data that cover 17 years' time series temperature and precipitation data across 3 provinces over the 1992-2008 period in Northeast region and 34 panel data that cover 17 years' time series temperature and precipitation data across 2 provinces over 1992-2008 periods in Southwest region are collected.

Table 4.3 The Northeast and the Southwest's Climate Stations

Country, Region	Province	Station Number, Station	Geographic Position
CHINA, Northeast	Liaoning	54497, Dandong	Latitude: 40.03°N; Longitude: 124.20°E
CHINA, Northeast	Liaoning	54337, Jinzhou	Latitude: 41.08°N; Longitude: 121.07°E
CHINA, Northeast	Liaoning	54493, Kuandian	Latitude: 40.43°N; Longitude: 124.47°E
CHINA, Northeast	Liaoning	54236,Zhangwu	Latitude: 42.25°N; Longitude: 122.32°E
CHINA, Northeast	Liaoning	54342, Shenyang	Latitude: 41.44°N; Longitude:123.27°E
CHINA, Northeast	Liaoning	54259, Qingyuan	Latitude: 42.06°N; Longitude:124.55°E
CHINA, Northeast	Jilin	54049, Changling	Latitude: 44.15°N; Longitude:123.58°E
CHINA, Northeast	Jilin	54161, Changchun	Latitude: 43.54°N; Longitude:125.13°E
CHINA, Northeast	Jilin	54186, Dunhua	Latitude: 43.22°N; Longitude: 128.12°E
CHINA, Northeast	Jilin	54273, Huadian	Latitude: 42.59°N; Longitude:126.45°E
CHINA, Northeast	Jilin	50949, Qianguoerluosi	Latitude: 45.07°N; Longitude:124.50°E
CHINA, Northeast	Jilin	54157, Siping	Latitude: 43.11°N; Longitude: 124.20°E
CHINA, Northeast	Heilongjiang	50978, Jixi	Latitude: 45.17°N; Longitude:130.57°E
CHINA, Northeast	Heilongjiang	50844, Tailai	Latitude: 46.24°N; Longitude:123.25°E
CHINA, Northeast	Heilongjiang	50968, Shangzhi	Latitude: 45.13°N; Longitude: 127.58°E
CHINA, Northeast	Heilongjiang	50745, Qiqihar	Latitude: 47.23°N;

			Longitude: 123.55°E
CHINA, Northeast	Heilongjiang	50854, Anda	Latitude: 46.23°N; Longitude: 125.19°E
CHINA, Northeast	Heilongjiang	50788, Fujin	Latitude: 47.14°N; Longitude: 131.59°E

Country, Region	Province	Station Number, Station	Geographic Position
CHINA, Southwest	Sichuan	57426, Liangping	Latitude: 30.41°N; Longitude: 107.48°E
CHINA, Southwest	Sichuan	57516, Chongqing	Latitude: 29.35°N; Longitude: 106.28°E
CHINA, Southwest	Sichuan	56571, Xichang	Latitude: 27.54°N; Longitude: 102.16°E
CHINA, Southwest	Sichuan	57633, Youyang	Latitude: 28.50°N; Longitude: 108.46°E
CHINA, Southwest	Sichuan	56671, Huili	Latitude: 26.39°N; Longitude: 102.15°E
CHINA, Southwest	Sichuan	57328, Daxian	Latitude: 31.12°N; Longitude: 107.30°E
CHINA, Southwest	Yunnan	56651, Lijiang	Latitude: 26.52°N; Longitude: 100.13°E
CHINA, Southwest	Yunnan	56786, Zhanyi	Latitude: 25.35°N; Longitude: 103.50°E
CHINA, Southwest	Yunnan	56985, Mengzi	Latitude: 23.23°N; Longitude: 103.23°E
CHINA, Southwest	Yunnan	56886, Luxi	Latitude: 24.32°N; Longitude: 103.46°E
CHINA, Southwest	Yunnan	56751, Dali	Latitude: 25.42°N; Longitude: 100.11°E
CHINA, Southwest	Yunnan	56778, Kunming	Latitude: 25.01°N; Longitude: 102.41°E

4.3.2 Other input variables

In addition to climate variables, production variables (land, labor, machinery and fertilizer) are also important inputs in the maize production process. Illustrated in Figure 4.4, these inputs are also incorporated in the model.

4.3.2.1 Land variable

Land size indicates land availability for maize production. When it varies in a region, maize outputs change correspondingly. Thus, land is a significant variable in deciding the result of each year's maize output.

In China, policy is a tool to help agriculture sustainable. In most cases, national policies are often established and adjusted with social needs. Given the background of large population size, 1) providing enough foods to people, 2) meeting the national energy requirement have been two important national targets. Over the years, government has set various policies related to these two targets. Since maize crop is an important food, a feed crop, and a renewable bioethanol energy source, it has been a key agricultural crop in China. Definitely, maize crop will continue to play its key role in agricultural sector and energy sector in the future.

Overall speaking, policies can be effective means to control farmers' land use and decisions. To stimulate the incentives of farmers to grow crop plants and to ensure a stable food supply to the market, various policies have been designed and established by the Chinese government. Law of the Peoples Republic of China on Land Contract in Rural Areas is one of them. Activated from 2003 (The central people's government of the people's republic of China, 2005), this new law specified a long-term contract of land use right (at least 30 years) and guaranteed farmers that during the contract period, changes in land use and land boundaries by the government are not allowed (The central people's government of the people's republic of China, 2005). The law gives farmers the guaranteed right to use agricultural lands, aiming to stimulate the incentives of farmers to stay in the rural areas and work in the agricultural sector instead of moving out for cities. In addition to this land policy, the law of land administration of the people's republic of china is established in 2004 in order to officially prohibited inappropriate land conversion from cultivated farm lands to other non-agricultural production land uses such as housing lots, and to protect agricultural land from other illegal uses (Ministry of Land and Resources of the People’s Republic of China, 2005).

Since farmers’ decisions, either increasing, decreasing, or maintaining the same sized land each year highly affect the final maize outputs available to the market, other policies (e.g., subsidies) are also purposely established by the government to affect farmers’ decision-making processes and to stimulate the desires of farmers to produce maize. Since bioethanol produced from maize is considered to be an environmental friendly energy, subsidies specific for bioethanol production have been provided to the companies that produce maize processed bioethanol. Comparatively, bioethanol subsidy amount in 2012 is adjusted to 776 Yuan/tonnes from 1276 Yuan/tonnes in 2011. Though subsidy amount in each year is adjusted based on the changes of food demand and supply, it has acted as a tool to stimulate the incentive of companies to produce maize processed bioethanols, which in turn indirectly affecting the incentives of farmers in the primary sector to produce maize (China Grain 2012). Because of these policy efforts, land size for maize production in 3 provinces in Northeast region and 2 provinces in Southwest region, except Sichuan province where the planted area of maize are relatively stable, have increased in compensation for the reduction of land size for other crop production, such as soybean.

For analysis, data on maize planted area (thousand hectares) that are available in

China' agriculture department (2009) are collected. In order to ensure unit consistency in the model, collected data are converted to acre over the 1992-2008 periods in each province in Northeast region and Southwest region of China.

4.4.2.2 Labor input variable

Labor is also an important input in the maize production process. In Northeast China, the history of region is relatively shorter and hence the systematical development of land is around 100 years. In addition to the fact that Northeast region has a large land size and fertile black soils, population density in this region is lower compared to other regions in China. Though agricultural equipments/machines have used for cultivation at a large scale in this region, enough number of labor force is a prerequisite to produce maize and operate machines.

In Southwest China, slope terrains are the dominant geographic structure. Diverting from the Northeast, population density in this region is extremely high. According to statistics, 80.2% of population in Southwest China depends on agriculture to support their families (Liu and Chen 2005). In this region, average land size for each farmer is 0.05 hm^2, the smallest level in the nation. High population density and strict landscape force farmers to cultivate land intensively in the region in order to meet food demand and money needs. Because of land limitation and warmer climate, crops are planted twice or three times rather than once each year. Given the fact that China has a custom to separate the family land to equal sizes and passes them from parents to sons, land inherited generation by generation usually decreases in size. As a result of these reasons, intensive labor rather than machines has to be applied to the land in this region to produce food and earn money.

In both Northeast region and Southwest region, aging and revenue differences between urban areas and rural areas affect the available number of labor force working in the agricultural sector. At present, average population ages in rural areas of China are between 40 and 44 (Figure 1.4). Under the current birth control policy, the pyramid population structure will distort in the near future. Aging could be a threatening variable to the nation and affect agricultural population number. As United Nation DESA (2012) predicted, the old-age dependency ratio (the ratio of persons aged 65 or over to those of working age 15-64 years old) will grow from 9 to 26 in Asia (The United Nations DESA 2012, Figure 1.3).

For both Northeast region and Southwest region, aging could significantly affect the availability of agricultural population. Revenue differences between rural areas and urban areas can also affect the structure and the number of agricultural population. Along with the development of Chinese economy and policy supports, life standards and revenue differences between urban and rural areas has increased over the years. Moving to cities to earn more money is attractive to people working in the agricultural sector in rural regions. Though family register executed over the years has been a tool to control large population movements among regions in the nation, many rural workers still move out for more revenues and better lives in urban areas. Along with economic development, urban areas have increased labor force demand and accumulate more workers from the agricultural sector. Among agriculture population in the rural areas, young to middle age population (major age cohorts) in special show more interests to work in urban areas. Given the background of reality, revenue difference between urban and rural areas as well as aging may impact agricultural population size and structure in rural areas in the future.

In this study, the number of rural agricultural labor population work to produce maize in each region is used as a production input in the model. Since consecutive data prior to 1992 are not available, data thereafter are collected. In China Labor Statistical Yearbook 1993-2009, the added up total rural labor population working in all of the primary sectors (agriculture, forestry, animal husbandry, and fishery) in each province is provided (Ministry of Labour and Social Security 1993-2009). Thus, data in each province over 1992-2008 periods are first collected. Since agricultural crops are generally produced in rural areas, rural agricultural labor population rather than all types of agricultural labor working in different sectors are estimated. In the National Census division data center, yearly rural agricultural labor population in each province is not provided. The most recent data that is available to use is in the fifth National Population Census of the 2000 version (National Bureau of Statistics of China 2008). Thus, the ratio of rural agricultural labor population and the total rural labor population working in all sectors collected in the fifth National Population Census are estimated (rural agricultural labor population/total rural labor population working in all sectors) for each province. The estimated ratio is then multiplied by the total rural labor population working in all sectors in each province over the 1992-2008 periods to acquire the available rural agricultural population in each province over the 1992-2008 periods. To estimate the rural labor population working in the agricultural sector and produce maize crops, maize crop production versus total agricultural crop production ratio in each province (maize production amount/total agricultural production amount) is estimated (USDA 2012; China Statistical Database 2012). The calculated maize crop production ratio is then multiplied to the processed rural agricultural population to calculate rural agricultural population working for maize production in each province over the 1992-2008 periods. Thus, 51 panel data points in Northeast region (17 time series data in 3 provinces) and 34 panel data points (17 time series data in 2 provinces) are acquired in Southwest region.

4.3.2.3 Agricultural Machinery variable

Agricultural machinery is an important tool for maize production. Choices between labor force dependent agricultural style and agricultural machinery dependent agricultural style can significantly affect the efficiency of maize production, and hence affecting the final result of maize production.

In Northeast region, agricultural lands are flat and large. Rural agricultural population size is smaller compared with other regions in the nation. Hence, average land size each farmer can have in this region is comparatively larger (average land size is 0.2hm^2). Moreover, Northeast China is one of regions in the world that has a high quality of organic soil, known as black soils. Large land size, fewer farm population and fertile soils make the revenues of farmers in this region (1863 Yuan/person) stable, close to the national average of 1984 Yuan/person (Liu and Chen 2005). The geographic condition and farm revenues in this region hence enable farmers to invest on new farm equipments (e.g., machines), which in turn links to an increase in cultivation efficiency, a higher production outputs and more revenues in return. At present, mechanization level in Northeast region is the highest in China (Liu and Chen 2005).

In Southwest region, traditional agricultural practice is mainly performed among farmers. Due to its terrain geography and a higher population density, farmers in Southwest region in average have lower land size (0.05 hm^2) (Liu and Chen 2005). Correspondingly, average revenue in this region is also lower (1335 Yuan/person) compared to the national average (1863 Yuan/person) (Liu and Chen 2005). Because of these reasons, many young to middle aged population in rural areas of this region are more attracted to the lives in urban areas, and have stronger desires to earn more money for family use. Though smaller land sizes with terrain geography added together has limited the farmers to rely on the labor force for crop production, the use of agricultural machinery has also increased over the past years to increase the efficiency of agricultural cultivation and to produce more crops for more revenues.

In both Northeast region and Southwest region, progressive aging issue and revenue difference between rural areas and urban areas will continue to affect the structure and the number of the working population in the agricultural sector in the future, which in turn will force farmers to make decisions: either to stop maize production and leave the agricultural sector, maintain the current production level, or to invest on new technologies such as farm equipment to cover the reduced working loads of labor to maintain the maize production level. The choices of farmers will force farmers to use agricultural machinery.

In China agricultural products cost-benefit compilation of information statistics series, data on maize machinery costs (Yuan/mu) in each province are provided (2012). For unit consistency, the collected data are converted (Yuan/acre). Then, the converted data are multiplied to the corresponding maize planted areas in each year to estimate provincial agricultural machinery cost (unit: Yuan) over 1992 to 2008. The estimated machinery cost data is divided by price index of agricultural means of production data (the Index reflects agricultural production input price trend, and agricultural machinery prices change with changes of this index) over 1992-2008 (1992 level=100) to estimate agricultural machinery input (National Bureau of Statistics of the Peoples Republic of China statistics).

4.3.2.4 Variable Capital input fertilizer

Among various variables that can potentially affect crops, chemical fertilizer is the major variable that can affect crop outputs (Yuan 2011). The ingredient of the present chemical fertilizer is petroleum. In most cases, variability of international petroleum price directly alters the prices of chemical fertilizer, which in turn affects the costs of chemical fertilizer and applied amount to the maize crop. In addition to this point, maize price and maize processed bioethanol subsidies also play roles in the choice-making processes of farmers. Thus, final decisions on the applied chemical fertilizer amount will be affected by international petroleum price, market maize price, and bioethanol subsidy policies.

In Chinese governmental statistics database, provincial chemical fertilizer data (kg/mu) are available over the 1992-2008 periods (China agricultural products cost-benefit compilation of information 1993-2008). Thus, the collected provincial chemical data are converted (bushel/acre) for unit consistency. Then, the converted data are multiplied to maize planted area of the corresponding year to respectively estimate 51 and 34 chemical fertilizer data (bushels) in Northeast region and Southeast region.

4.3.3 Maize output variable

Provincial total maize production (10000 tons) can be found from the USDA statistics. Maize production data in each province in Northeast region and Southwest region over 1992-2008 periods are collected from the USDA statistics (2012). For unit consistency, the collected data are converted to bushels.

Presented in Figure 4.4, land, labor, agricultural machinery and chemical fertilizer affect maize production through impacting the decision-making processes of farmers. Climate, uncontrollable by human beings, can directly affect maize output.

4.4 Empirical model

For Northeast region and Southwest region in China, the following regression function in format of Cobb–Douglas production function (1) in double logarithmic form is used to analyze the effects of climate and production inputs on maize outputs.

$$\ln Y=\beta_0+\beta_1\ln A+\beta_2\ln L+\beta_3\ln MA+\beta_4\ln CF+\beta_5 wmT +\beta_6 wmT^2+\beta_7 wmP+\beta_8 wmP^2 \quad (1)$$

where: Y is the maize production (bushels), A the planted area of maize (acre), L the number of agricultural labour force that directly contribute to the processes of maize production (persons), MA is agricultural machinery use where the annual maize machinery cost is deflated by agricultural means of production price index, and CF is the amount of chemical fertiliser applied to maize (bushels). wmT is the weighted mean temperature in the key seasons of maize's life, including the planting and growing stages (vegetative stage and reproductive stage) of maize, whereas wmP is the weighted mean precipitation in the key seasons of maize's life, including the planting and growing stages (vegetative stage and reproductive stage) of maize.

Specifically about Eq. (1), it is estimated with panel data collected from three provinces in the Northeast region and two provinces in the Southwest region over the time period from 1992 to 2008. Hence, 51 observations across the Northeast region and 34 observations across the Southwest region are included in the regression.

4.5 Results

4.5.1 Model analysis Results

For both Northeast region and Southwest region, the same modeling method is used (Table 4.4). In the model, climate inputs temperature and precipitation in maize's sensitive planting and growing stage (vegetative stage and reproductive stage) are critical in determining the growth of maize. Thus, 50% importance is equally applied to two input variables (Table 4.4). Other production inputs: 1) maize planted area ln(*A*), 2) agricultural labor number that participates the production process ln(*L*), 3) agricultural machinery use ln(*MA*), and 4) applied amount of chemical fertilizer ln(*CF*) are also included (Table 4.4). The links between inputs and output are well estimated as the estimated R-squared were 0.86 and 0.92 in Northeast analysis model and Southwest analysis model.

Table 4.4 Modeling results in Northeast region and Southwest region in China (Data over 1992-2008 periods are utilized)

Explained variable, (maize outputs)	China Northeast region	China Southwest region
Explanatory variables	Coefficients (t-value)	Coefficients (t-value)
Constant	-13.76 (-1.8)	-12.55 (-2.3)
In (A)	4.70×10^{-1} (2.3)	6.00×10^{-1} (4.7)
In(L)	4.20×10^{-1} (3.1)	4.90×10^{-1} (2.6)
In(MA)	6.00×10^{-2} (1.2)	3.00×10^{-2} (2.7)
In(CF)	2.10×10^{-1} (1.9)	1.3×10^{-1} (1.4)
wmT	1.75 (2.1)	1.17 (2.3)
wmT^2	-5.00×10^{-2} (-2.2)	-3.00×10^{-2} (-2.0)
wmP	2.00×10^{-3} (1.6)	2.00×10^{-3} (2.0)
wmP^2	-8.44×10^{-6} (-2.0)	-6.20×10^{-6} (-1.9)
R squared	0.86	0.92
Adjusted R squared	0.83	0.89
D.W.	1.57	1.76

Data source: CLIMVIS Global Summary of the Day, 2010; China's agriculture department, 2009; China Statistical Database 2012; USDA, 2012; National Bureau of Statistics of China, 2008; China agricultural products cost-benefit compilation of information 1993-2008)

4.5.1.1 Planted area input

The estimated production functions indicate that among human-controllable inputs, planting area has the highest output "elasticity" in both the regions. Given the background of a shorter agricultural and economic history, good environmental condition for agricultural practices (fertile black soils and large flat lands), and national average revenue level, population size moving out of this region is not large (He 2009). A 1% increase in land in this region leads to an increase in maize production of 0.468%, holding all other factors constant.

Comparatively, in Southwest region, due to a higher population density, terraced lands, smaller land size, poorer economic condition, worse soil quality, the figure is 0.604%. While both elasticity estimates indicate diminishing returns to scale, the comparatively higher elasticity for the Southwest region also reflects that land is an important limiting factor in the region, i.e., a further increase in land devoted to maize production can significantly improve output.

4.5.1.2 Agricultural Labor input

Notwithstanding an increased use of agricultural machinery over the years, manual labour remains to be an important input to maize production across the country.

In the Northeast region, two types of agricultural practices exist: rain-fed flat land with a half use of agricultural machinery and government-run large-scale mechanized farm with a high mechanization utilization rate (He, 2009). Though the government-run large-scale mechanized farm is more efficient in maize production, rain-fed flat land with a half use of agricultural machinery in the whole maize production process is the dominant maize production style in this region. Further, a shorter history in Northeast region has made its regional village systems undeveloped (He 2009). Thus, labor input, next to maize planted area input, has the second largest output “elasticity” in this regions (Figure 4.4). A 1% increase in labour force increases maize output by 0.425% in the Northeast region, holding all other factors constant (Figure 4.4).

In the Southwest region, agricultural lands appear to be small, terraced, and sloped. Regional land characteristics thus make manual labour a critically important input in the maize production process. A 1% increase in labour force increases maize output 0.489% in the Southwest region, holding all other factors constant (Figure 4.4). These results illustrate the importance of labour in Chinese agriculture.

4.5.1.3 Agricultural Machinery input

In Northeast region, agricultural mechanization is already at the highest level in China. While rain-fed flat land with a half use of agricultural machinery agricultural practice style utilizes machinery for 50% of the whole maize production process, government-run large scale mechanized farm maize production style can use machinery for over 90% of the whole maize production process. Thus, aagricultural machinery has a positive impact on maize production, although the effect is not as large as that of labour. The result suggests that a 1% increase in agricultural machinery increases maize output by 0.059% in the Northeast regions, all else constant.

In the Southwest region, terrain geography makes the use of agricultural machinery at a large scale difficult. Thus, agricultural labor force has to be intensively used in the region. Comparatively, a 1% increase in agricultural machinery increases maize output by 0.034% in the Southwest region (Figure 4.4). The smaller effect shown for the Southwest region is likely the result of its topography, on which small-scale, terraced farmlands can be observed.

4.5.1.4 Chemical Fertilizer input

Chemical fertilizer is an important input in the maize production process. Its importance is also proved in the agricultural input-output study conducted in Hebei province (Yuan 2011). Despite being the largest source of expenditure for Chinese maize producers, the contribution of chemical fertiliser to the maize production is smaller relative to the other main inputs.

In Northeast region, agricultural lands are generally fertile. However, as agricultural lands increase uses in intensity, soil quality degrades. Nutrient rich black soils in some parts of the region have been found to lose their nutrient levels. The estimation results show that a 1% increase in chemical fertiliser application increases maize production by 0.21% in the Northeast region. In all likelihood, accelerated utilization of natural nutrient rich black soils over the years in the Northeast region has made some parts of lands loses nutrients, leading to a relatively stronger response to fertiliser.

In Southeast region, soil quality is poorer. Intensive land use each year has made soils infertile. The amount of chemical fertilizer applied in this region can directly improve the nutrient contents in the soils, which in turn improves the maize outputs. Thus, it is reasonable that a 1% increase in chemical fertilizer increases maize production by 0.13% in Southwest region.

4.5.1.5 Climate inputs

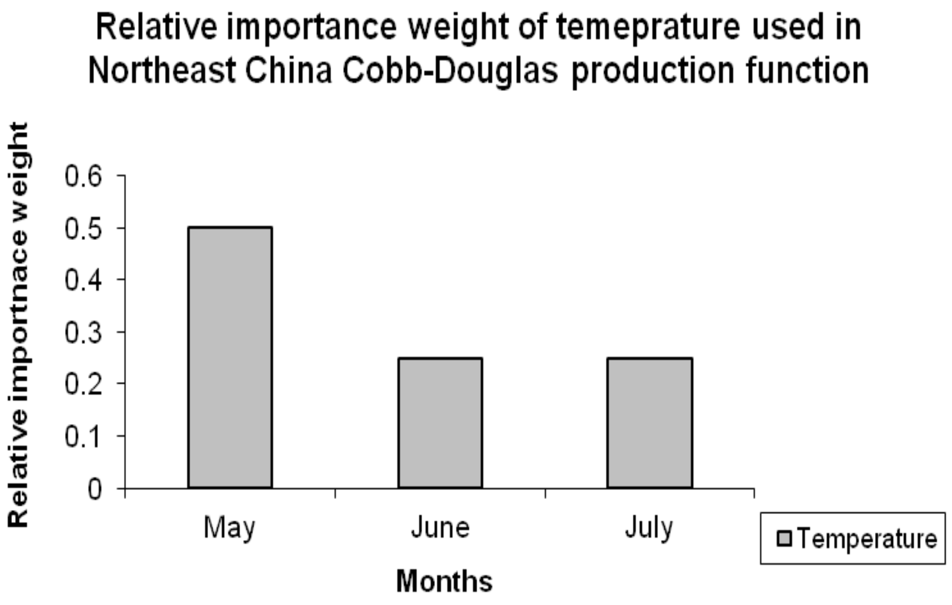
The latitude of Northeast China is higher than Middle China. Annual accumulated heating degrees over 10°C in the Northeast are 2200~2800°C, a much lower level compared to Middle China region (Liu and Chen 2005). Maize is planted under a single-cropping system each year and it is a dominant agricultural practice style performed among farmers in this region (Liu and Chen 2005).

In Northeast China, maize is planted in May, when the optimal soil temperature is reached for germination. Though the temperature 6-8°C is the minimum required temperature range to germinate maize seeds in Northeast China, 10°C is a benchmark of biophysical growth requirement of maize (Chai 2005). Usually, a higher temperature in planting season leads to a good seed germination result and shorten the time duration for maize seed germination (Chai 2005). Thus, the efficiency and speed of seed germination highly depend on temperature condition in planting season. In addition to temperature, moisture condition is also a key element. For seed germination, a seed needs to absorb the water amount in proportion to 48-50% of the seed's absolute dry weight (Chai 2005).

Over the life cycle of maize, after the planting, stem elongation and tasseling period in the vegetative growth stage and silking and grain-filling in the reproductive stage of maize crop are also important (He 2009). June corresponds to the vegetative stage and July corresponds to the climate-sensitive reproductive stage (silking and grain-filling) of maize in North China (Table 4.5). Over the growing stage (vegetative stage and reproductive stage), the speed of growth of maize generally increases with the increased temperature (Chai 2005). For example, the days required to have the mid to late ripening varieties of maize plants reach their tasseling stages are between 60-70 days when the average day temperature is below 20°C (Chai 2005). When the average day temperature increases to above 22°C, the required days to have maize crops reach their tasseling stages reduces to 45-58 days (Chai 2005).

Though a higher temperature is better for the development of maize, a temperature too high above a certain level can bring about negative effects on maize. For example, when the temperature increases above 32-35°C and the relative moisture contents in the atmosphere is lower than 30% in the pollination stage of maize, the life span of pollen decreases, the quality of pollination drops, and maize outputs decrease (Chai 2005). In addition to the temperature effects, precipitation is also important in adjusting the water contents in the atmosphere and in the soils. During the stem elongation and tasseling period of vegetative stage of maize, the growth in the root system and organ developments of maize reaches its quickest and most active level, and the required relative water contents in the soil becomes 70-80% (Chai 2005). In the reproductive silking and grain-filling stage, enough water amounts are also important. Water availability can directly affect the balance of water absorption and evaporation of maize plants and affects the final harvesting result. Hence, temperature and precipitation in maize's sensitive growing season, including vegetative and reproductive stage, are equally assigned to 50% in the model, as presented in Figure 4.5.

In Northeast region, average temperature over the analysis period in 2008 (18.46°C) is already over the peak temperature (17.87°C), holding all other factors constant. A 1°C increase further above the 2008 level is found to decrease maize production by 10.18%. Northeastern average precipitation over the analysis period in 2008 (127.09mm) is also over the regional turning point of precipitation level (112.90mm). Though the effect is small, a 1mm increase further above the 2008 level is found to decrease maize production by 0.02%.



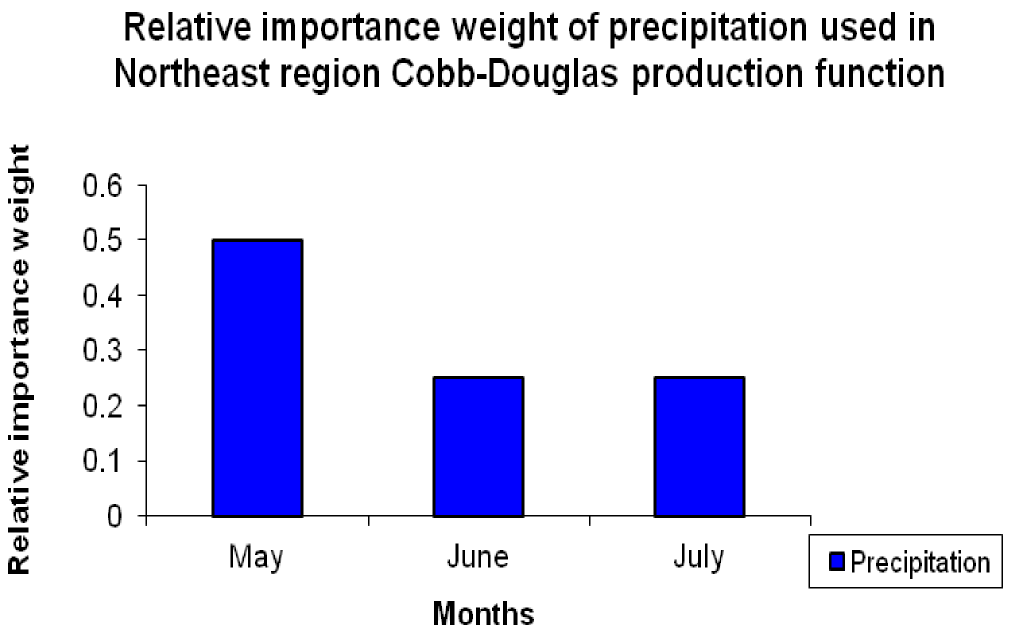
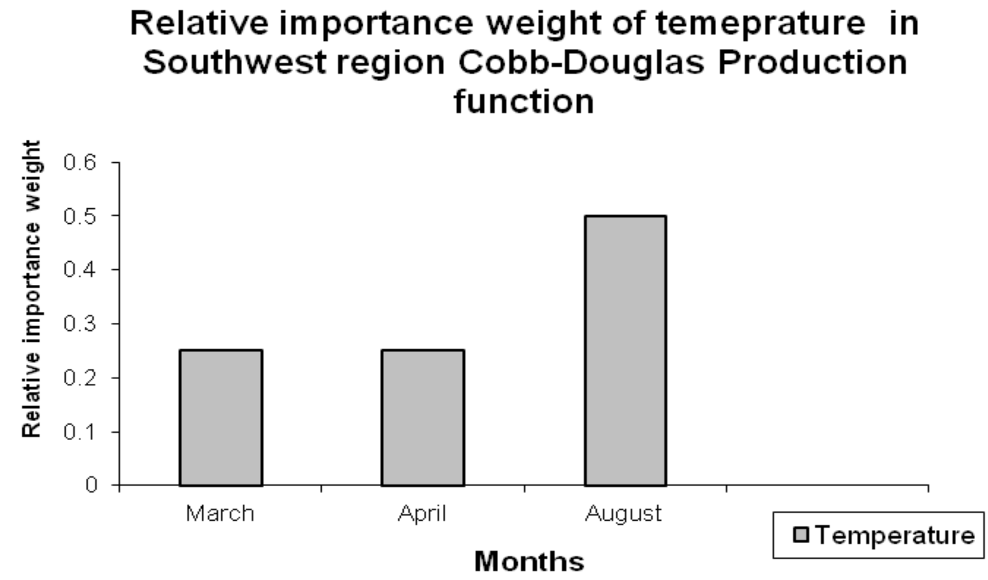


Figure 4.5. Weight of Relative importance of temperature and precipitation in Northeast region Cobb-Douglas production function

Southwest region, in contrast, is positioned in lower latitude. Annual accumulated heating degrees over 10°C are highest among three maize producing regions in China (Northeast region, Middle region, Southwest region), between 5000-6000°C (Liu and Chen 136-137). Since maize crops are sensitive to climate variation in planting and growing stage, temperature and precipitation during these time periods are two critical in affecting the survival and development of maize.

Located in lower latitude, Southwest China is warmer than other two major maize producing regions in China, and hence maize is planted under a double-cropping system with rice, rapeseeds, potatoes or various kinds of legumes. In Southwest China, farmers choose to plant maize crop in mid-March and April for the spring planting season, and August for the key-growing season, known as "spring maize". Though spring maize is mainly produced in Southwest China, some farmers also choose to plant the early ripening varieties of maize in June after the harvest of other crops such as winter wheat, then harvest them in September (known as "summer maize"). Some other farmers choose July to August for maize plantation and harvest in early October (known as "autumn maize"). For either plantation type, August is an important month corresponds to the reproductive stage of spring maize and summer maize, and reproductive stage of autumn maize (Table 4.6). Hence, 50% weight of relative importance is equally applied to temperature and precipitation in corresponding planting and growing season of maize, as illustrated in Figure 4.6.



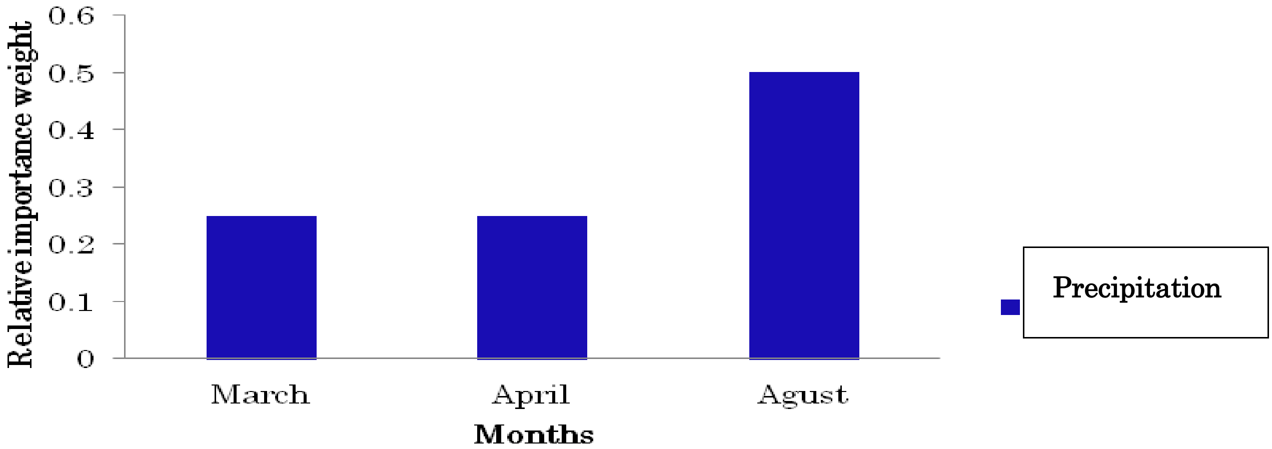


Figure 4.6 Weight of Relative importance of temperature and precipitation in Southwest region Cobb-Douglas production function

Southwestern average temperature in 2008 (19.18°C) is below the turning point of temperature (21.61°C), holding all other factors constant. A 1°C increase above 2008 level is found to increase maize production 10.98%. A better response in the Southwestern China is likely the result of flexible timing of regional maize production. The Southwestern average precipitation in 2008 (127.48mm) is below the peak precipitation level (172.56mm). A 1mm increase in precipitation above the 2008 level is found to increase maize production by 0.06%. A relatively higher result in the

Southwest implies the importance of water supply to maize production and is consistent with an earlier report that Southern precipitation in spring is a limiting factor (Liu and Chen, 2005; Li et al., 2011).

4.5.2 Analysis of climate inputs on maize output

The biophysical link between climate inputs (temperature, precipitation) and maize output are analyzed. To examine the biophysical relationship between temperature and maize outputs, all inputs, excluding temperature, are controlled at the 2008 year level. The results are summarized in Figure 4.7 and Figure 4.8. In Northeast region, average temperature over the analysis period in 2008 (18.46°C) is already over the peak temperature (17.87°C), holding all other factors constant. A further increase in temperature could affect maize growth and leads to a decrease in maize output (A 1°C increase further above the 2008 level is found to decrease maize production by 10.18%).

In Southwest region, average temperature in 2008 (19.18°C) is below the turning point of temperature (21.61°C), holding all other factors constant. A slight increase in temeprature may not have negative effects on maize outputs under the current technology level. The simulated result in the Southwest is opposite to the Northeast where an increase in temperature can have a negative effect on maize output. It is found that a 1°C increase above 2008 level could increase 10.98% of maize production in Southwest region.

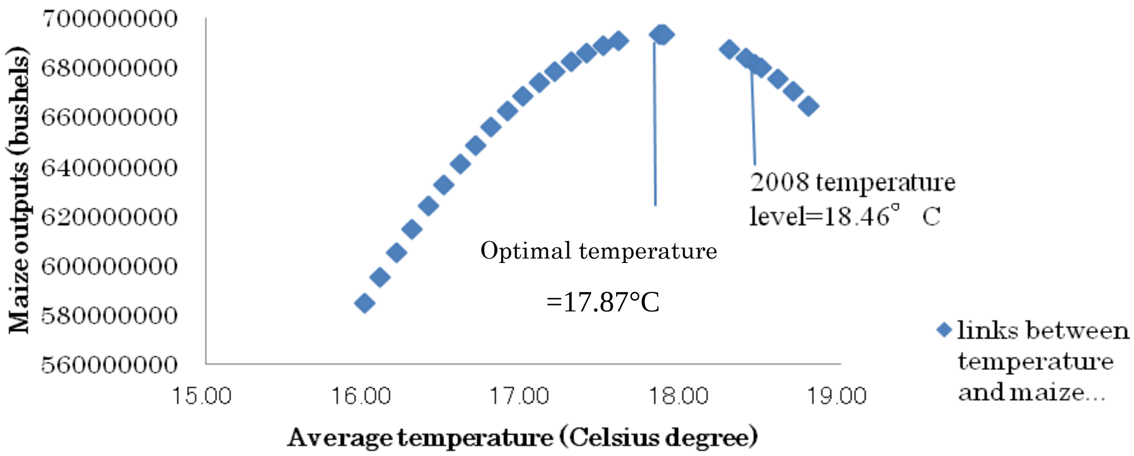


Figure 4.7 Relationships between average temperature over the sensitive stages of maize crop and maize output in China Northeast region

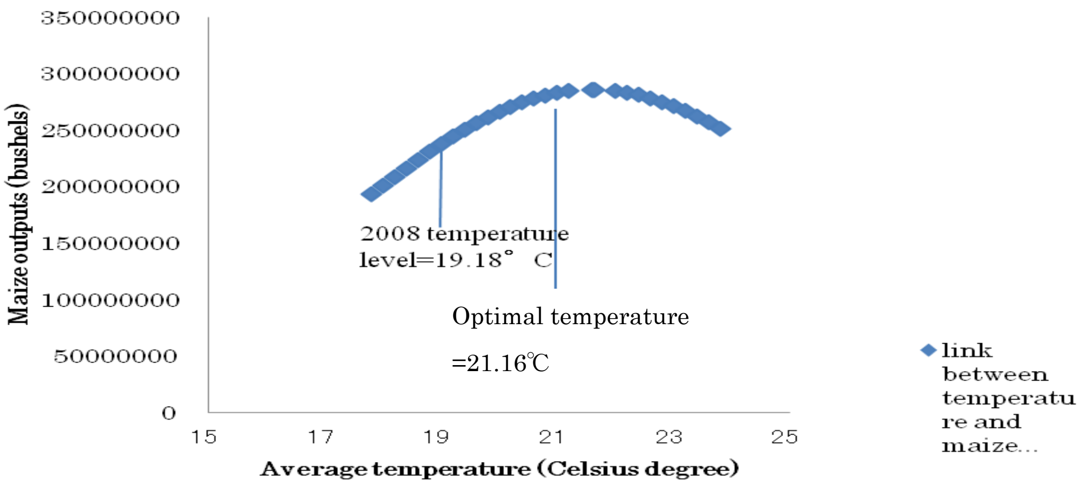


Figure 4.8 Relationship between average temperature over the sensitive stages of maize crop and maize output in China Southwest region

Similarly, the biophysical relationship between precipitation and maize output are analyzed (Figure 4.9, Figure 4.10). Northeastern average precipitation over the analysis period in 2008 (127.09mm) is also over the regional turning point of precipitation level (112.90mm) (Figure 4.9). Though the effect is small, a 1mm increase further above the 2008 level is found to decrease maize production by 0.02%.

In contrast, the Southwestern average precipitation in 2008 (127.48mm) is below the peak precipitation level (172.56mm) (Figure 4.10). A 1mm increase in precipitation above the 2008 level is found to increase maize production by 0.06%. In Southwest region, though annual precipitation is higher, its pring climate is dry. Since precipitation is the major water source for irrigation, water in spring is a limiting factor. In addition to this point, a poorer economic condition in the Southwest force farmers rely on natural climate. A relatively higher result in the Southwest implies the importance of water supply to maize production and is consistent with an earlier report that Southern precipitation in spring is a limiting factor (Liu and Chen, 2005; Li et al., 2011).

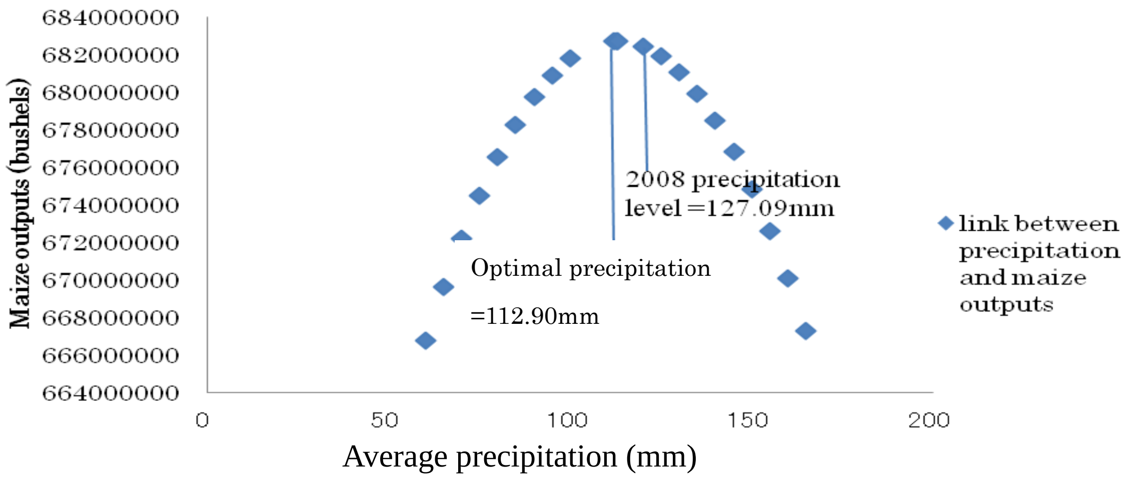


Figure 4.9. Relationship between average precipitation over the sensitive stages of maize crop and maize output in China Northeas region

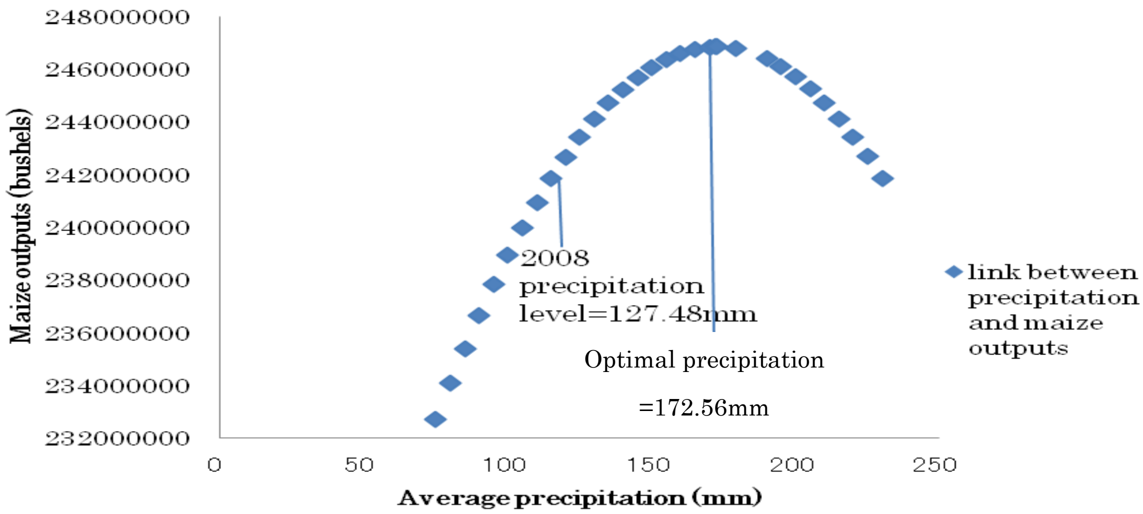


Figure 4.10 Relationship between average precipitation over the sensitive stages of maize crop and maize output in China Southwest region

4.5.3 Projection of population and agricultural machinery

In this case study, the cohort-component method was used to project the structural change in agricultural population. Data on working population by age cohort and gender were collected from the government data (Natural Bureau of Statistics of China, 2012) and processed to estimate the rural population available for maize production at each year. For each province, the rural population in each 5-year cohort at the base year *t* was first multiplied by the cohort-change rate to estimate the population in the next-up cohort at year $t + 5$. At the calculation of the cohort-change rate, both the survival rate and the net migration rate were taken into consideration. Given the time span of the analysis focus (2008-2030), these two rates were assumed to stay at the 2003 to 2008 levels for the duration of the analysis. For prediction of population belonging to the youngest age cohort of 0–4, the real-life ratio (female/male) of children to women of childbearing age (between 15 and 49) was used.

Of the estimated rural population, those falling on the working age between 15 and 64 were aggregated to produce the size of rural labour force. This figure was then multiplied by the ratio of labour force engaging in maize production to produce the size of labour force available for maize production in each province, each year.

For the forecast on agricultural machinery use, the annual rate of change between 1992 and 2008 was averaged to produce the annual rate of change to be applied throughout the simulation period. This rate was then applied to the baseline data of 2008 to obtain the annual use of machinery in each province, each year.

Estimated data on future population and agricultural machinery are used in the second set of simulations.

4.5.4 Projections of production inputs effects on maize outputs with varying climate scenarios

For the Northeast region and the Southwest region, the estimated production functions were used at first to forecast the effect of the climate change on maize production in each region over the period from 2009 to 2030.

Among past studies that analyzed the potential directions of precipitation, Wu (2008) found a positive phase of the dipole anomaly could increase the average summer rainfall in the Northeast region (2008). International Pacific Research center on the other hand indicated the precipitation in summer will decrease in Northeast region (IPRC 2005). IPCC indicated precipitation would decrease in both spring and summer in both the Northeast and the Southwest (1997). IPRC pointed out the Southwest's precipitation has increased in spring (2005). Li et al (2012) linked the severe drought in spring after year 2000 to the earlier Bay of Bengal (BOB) monsoon. Given the facts that different directions of precipitation projection are possible, predicting an exact direction of potential precipitation is difficult. Thus, changes in precipitation over the analysis period were not presupposed.

In this case study, based on the estimated production function, maize production was simulated under five climate scenarios for future changes in temperature for 2009-2030: (1) no change from the 2008 level, (2) mild change (3) moderate change (4) pessimistic change, and (5) extreme change. Changes in temperature over the simulation period were set at 0.32°C (mild), 0.72°C (moderate), and 1.32C° (pessimistic and extreme) above the 2008 levels, corresponding to the projected changes indicated in the Fourth Assessment Report of the Intergovernmental Panel of Climate Change (IPCC, 2007; Table 4.5). Since the consensus on future precipitation patterns has not been established, changes in precipitation over the analysis period were not presupposed. Instead, two patterns were simulated for each of the four assumptions on temperature change, namely to increase and decrease by 2.5% (mild), 5% (moderate), 10% (pessimistic), and 30% (extreme) from the 2008 level.

Table 4.5 Projection on temperature increases corresponding to atmospheric CO_2 concentration levels in different scenarios over the period 2008-2030 (IPCC, 2007)

Scenarios	CO2 concentration in ppm (IPCC scenario)	Temperature changes (°C)
Staying at 2000 level	369 (IPCC A1 scenario)	No change
Optimistic	420 (IPCC A2 scenario)	0.32°C increase
Moderate	462.5 (IPCC B scenario)	0.72°C increase
Pessimistic and Extreme	527.5 (IPCC C scenario)	1.32°C increase

In addition, each climate change scenario was simulated under two sets of assumptions on the human-controllable variables. In the first set of simulations, all human-controllable variables were fixed at the 2008 level (Figure 4.11). In the second set of simulations, the agricultural labour force and machinery inputs were changed for each year based on our own forecasts (Figure 4.12).

When the human-controllable inputs are fixed at the 2008 level, the two regions have completely different responses to the climate change. In the Northeast region, climate change has a negative impact on maize production over the next two decades. This finding is in line with the results of the entire-country analysis carried out in previous studies (Brown, 1995; Tan and Shibasaki, 2003). For a given level of temperature increase, the direction of change in the precipitation pattern does not matter much. In the Northeast region, precipitation during the climate sensitive stages of maize growth accounts for 62–67% of total annual precipitation (Gao et al, 2010). In other words, rainfall does not seem to be a limiting factor as far as maize production is concerned. Thus, the overall effects of climate variation on maize production are negative, consistent with the estimated results found by Lester Brown (1995) and Tan and Shibasaki (2003).

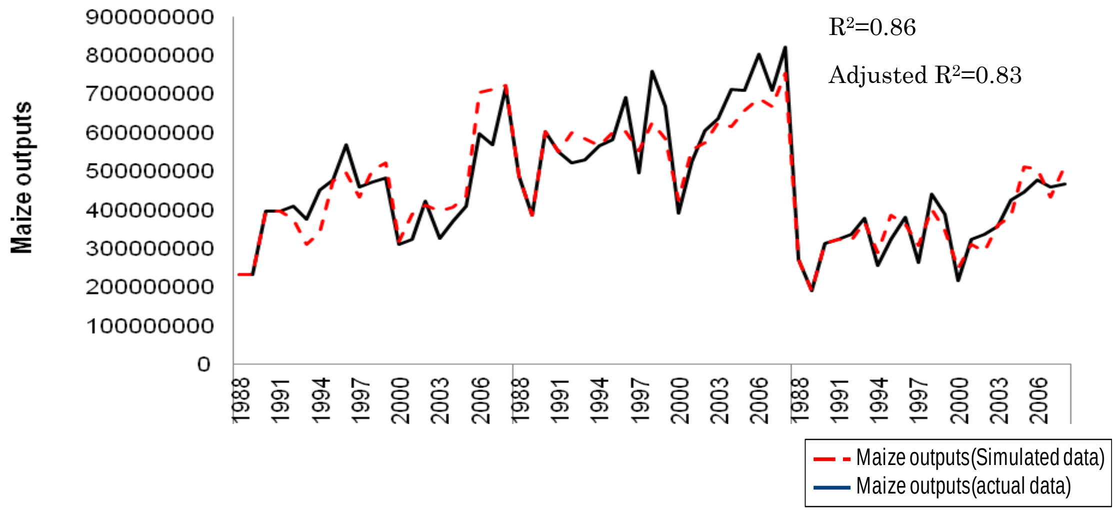
Under the extreme scenario where the temperature increases by 1.32°C and the precipitation by 30% from the 2008 levels, maize production in 2030 is predicted to decrease by 17% from 624 million bushels to 518 million bushels. Under the other extreme scenario where the temperature increases by 1.32°C and the precipitation decreases by 30%, the forecasted output decreases by 18% to 511 million bushels.When climate is assumed to be unchanged from the 2008 level over 2009-2030, maize production level is found to be an optimal condition (Figure 4.11a and Figure 4.11b).

Regional differences of environmental, socioeconomic, and geographic conditions makes maize outputs in Southwest region respond oppositely to that in Northeast region. Contrastingly, the Southwest region is forecasted to experience an increase in maize production. In the Southwest region, warmer climate enables farmers to produce maize more than once in a year. Flexibility of producing timing thus enables the region to better adapt to climate change, and hence a further variation of climate is found to increase maize output even further above the 2008 levels.

Diverting from the results in Northeast, a further increase in temperature in the Southwest has a better effect on maize output than the scenario where climate is unchanged from the 2008 level. In Southwest region, the change in precipitation also affects the production. Since water is a key variable for maize's growth, water availability can signicantly impact maize output. During the planting stage of maize, an appropriate amount of water helps seed sprouts; during the growing season of maize, specific for the reproductive stage, water maize's water demand reaches its highest level, and the deficiency in water in reproductive stage could significantly reduce maize output (Chai 2006). Thus, an increase in precipitation in climate sensitive periods of maize production can increase the soil moisture and mitigate the negative effects of the increased temperature on maize plants, and hence is linked to the development health of maize and the final outcomes of maize outputs. These results are consistent with an earlier report that the precipitation in spring has been the limiting factor in China's Southwest (Liu and Chen, 2005; Li et al., 2011).

Under the same extreme scenario where temperature increases by 1.32°C and precipitation by 30% from the 2008 levels, the Southwest's maize production in 2030 is forecasted to increases by 22% from 216 million bushels to 263 million bushels. If the precipitation decreases by 30%, the production increases by 15% to 249 million bushels.

a. Northeast China (Actual and Simulated Maize outputs)



b. Nine simulated maize outputs result

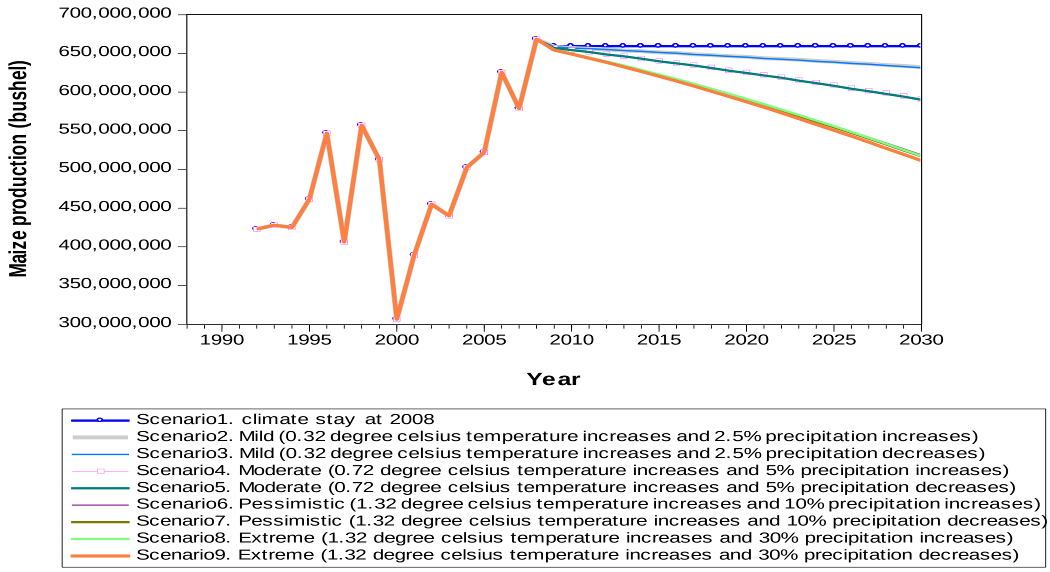
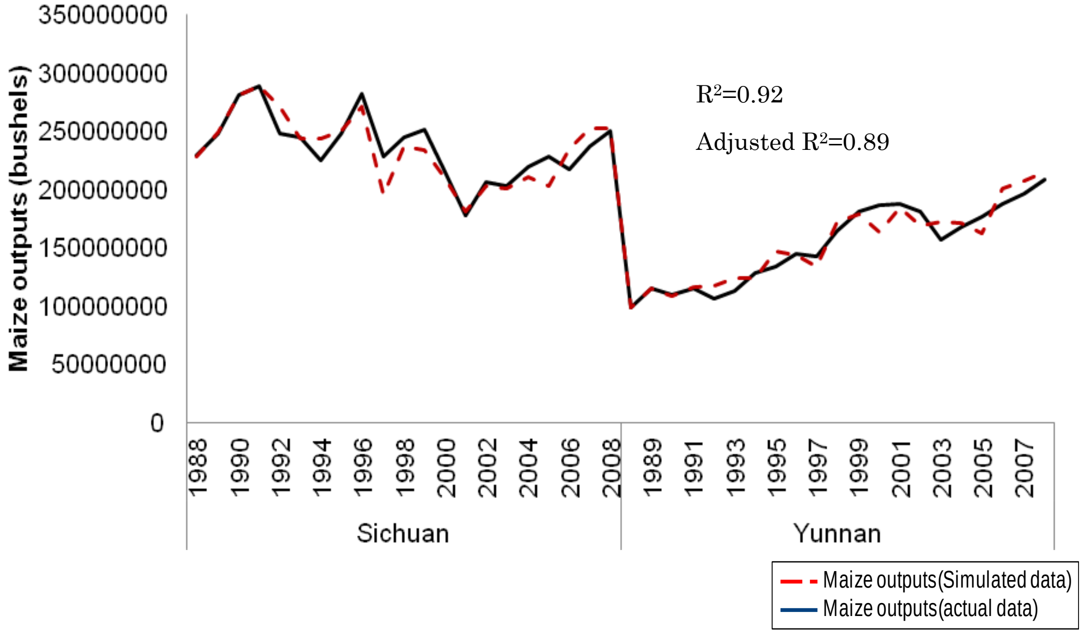


Figure4.11Comparison between actual and simulated maize outputs and simulated maize outputs under nine climate change scenarios in Northeast region (production inputs are fixed at the 2008 level)

b. Southwest China (Actual and Simulated Maize outputs)



b. Southwest China (Nine simulated maize outputs result)

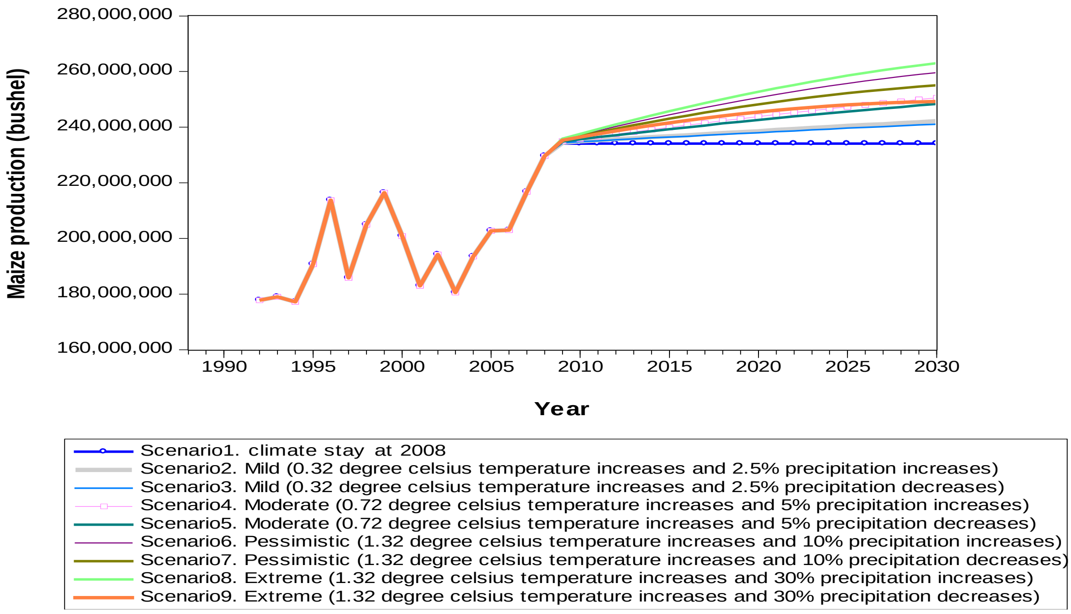
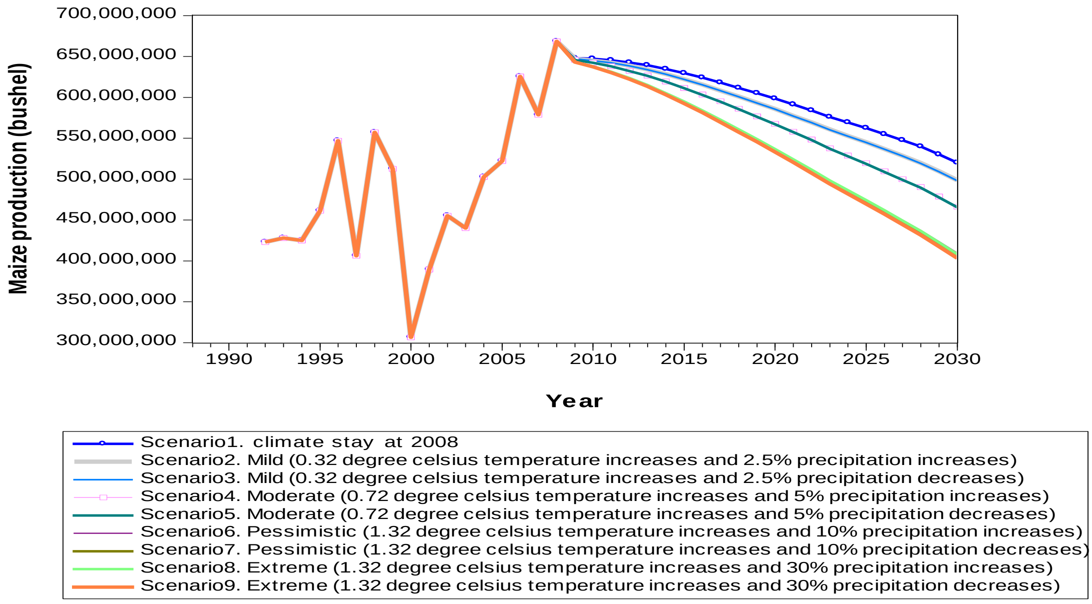


Figure4.11. Comparison between actual and simulated maize outputs and simulated maize outputs in nine climate change scenarios in Southwest region (production inputs are fixed at the 2008 level)

When the climate change is accompanied by a decline in agricultural labour force, the simulation result was less optimistic for both national and international food security. In China, agricultural sector and maize production highly depend on labor force. The reduction of agricultural labor population induced by a structural change of agricultural labor force and aging could lead to a decrease in final maize outputs, even under which substitution of human labour by machinery was also incorporated (Figure 4.12).

In the Northeast region, the extreme increase in temperature leads to a decrease in maize production in 2030 by 34.6% (with increased rain) and 35.4% (with decreased rain) from the 2008 level (see Figure 4.12). These results correspond to only 79% of maize output realised under the assumption of constant labour force and machinery use. Even in the Southwest region, the production will decrease rather than increase, by 6% and 11% under the respective precipitation change. Again, these results are only 78% of what would be produced if labour force and machinery use stay at the 2008 level. A relatively higher vulnerability of maize production in the Southwest region is related to the limitation of its terraced, sloped geography. Machinery cannot be efficiently used in such lands. Therefore, even with an increase machinery use, a decrease in labour force would have negative effect on maize output in this region. Public policies that enable agricultural population to stay in the agricultural sector should be designed and established by the government.

a. Northeast region



b. Southwest region

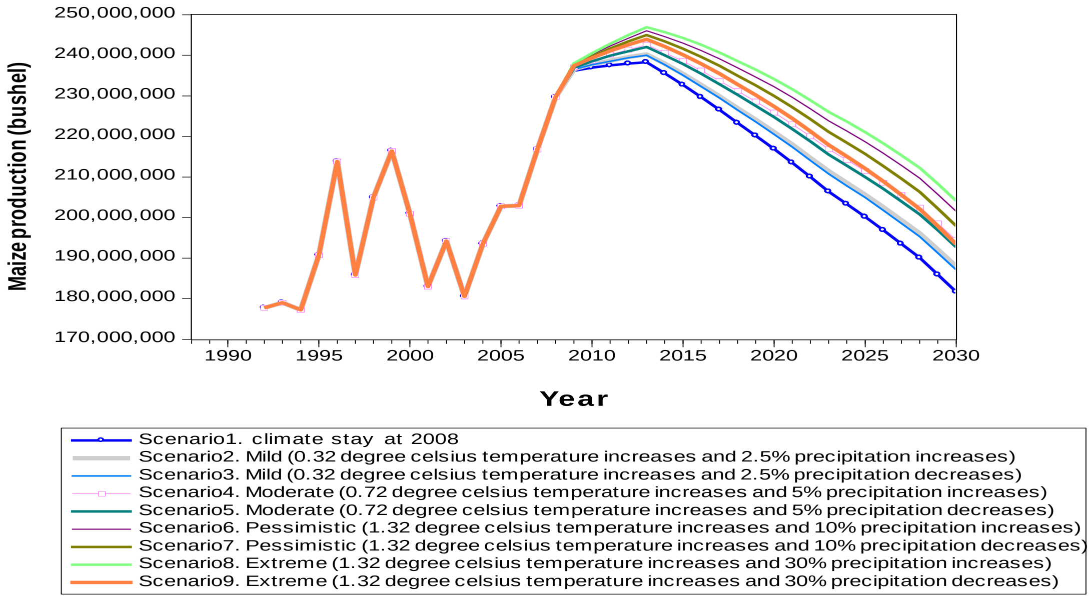


Figure 4.12 Impacts of the climate change on maize production (changes in agricultural population and machinery use assumed based on a separate analysis)

4.5.5 Supply function in profit maximizing condition

4.5.5.1 Conversion of maize production functions to supply functions

Estimated regression functions in format of Cobb-Douglas production functions for the Northeast and the Southwest are summarized in Table 4.6. These functions are converted to supply functions in profit maximizing condition to examine the effects of climate change and input prices on maize production.

Table 4.6 The Northeastern and the Southwestern Cobb-Douglas maize production functions

Country, Region	Cobb-Douglas maize production functions
China, Northeast	$Y = \alpha A^{0.47} L^{0.42} MA^{0.06} CF^{0.21} e^{1.75T} e^{-0.05T^2} e^{(1.91 \cdot 10^{-3})R} e^{(-8.44 \cdot 10^{-6})R^2}$
China, Southwest	$Y = \alpha A^{0.6} L^{0.49} MA^{0.03} CF^{0.13} e^{1.17T} e^{-0.03T^2} e^{(2.14 \cdot 10^{-3})R} e^{(-6.19 \cdot 10^{-6})R^2}$

To do so, the original Cobb-Douglas maize production function explained earlier in this chapter is first prepared at the format below.

Original Cobb-Douglas Maize production function

$$Y = \alpha A^a L^b MA^c CF^d e^{eT} e^{-fT^2} e^{gR} e^{-hR^2} \qquad 1),$$

where Y indicates maize production amount, A for land, L for labor population that participate the maize production process, MA for agricultural machinery use, CF for the applied chemical fertilizer amount, T is average temperature in maize's temperature sensitive periods, and P is average total accumulated precipitation amount in maize's precipitation sensitive periods.

Considering profit maximization:

$$\pi = py - C$$
$$= pf(A, L, MA, CF, T, P) - C(A, L, MA, CF, W_A, W_L, W_{MA}, W_{CF})$$

Where π represents profit, p indicates maize price, py indicates revenue, C represents the total cost, and W represents cost of corresponding input variables.

Inserting production function Y into the profit maximization function and rewrite the function as follow:

$$\pi = p \cdot \alpha A^{a} L^{b} MA^{c} CF^{d} e^{eT} e^{-fT^{2}} e^{gR} e^{-hR^{2}} - C \qquad 2)$$

where $C = W_A A + W_L L + W_{MA} MA + W_{CF} CF$

For the purpose of profit maximization $\pi' = 0$, differentiates *A, L, MA,* and *CF* input variables as below:

$$\frac{\partial y}{\partial A} = p \cdot \alpha a A^{a-1} L^{b} MA^{c} CF^{d} e^{eT} e^{-fT^{2}} e^{gR} e^{-hR^{2}} - W_A A = 0$$

$$\Rightarrow p \cdot \alpha a A^{a} L^{b} MA^{c} CF^{d} e^{eT} e^{-fT^{2}} e^{gR} e^{-hR^{2}} = W_A A \qquad 3.1)$$

$$\frac{\partial y}{\partial L} = p \cdot \alpha b A^{a} L^{b-1} MA^{c} CF^{d} e^{eT} e^{-fT^{2}} e^{gR} e^{-hR^{2}} - W_L L = 0$$

$$\Rightarrow p \cdot \alpha b A^{a} L^{b} MA^{c} CF^{d} e^{eT} e^{-fT^{2}} e^{gR} e^{-hR^{2}} = W_L L \qquad 3.2)$$

$$\frac{\partial y}{\partial MA} = p \cdot \alpha c A^{a} L^{b} MA^{c-1} CF^{d} e^{eT} e^{-fT^{2}} e^{gR} e^{-hR^{2}} - W_{MA} MA = 0$$

$$\Rightarrow p \cdot \alpha c A^{a} L^{b} MA^{c} CF^{d} e^{eT} e^{-fT^{2}} e^{gR} e^{-hR^{2}} = W_{MA} MA \qquad 3.3)$$

$$\frac{\partial y}{\partial CF} = p \cdot \alpha d A^{a} L^{b} MA^{c} CF^{d-1} e^{eT} e^{-fT^{2}} e^{gR} e^{-hR^{2}} - W_{CF} CF = 0$$

$$\Rightarrow p \cdot \alpha d A^{a} L^{b} MA^{c} CF^{d} e^{eT} e^{-fT^{2}} e^{gR} e^{-hR^{2}} = W_{CF} CF \qquad 3.4)$$

Since production function in previous equation 2 is expressed as $Y = \alpha A^{a} L^{b} MA^{c} CF^{d} e^{eT} e^{-fT^{2}} e^{gR} e^{-hR^{2}}$, equations from 3.1 to 3.4 above can be converted to the following expressions.

$$apY = W_A A \Rightarrow A = \frac{apY}{W_A} \qquad 3.5)$$

$$bpY = W_L L \Rightarrow L = \frac{bpY}{W_L} \qquad 3.6)$$

$$cpY = W_{MA}MA \Rightarrow MA = \frac{cpY}{W_{MA}} \qquad 3.7)$$

$$dpY = W_{CF}CF \Rightarrow CF = \frac{dpY}{W_{CF}} \qquad 3.8)$$

Inserting the results 3.5 to 3.8 to the original production equation 2) can obtain a long-term supply function under a completely competitive condition (4.1-4.4)

$$Y = \alpha \frac{apY^{a}}{W_A}\frac{bpY^{b}}{W_L}\frac{cpY^{c}}{W_{MA}}\frac{dpY^{d}}{W_{CF}} e^{eT}e^{-fT^2}e^{gR}e^{-hR^2} \quad 4.1)$$

$$Y = \alpha a^a b^b c^c d^d W_A{}^{-a} W_L{}^{-b} W_{MA}{}^{-c} W_{CF}{}^{-d} p^{(a+b+c+d)} Y^{(a+b+c+d)} e^{eT}e^{-fT^2}e^{gR}e^{-hR^2}$$

4.2)

$$Y^{1-(a+b+c+d)} = \alpha a^a b^b c^c d^d W_A{}^{-a} W_L{}^{-b} W_{MA}{}^{-c} W_{CF}{}^{-d} p^{(a+b+c+d)} e^{eT} e^{-fT^2} e^{gR} e^{-hR^2}$$

4.3)

The converted supply function in profit maximizing condition over the long-term is as follow:

$$Y = \alpha a^a b^b c^c d^{d\frac{1}{1-(a+b+c+d)}} W_A{}^{\frac{-a}{1-(a+b+c+d)}} W_L{}^{\frac{-b}{1-(a+b+c+d)}} W_{MA}{}^{\frac{-c}{1-(a+b+c+d)}}$$

$$W_{CF}{}^{\frac{-d}{1-(a+b+c+d)}} p^{\frac{a+b+c+d}{1-(a+b+c+d)}} e^{\frac{eT}{1-(a+b+c+d)}} e^{\frac{-fT^2}{1-(a+b+c+d)}} e^{\frac{gR}{1-(a+b+c+d)}} e^{\frac{-hR^2}{1-(a+b+c+d)}}$$

4.4)

In short-term, medium-term and long-term, a different combination of area planted *A*, agricultural labor for maize production, and *L* and agricultural machinery use *MA* are fixed in the equations

In the case where area planted *A* is fixed,

$A = \bar{A}$, the price elasticity of supply $= \dfrac{b+c+d}{1-(b+c+d)}$

In the case where area planted *A* and agricultural machinery *MA* are fixed,

$A = \bar{A}, MA = \overline{MA}$, the price elasticity of supply $= \dfrac{b+d}{1-(b+d)}$

In the case where area planted *A*, agricultural machinery *MA* and agricultural labor for maize production L are fixed,

$$A = \overline{A}, MA = \overline{MA},\ L = \overline{L}, \text{ the price elasticity of supply} = \frac{d}{1-(d)}$$

For each case where one or two or three inputs are fixed, the fixed input values at the current 2008 are combined with α in the converted supply function.

Therefore, α becomes $\alpha = \alpha \times A_{2008}{}^{a}$ when land *A* is fixed; α becomes $\alpha = \alpha \times A_{2008}{}^{a} \times MA_{2008}{}^{c}$ when land *A* and agricultural machinery *MA* inputs are fixed, α becomes $\alpha = \alpha \times A_{2008}{}^{a} \times MA_{2008}{}^{c} \times L_{2008}{}^{b}$ when land *A*, agricultural labor for maize production *b*, and agricultural machinery *c* are fixed.

Thus, the Northeastern and the Southwestern supply functions in different periods (from the short-term to the long-term) under a completely competitive condition can be obtained through above processes (Table 4.7). In Table 4.7, short-term supply functions are provided for the Northeast and the Southwest, where land, agricultural machinery use, and agricultural labor for maize production are fixed, and only the *CF*=chemical fertilizer variable is allowed to adjust. Comparatively, mid-term supply functions for both regions allow labor and chemical fertilizer to adjust. In the long-term, more variables become adjustable. Agricultural Machinery, in addition to labor and chemical fertilizer, are allowed to vary. Though a further long-term allows farmers to adjust all variables, including land, the profit maximization problem no longer yields a solution, and therefore an analysis of the price elasticity of supply becomes meaningless in an extremely long-term. Hence, three patterns of supply functions (short-term, mid-term, long-term) in each region are estimated.

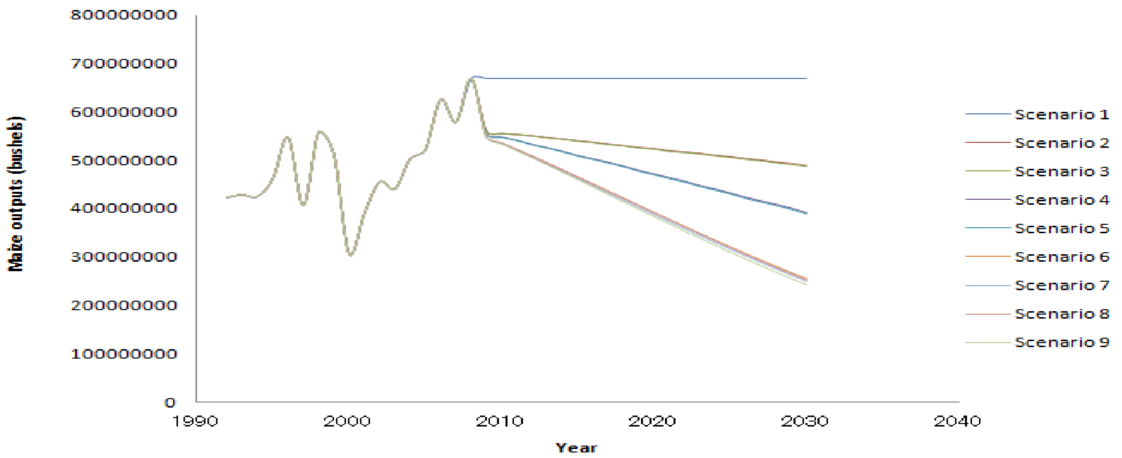
Table 4.7 Converted Northeast and Southwest regional maize supply functions in different periods (from short-term to the long-term periods)

Country, Region	Scenario, periods, (condition)	Maize supply functions
China, Northeast	Short-term, (Variables *A*, *MA*, *L* are fixed, and only the *CF* is adjustable)	$Y = 2.1{W_{CF}}^{-0.27}\mathrm{p}^{0.27}\mathrm{e}^{2.23T}\mathrm{e}^{-0.06T^2}\mathrm{e}^{(2\cdot 10^{-8})R}\mathrm{e}^{(-1.07\cdot 10^{-5})R^2}$
China, Northeast	Mid-term, (Variables *A*, *MA*, are fixed, *L* and *CF* are adjustable)	$Y = 3.82\times 10^{-8}{W_L}^{-1.18}{W_{CF}}^{-0.59}\mathrm{p}^{1.77}\mathrm{e}^{4.85T}\mathrm{e}^{-0.14T^2}\mathrm{e}^{0.01R}\mathrm{e}^{(-2.34\cdot 10^{-5})R^2}$
China, Northeast	Long-term, (Variable *A* is fixed, and *L*,*CF*, and *MA* are adjustable)	$Y = 3.74\times 10^{-11}{W_L}^{-1.41}{W_{MA}}^{-0.2}{W_{CF}}^{-0.71}\mathrm{p}^{2.31}\mathrm{e}^{5.8T}\mathrm{e}^{-0.16T^2}\mathrm{e}^{0.01R}\mathrm{e}^{(-2.79\cdot 10^{-5})R^2}$
China, Southwest	Short-term, (Variables *A*, *MA*, *L* are fixed, and only the *CF* is adjustable)	$Y = 132.89{W_{CF}}^{-0.15}\mathrm{p}^{0.15}\mathrm{e}^{1.34T}\mathrm{e}^{-0.03T^2}\mathrm{e}^{(2\cdot 10^{-8})R}\mathrm{e}^{(-7.12\cdot 10^{-6})R^2}$
China, Southwest	Mid-term, (Variables *A*, *MA*, are fixed, *L* and *CF* are adjustable)	$Y = 7.24\times 10^{-5}{W_L}^{-1.28}{W_{CF}}^{-0.34}\mathrm{p}^{1.63}\mathrm{e}^{3.07T}\mathrm{e}^{-0.07T^2}\mathrm{e}^{0.01R}\mathrm{e}^{(-1.62\cdot 10^{-5})R^2}$
China, Southwest	Long-term, (Variable *A* is fixed, and *L*, *CF*, and *MA* are adjustable)	$Y = 5.2\times 10^{-6}{W_L}^{-1.41}{W_{MA}}^{-0.1}{W_{CF}}^{-0.38}\mathrm{p}^{1.88}\mathrm{e}^{3.37T}\mathrm{e}^{-0.08T^2}\mathrm{e}^{0.01R}\mathrm{e}^{(-1.78\cdot 10^{-5})R^2}$

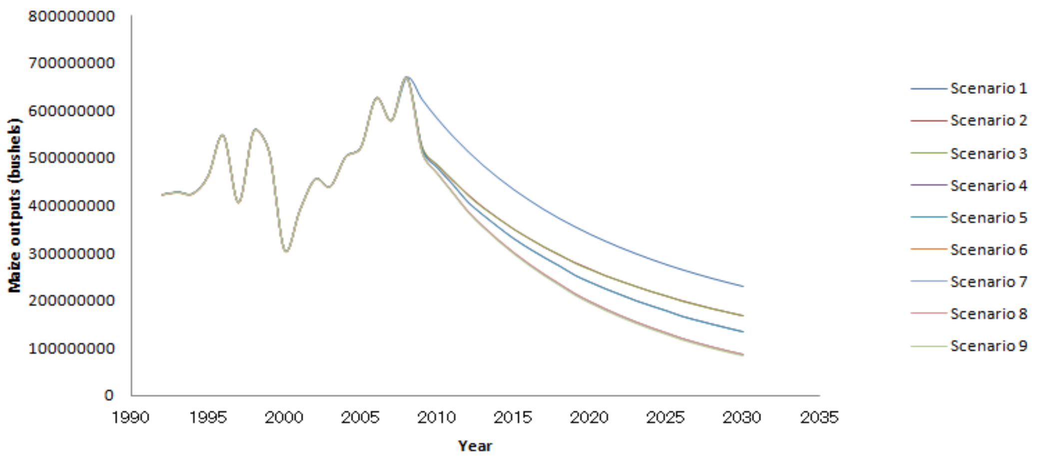
For comparison, supply function in the long-term scenario in Table 4.7 is used to project the potential changes of maize under 9 climate scenarios in three types of time spans (short-term, mid-term, long-term) in both the Northeast and the Southwest regions of China (Figure 4.13 and Figure 4.14). Over the projected period, the productivity of maize production in China is assumed to be unchanged from the 2008 level. Thus, the multiplication of labor and machinery is assumed to be 1. While the cost on labor increase over time due to a reduction of labor supply, machinery cost decreases corresponding as a process of learning-by-doing, a key economic theory stated by the scholars (Dutton and Thomas, 1984). Taken the consideration that the cost on labor is directly affected by changes in labor supply, the inverse of labor population change from 2009-2030 is used (1/labor population change). Similar to the results undergone with production functions, the same trend of projection in both regions can be observed. As stated earlier, the Northeastern average temperature in the 2008 level is over the region's peak level, a further increase in temperature could decrease maize output (Figure 4.13). Thus, maize outputs under different scenarios of climate change decrease in short-term. The Southwestern average temperature in the 2008 level is below the region's peak level. Thus, maize outputs increase in different scenarios (Figure 4.14). Along with time, in mid-term where chemical fertilizer and labor become adjustable, an increase in labor cost as a result of a decrease in labor supply and the nature of labor-dependent agricultural practice style in China make maize outputs in both regions decrease further. Though the learning-by-doing process could help machinery costs decrease over time, the compensation effect of this input to cover the reduced labor input has limitation (maize production level in the long-term is slightly higher than mid-term). It is found that labor is an indispensable input to Chinese agriculture by

2030.

a. Short-term maize outputs in the Northeast region of China



b. Mid-term maize outputs in the Northeast region of China



c. Long-term maize outputs in the Northeast region of China

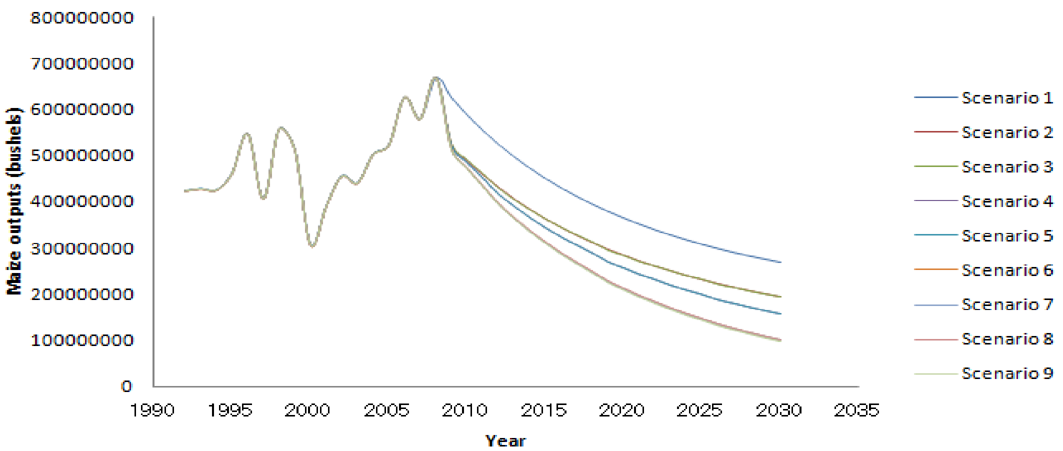
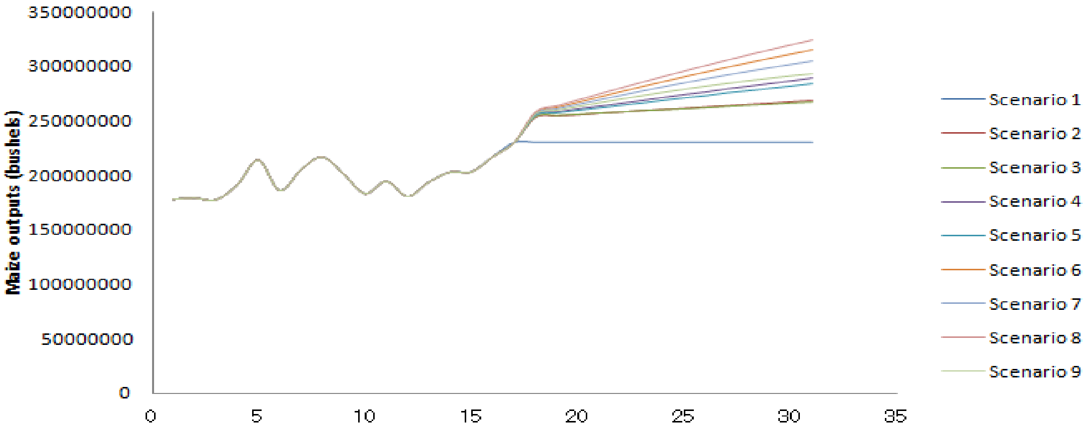


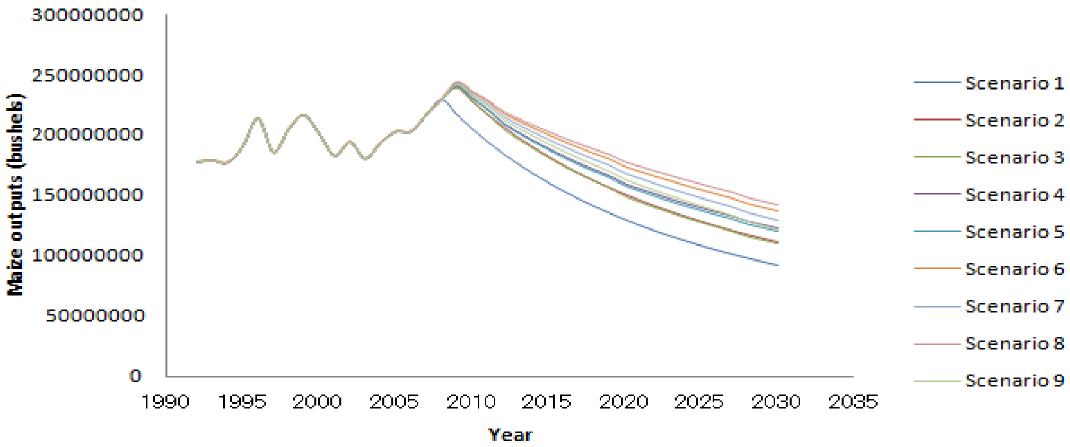
Figure 4. 13 Projected maize outputs in the Northeast region of China over 2009-2030

periods with convereted supply functions (long-term supply function)

a. Short-term maize outputs in the Southwest region of China



b. Mid-term maize outputs in the Southwest region of China



c.Long-term maize outputs in the Southwest region of China

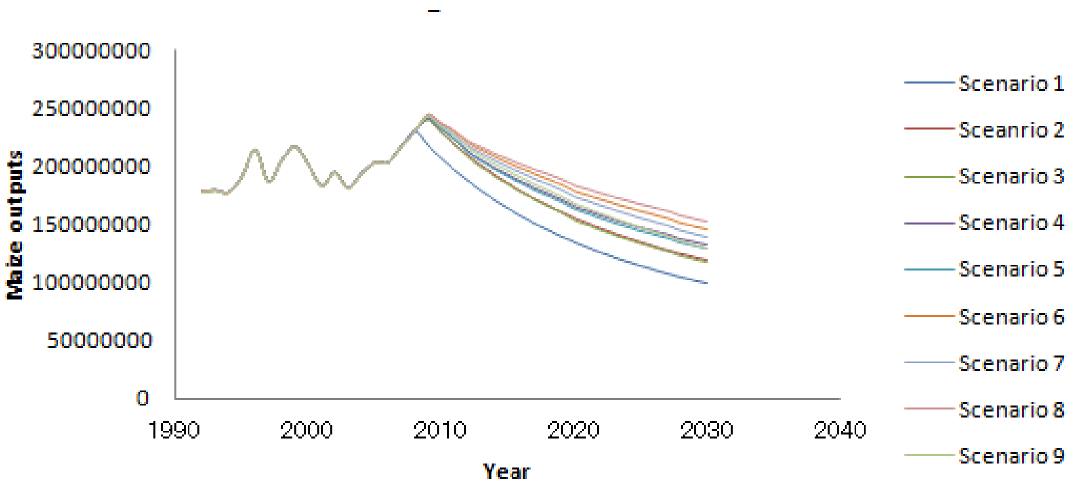


Figure 4. 14 Projected maize outputs in the Southwest region of China over 2009-2030

periods with convereted supply functions (long-term supply function)

It has been noticed that the simulated results under production function utilized case and converted suppply function utilized case are different (Table 4.8 and Table 4.9). Under the case where no change in labor and machinery use occurs, simulated results estimated with a supply function appears to be slightly lower in the Northeastern China, and slight higher in the Southwestern China (Table 4.8). The obvious differences are results of the functions' differences. Under the production function utilized case, farmers are assumed to not to respond to the exterior environment in an optimized way, supply function on the other hand does so.

Though the Cobb-Douglas production function is a widely known mathematical function and is used among researchers to analyze input-ouput relationship, it overlooks the significance of price incentives and management in the crop production process. Under a competitive environment, farmers tend to act in a profit maximizing way and produce maize based on the balance of revenue and cost. Moreover, prices of production inputs and crop output are generally set by the market. Thus, farmers need to take an optimized management approach under an exterior environment determined condition to produce maize. Diverting from past studies that analyzed input-output relationship with a simple production function and overlooked the importance of price incentives and management in the maize production process, this case study converts a production function to a supply function to reflect the importance of prices and farmers' reactions to an exterior environment in an optimal condition for maize production. With this approach, more accurate simulating results can be obtained.

When labor and machinery use are assumed to be unchanged, maize production appears to decrease in both functions in Northeast region and increase in both functions in Southwest region (Table 4.8). Given the background that the Northeast level has a higher mechanization level, fewer farmers, and stadard revenue level, farmers’s responses to an exterior environment can be captured. Appeared in Table 4.8, the reduction level of maize production estimated with a supply function appears to be higher in this region, reflecting the significance of farmers’ response to maize production. Given the background that the Southwest region is poorer, farmers are more responsive to the exterior environment (e.g., price changes) and hence the results estimated with a supply function in an optimized condition in this region are higher.

When the alteration in labor and machinery is allowed, reduction level of maize production is more apparent (Table 4.9). Northeast region in specific appears to have a further reduction in maize production in supply function utilized case. Given the background that the Northeast region has a higher mechanization level, fewer labor and standard revenue level, a further reduction of labor population as a result of ageing will increase labor cost, which turn impact the incentives of farmers and lead to a reduction of maize production. As a result of more abundant labor population, the difference between two functions’s results in the Southwest region is smaller.

Table 4. 8 Simulated results of maize production (difference ratios of maize outputs between 2008 and 2030) under two sets of simulating functions (Cobb-Douglas production function and converted supply function in the Northwest and the Southwest of China (no change in labor and machinery is assumed)

Scenario	Northeastern China		Southwestern China	
	Production function	Supply function	Production function	Supply function
Scenario 1	1.00	1.00	1.00	1.00
Scenario 2	0.95	0.73	1.11	1.21
Scenario 3	0.95	0.73	1.10	1.20
Scenario 4	0.89	0.59	1.14	1.34
Scenario 5	0.89	0.58	1.13	1.30
Scenario 6	0.78	0.38	1.19	1.48
Scenario 7	0.78	0.38	1.16	1.41
Scenario 8	0.78	0.38	1.20	1.54
Scenario 9	0.77	0.36	1.14	1.32

Table 4. 9 Simulated results of maize production (difference ratios of maize outputs between 2008 and 2030) under two sets of simulating functions (Cobb-Douglas production function and converted supply function in the Northwest and the Southwest of China (changes in labor and machinery are assumed)

Scenario	Northeastern China		Southwestern China	
	Production function	Supply function	Production function	Supply function
Scenario 1	1.00	0.4	0.79	0.43
Scenario 2	0.75	0.29	0.82	0.52
Scenario 3	0.75	0.29	0.81	0.51
Scenario 4	0.70	0.23	0.85	0.57
Scenario 5	0.70	0.23	0.84	0.56
Scenario 6	0.61	0.15	0.88	0.63
Scenario 7	0.61	0.15	0.86	0.6
Scenario 8	0.61	0.15	0.89	0.66
Scenario 9	0.60	0.15	0.84	0.56

4.5.5.2 Analysis of price elasticity of maize supply in Northeast region and Southwest region of China over 3 different terms

For both Northeast and Southwest regions, price elasticity of maize supply over 3 different terms are examined to analyze the effects of changes in price on the changes in maize supply (Table 4.10). In short-term where only the chemical fertilizer variable is adjustable, both the Northeast and the Southwest show inelastic price elasticity of supply (Pes<1). While the Northeast shows a higher price elasticity of maize supply (0.27), the Southwest region is 0.15. Since maize crop is an important economic crop in Northeast region and accounts for 30-70% of total agricultural production of the region, farmers in this region are more responsive to price changes. Maize production in Southwest region in contrast accounts for 20-30% of the regional agricultural production. Hence, maize price dependency ratio in the Southwest is lower compared to that in Northeast region.

When the term becomes longer and maize labor also becomes adjustable, the price elasticity of maize supply increases to above 1 (Pes>1) in both the Northeast region and the Southwest (Table 4.10). In mid-term scenario where applied chemical fertilizer amount in addition to maize labor number become adjustable, farmers become more responsive to price changes in both regions. In long-term scenario, farmers show higher reactions (Pes>1). When chemical fertilizer, agricultural maize labor, and machinery use become adjustable, farmers can efficiently adjust their behaviors more to changes in prices. The price elasticity of supply in this case scenario shows the highest value in both regions (2.31 in the Northeast and 1.88 in the Southwest). Again, price elasticity is higher in Northeast region as farmers in this region highly rely on the maize production to support their family. When all variables (land, labor, chemical fertilizer and machinery) are adjustable in an extremely long-term, the summation of coefficients A, L, MA, and CF becomes larger than 1 ((a+b+c+d)>1), indicating the increasing returns to scale characteristics. The original Cobb-Douglas maize production function indicates that maize production outputs increase more than proportionally to the increases in inputs. Hence, the profit maximization problem no longer yields a solution, and therefore an analysis of the price elasticity of supply becomes meaningless.

Table 4.10 Price elasticity of maize supply in the Northeast and the Southwest regions over three different terms specified in the previous Table 4.7

Scenario	Country	Price elasticity of Supply	
		Northeast region	Southwest region
Short-term, (Variables *A*, *MA*, *L* are fixed, and *CF* is adjustable)	China	0.27	0.15
Mid-term, (Variables *A* and *MA* are fixed, *L* and *CF* are adjustable)	China	1.77	1.63
Long-term, (Variable *A* is fixed, and *L*, *CF*, and *MA* are adjustable)	China	2.31	1.88

Next to the maize price elasticity of supply, agricultural maize labor's price elasticity of supply is also examined (Table 4.11). Due to the fact that maize labor is fixed and only the chemical fertilizer variable is adjustable in short-term, maize labor's price elasticity of supply in short-term is not included in analysis. In mid-term where both maize labor and chemical become adjustable, maize labor's price elasticity of supply becomes inelastic in both regions, -1.18 in the Northeast and 1.28 in the Southwest. The results indicate an increase in agricultural labor cost decreases maize supply more than proportion in both regions. In Northeast region, though mechanization level is not low, the major agricultural practice style still relies on labor for a half of the whole maize production process. Thus, labor is a key input for maize production. When an increase in labor cost occurs, it can reduce labor use, which in turn negatively impacts the final result of maize output. On the other hand, the Southwest is poorer and agricultural practice heavily relies on labor. An increase in labor cost directly affects the decisions of farmers, either staying in the rural areas to produce maize or to move to urban for better revenues. Thus, Southwest region shows a stronger negative response to the labor price change, -1.28 (Table 4.11). As more variables become adjustable in the long-term, the Northeast and the Southwest respond further. When the adjustments of input variables become more flexible, farmers become more sensitive and responsive to labor price changes. Maize labor's price elasticity of supply is more elastic in both regions, where the Northeast region is -1.41, and the Southwest is -1.41 in mid-term (Table 4.11). Given the fact that geographical limitation induced labor dependent agricultural practice style and lower average revenue condition could make farmers more sensitive to changes in input costs, a higher response in the Southwest is understandable. In an extremely long-term scenario, the profit maximization problem no longer yields a solution, and therefore an analysis of the price elasticity of supply becomes meaningless. Thus, an extremely long-term scenario is not included in the consideration.

Table 4.11 Maize labor's price elasticity of supply in the Northeast and the Southwest regions over 2 different terms

Scenario	Country	Maize Labor's Price elasticity of Supply	
		Northeast region	Southwest region
Mid-term, (Variables *A* and *MA* are fixed, *L* and *CF* are adjustable)	China	-1.18	-1.28
Long-term, (Variable *A* is fixed, and *L*, *CF*, and *MA* are adjustable)	China	-1.41	-1.41

Chapter V. CASE STUDY 3: The Regional Impacts of Climate Change on Maize Production in the United States and risk mitigation strategies

5.1 Purposes and background of this study

The United States is the largest producer of maize in the world and accounts for over one-third of the world market share in terms of exports. Most of the maize produced in the United States is grown in the "Corn Belt", which includes states in the North Central region of the country (Figure 5.1). The South Central region is a much smaller producer of national output, but is included in the analysis since it may experience different impacts of climate change relative to the North Central region (Figure 5.2). Within a large country like the United States, different climatic and socioeconomic conditions in the North Central and the South regions could imply different regional impacts of climate change on crop production.

Along with the increase in climate change induced climate disasters, the region that had been suitable to produce a particular agricultural crop may no longer be able to maintain its production level in the near future. Furthermore, maize is a key crop in the United States as it is used in both food and energy industries. Moreover, the consumption of maize is not limited to the U.S., but the world. Thus, ensuring a sustainable supply of maize is critically necessary for both the U.S. and the world. In addition, mitigating the potential risks of having a large maize reduction is also important. By distributing the maize production to different regions rather than a concentrated, clustered style, the overall risk of having a large national crop loss could be mitigated.

This case study used a regression function (Cobb-Douglas production function) and converted supply functions in profit maximizing condition to analyze the effects of climate change on maize production in two regions in the United States: the North central region and the South region, to project the potential effects of climate change on maize production in these regions, and to propose potential risk mitigation solutions to combat climate change for protection of maize production industry. With corresponding policies, mid-term to long-term U.S. maize supply stability can be safeguarded.

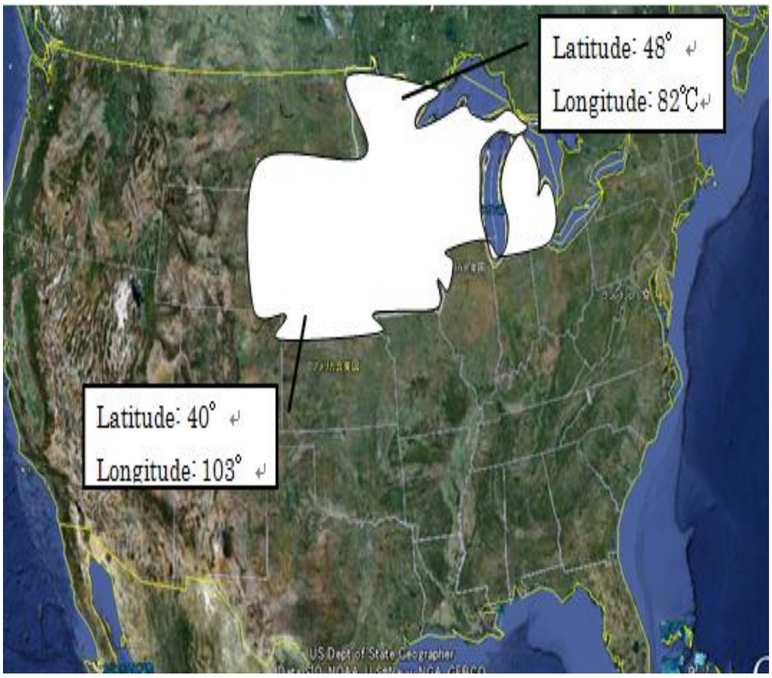
5.2. Materials and Methods

5.2.1 Study Sites

In this case study, the effects of climate change on maize production are analyzed in the North Central region and the South region of the United States. In the United States, the U.S. Climate Zones measure heating degree days (HDD) and cooling degree days (CDD) of each site through calculating the change of temperature to a base temperature (65 degrees Fahrenheit) (EIA, 2002). The whole country is categorized to different zones based on HDD and CDD. Since the U.S. Climate Zones is helpful for people to learn the variation of air temperature among regions, both the U.S. Climate Zones and the U.S. climate regions defined by NOAA (1984) are used to choose states in the two regions.

While the North Central region include six major maize producing states (Iowa, Michigan, Minnesota, Wisconsin, South Dakota, and Nebraska), which range from 40°to 48°north by latitude, 82°to 103°west by longitude, the South region include four major maize producing states (Texas, Louisiana, Oklahoma, Arkansas), which range from 26°to 36°north by latitude, 89°to 105°west by longitude (Table 5.1, Figure 5.1, Figure 5.2).

Presented in Figure 5.1, the North Central region accounts for 50% of total maize production amount in the U.S. Although its share of maize production accounts for only 3% of total national maize production, the South region’s potential for auxiliary maize production to offset or even outweigh potential climate change-induced reductions in maize production in the North Central region could be significant.



States in the U.S	% of maize production each state has on U.S total (Ave 1992-2008)
Iowa	18.51
Michigan	2.59
Minnesota	9.44
Wisconsin	3.8
Nebraska	11.6
South Dakota	3.77
Total	49.71

Figure 5.1 Geographic range of maize production in North Central region of the United States (Source: Google Earth)

States in the U.S	% of maize production each state has on U.S total (Ave 1992-2008)
Texas	2.24
Oklahoma	0.27
Louisiana	0.5
Arkansas	0.29
Total	3.3

Figure 5.2 Geographic range of maize production in South region of the United States (Source: Google Earth)

Table 5.1 Maize production regions in the North Central and the South

Country, Region	**Geographic Position**	**Geographic Position**	**Regional State (Description)**
U.S North Central region,	40°N ~48 °N	82°W~103°W	North Central Region (6 states) 1. Iowa, 2. Michigan, 3. Minnesota, 4. Wisconsin, 5. Nebraska, 6. South Dakota
China, South region,	26°N~36°N	89°E~105°E	South Region (4 states) 1. Texas, 2. Louisiana, 3. Oklahoma, 4. Arkansas

5.2.2 Overall Structure of the model

Departing from the previous studies where either climatic effects or production input effects are usually focused on separately, this research incorporates climate inputs, production inputs, and technology in a regression function (Cobb-Douglas production function) and uses converted supply functions in profit maximizing condition to analyze the impacts of climate change on maize production in the North Central and the South regions. The structure of the model is highlighted conceptually in Figure 5.3, which shows the relationships among the variables.

Temperature and precipitation link the growth and final outputs of maize, and correspond to the sensitive dates in the development of maize. Similar to the previous two case studies, the "CO_2 fertilizer effect" is not assumed to have any effects on maize yields, as the interaction of CO_2 with other environmental factors is still debatable among scientists (IPCC, 2007; Kaiser et al., 1993; Kaiser and Crosson, 1995; Li et al., 2011).

In addition to these two climate variables, maize production inputs that impact the final result of maize production are also included in the model (Figure 5.3). Among production inputs, land input is affected by the Government policies, labor input is affected by revenues, agricultural machinery is affected by revenue and regional geography, and fertilizer is affected by revenue for maize production and the price of international petroleum (Figure 5.3). Given the fact the United States is a leading country in technology R&D, the effect of technology on maize production under a progressive climate change could be significant. Inclusion of technology improvement input in this case study distinguishes this chapter from the previous chapter (Figure 5.3).

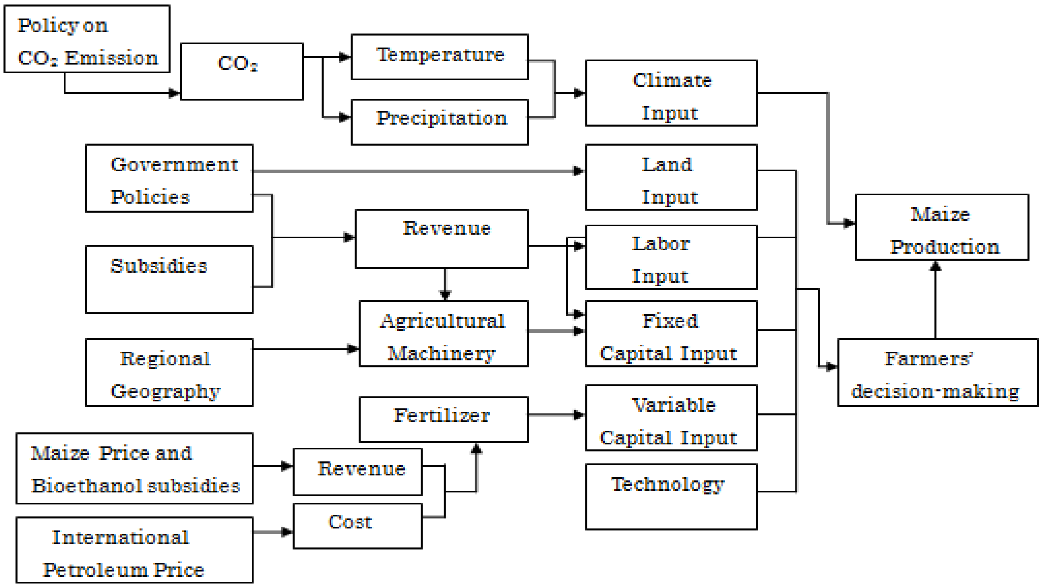


Figure 5.3 Model Structure of this case study

5.3 Model Variables

5.3.1 Climate variables

Temperature and precipitation are two important climate variables that govern the growth and the output of maize. Thus, changes in maize outputs each year are affected by variations of these inputs. Temperature and precipitation in sensitive stages (planting, vegetative and reproductive stages) of maize are crucially important. Thus, climate data (average monthly temperature and average monthly accumulated precipitation) during these stages in corresponding states of two regions are collected over the period of 1992 to 2008.

In both regions, planting season is between April and May and the growing season is between June to July (June for vegetative stage and July for reproductive stage) (Table 5.2). Though maize's plantation season in both regions fall to the same period, the warmer climate in the South enables farmers start plantation earlier.

Table 5.2 Months correspond to temperature and precipitation sensitive stages of maize in the North Central region and the South region of the U.S.

Growth stage	U.S North Central	U.S South
Planting Stage	April, May	April, May
Growing (Vegetative Stage)	June	June
Growing (Reproductive Stage (Silking Stage))	July	July

Diverting from China that is described in the previous studies, each state in the U.S. is composed of 8 to 10 districts under the climate division of NOAA (2012). Thus, cross sectional and time series data on average monthly temperature (Celsius degree) and average monthly accumulated precipitation (mm) that correspond to the planting and the key growing stages of maize over 1992-2008 period are collected at the district levels, and then pooled for each state of the North Central region and the South region

(Table 5.3 and Table 5.4).

Similar to the previous case study, changes in temperature over 2009-2030 period are projected with CO_2 scenarios described in the IPCC's report (2007). In terms of precipitation, two patterns were simulated for each of the four assumptions on temperature change, namely to increase and decrease by 2.5% (mild), 5% (moderate), 10% (pessimistic), and 30% (extreme) from the 2008 level.

Table 5.3 Geographic range of each state in the North Central region of the U.S

Country, Region	State	Geographic Range
U.S., North Central	Iowa	Latitude: 40-43°N; Longitude: 90-96°W
U.S., North Central	Michigan	Latitude: 41-45°N; Longitude: 82-86°W
U.S., North Central	Minnesota	Latitude: 43-48°N; Longitude: 89-96°W
U.S., North Central	Wisconsin	Latitude: 42-46°N; Longitude: 87-92°W
U.S., North Central	Nebraska	Latitude: 40-42°N; Longitude: 95-103°W
U.S., North Central	South Dakota	Latitude: 43-45°N; Longitude: 96-103°W

Table 5.4 Geographic range of each state in the South region of the US

Country, Region	State	Geographic Range
U.S., South	Texas	Latitude: 26-36°N; Longitude: 94-105°W
U.S., South	Louisiana	Latitude: 29-32°N; Longitude: 89-94°W
U.S., South	Oklahoma	Latitude: 33-36°N; Longitude: 94-102°W
U.S., South	Arkansas	Latitude: 33-36°N; Longitude: 89-94°W

5.3.2 Other input variables

Diverting from the previous study, this case study include technology improvement variable, in addition to climate inputs and production inputs (labor, agricultural machinery, fertilizer) in the model.

Comparatively, most data related to maize production in the U.S. were provided in money terms. Thus, production inputs in money terms are used in this case study. To correct for any quality difference in inputs between the two regions, all production inputs in equation (1) expressed in dollar terms are deflated by price paid index (USDA National Agricultural Statistics Service, 2012). States that have similar maize production practices were categorized to be the same region prior to 1995. Data in each state prior to 1995 are collected from the earlier defined regions (North Central; Plain States; Southeast). Thereafter, classification of ERS Farm Resource regions becomes a dominant method to better reflect the regional differences in farm types within the country (USDA, 2012). Thus, data thereafter are collected from the updated version of farm region classification system (Heartland; Northern Crescent; Northern Great Plains; Prairie Gateway; Southern Seaboard; Eastern Uplands).

5.3.2.1 Land input variable

Given the fact that land size can directly impact the final result of maize production, land is a specific input to maize production. Under the definition of USDA Commodity Costs and Return (2012), the importance of land production input is reflected as land rental costs. A previous study conducted by Mendelsohn et al (1994) also proved this view. They used a Ricardian approach and examined the direct impact of climate change on land values using cross sectional data for almost 3000 countries in the 48 contiguous states in the United States for 1982. Thus, data on lands (land cost:

dollars per planted acre) are first collected from the USDA (2012).

In the old regional classification prior to 1995, states in the North Central region are categorized into the following regions. Iowa, Michigan, Minnesota, and Wisconsin were defined to be North Central production region, Nebraska and South Dakota were defined to be Plain States production region. In the South region, Texas was grouped to be Plains States production region, Louisiana closes to Texas was also defined to be Southeast production region. Since the geographic position of Oklahoma is between upper Plains States production region, it is defined to be a Plains States production region. Arkansas on the other hand is located right above the Louisiana State; this state then was defined as a Southeast production region in this case study.

In the new regional classification (ERS Farm Resources regions) after 1995, states in the North Central region are categorized into the following farm resource regions. Iowa was defined to be a Heartland farm resource region; Michigan and Wisconsin were Northern Crescent farm resource region. Since Minnesota covers three farm resource regions (Heartland, Northern Crescent, and Northern Great Plains), Nebraska covers three farm resource regions (Prairie Gateway, Heartland, and North Great Plans), South Dakota covers two farm resource regions (heartland and North Great Plains), data on land costs in each state are pooled and averaged to estimate state-level land values in each year.

For States in the South region, Texas mainly belongs to two resource regions (Prairie Gateway and Southern Seaboard), but also covers a part of Fruitful Rim farm resource region. Given the fact that data in Fruitful Rim farm resource region is unavailable, Texas's land data are estimated by averaging values in
two resource regions. Oklahoma belongs to two resource regions (Prairie Gateway and

Eastern Uplands farm resource regions). Arkansas belongs to three resource regions (Eastern Uplands, Southern Seaboard and Mississippi Portal farm resource regions).Since data in Mississippi Portal farm resource region is unavailable, data in Eastern Uplands and Southern Seaboard are averaged. Louisiana belongs to two resource regions (Southern Seaboard and Mississippi Portal farm resource region). Since data in Mississippi Portal farm resource region is unavailable, Southern Seaboard data is used for Louisiana State. Hence, for states that have more than one state, land costs are averaged to estimate land value at state level.

Land cost in each state in the North Central region and the South region are multiplied to the planted area of maize (thousand acres) provided by USDA (2012) to estimate the state-level total land costs of each state in North Central region and South region (Li et al, 2011; USDA, 2012).

In this case study, land rental cost is deflated to reflect real value. For deflation, price paid index specific for rent is used. In USDA's statistics (2012), national price paid index specific for rent is available. It measures the changes of rental price farmers pay for land production input. While the price paid index data for rent prior to 1993 were provided relative to the base period 1977=100, data thereafter were provided relative to the base period 1990-92=100 under the guidance of agricultural prices in the USDA (2012). They are then converted to 1988=100 base period for unit consistency. Thus, land costs processed earlier is deflated by the paid index specific for rent (relative to the base period 1988=100).

5.3.2.2 Labor input variable

Another important production input for maize production is labor. In the U.S., agricultural sector mainly depends on machinery. However, labor force is still an important variable in supporting the production of maize. Because of a higher mechanization level in the U.S., a fewer number of laborers are needed in the agricultural sector. Though agricultural sector is still a primary sector under the current economic practice classification, large land size, fewer farmers, and subsidies become stimulating factors to farmers to stay in this sector.

In the U.S., labor is composed of two parts: hired labor and unpaid labor. While the self-employment belongs to the category of unpaid labor where the opportunity costs of providing unsalaried labor are measured, costs of hiring people for maize production are categorized as hired labor (USDA, 2012). The two types of labor costs (dollar/ acre unit) at state levels are then summed, multiplied to maize planted area (acre) to estimate the total labor costs (dollars) and deflated by the overall prices paid indexes for commodities and services, interests, taxes, and farm wage rates (PPITW) (USDA NASS, 2012). PPITW is used to estimate pays of farmers to the overall production inputs, such as farm machinery, fertilizer, and wages. Given the fact that the overall national price paid index prior to 1993 were described as relative to the base period 1977=100, and data thereafter were described as relative to the base period 1990-92=100, they are converted to the unified 1988=100 base period.

5.3.2.3 Agricultural Machinery variable

Over the production process of maize, agricultural machinery is also important. Capital costs incurred during the process of maize production are defined differently before and after 1995. Prior to 1995, capital costs were defined to be the sum of capital replacement costs and nonland capital costs (USDA, 2012). While the capital replacement costs were a part of machinery and equipment value, of which the repairs must be paid during the maize production process to maintain the production operation, nonland capital costs were the opportunity costs of investments on farm machinery and equipments that reflect the effective use of capital resources in the production process. To further improve the measuring quality of actual capital costs incurred during the process of maize production, the data switched to the AAEA task force recommendations in 1996, and capital recovery method replaced the previous capital replacement and nonland capital (USDA 2012). The new method estimates the asset ownership cost and levels up the estimation quality for actual capital costs in the production process.

Thus, two types of capital cost data (dollars/planted acre) prior to 1995 are collected from the U.S. commodity Costs and Return data sector and summed up. The processed data prior to 1995 and capital cost data defined by the updated system since 1996 are multiplied to the maize planted area (acre) to estimate the state-level total capital costs (dollars) of each state in North Central region and South region and deflated by PPITW relative to 1988=100 (USDA 2012).

5.3.2.4 Fertilizer

Fertilizer plays a key role in the agricultural sector. Without this input, a jump in crop production since the industrial era would not become possible. In addition, fertilizer costs account for the major share of total maize production costs. Similar to the processing method of land input, data on fertilizer costs (dollars/planted acre) that are available at the state levels are collected based on the different production region classifications prior to and after 1995, then multiplied to maize planted area (unit: acre) to estimate the total fertilizer costs (dollars) of each state in North Central region and South region and deflated by PPITW relative to 1988=100 (USDA 2012).

5.3.2.5 Technology

Technology has helped farmers maintain or increase maize crop production under climate change over the past years, and will continue to play its key role to combat climate change in the future. In addition to climate inputs and production inputs, technology improvement input is also included in the equation to reflect the reality of its importance to maize production under climate change. In this research, technology improvement over the estimated period is assumed to change at a stable rate. It is expressed as a linear time trend (e.g., year 2008 is 2008) as a proxy of technology improvement over time in the model. With this input is incorporated, the analysis of future maize production with technology improvement becomes possible.

5.3.3 Maize output variables

Maize is an important crop in the U.S agriculture. Policies such as subsidy provision and regulations have helped maintain the maize production industry healthy. Illustrated in Figure 5.4, the U.S is the leading country in maize production in the world. Since maize can be used to produce foods and bioethanol, this crop has been a major agricultural crop in the U.S. Over the years, the U.S. has been self-sufficient in maize and export a large amount of maize and maize related products to other countries (Figure 5.5 and Figure 5.6). Due to the stimulating effects of U.S.'s policies and international market, maize exports in the U.S. have increased (Figure 5.6).

In this study, input and output relationship are analyzed with Cobb-Douglas production model and converted supply function. Maize outputs (thousand bushels) in each state of both regions over the period 1992 to 2008 that are used in the estimation are collected from the USDA (2012) and converted to the units of bushels for unit consistency.

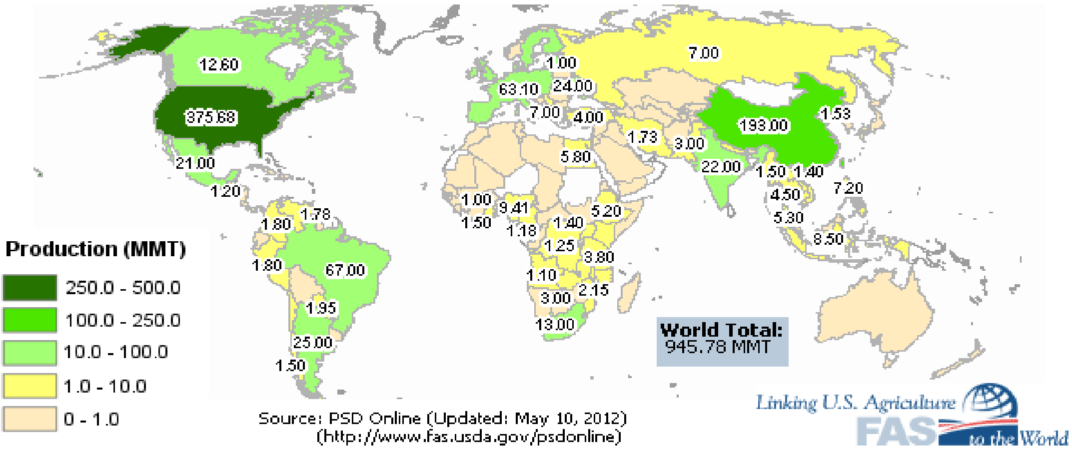


Figure 5.4 A high share of maize production in the U.S. in the global market (Source: Foreign agricultural service USDA)

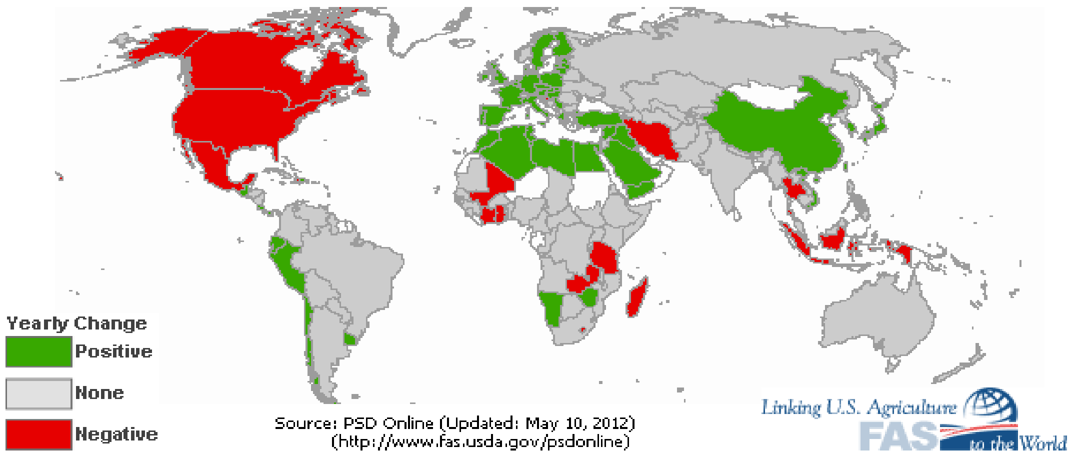


Figure 5.5 2012/2013 maize important (change from previous year) (Source: USDA)

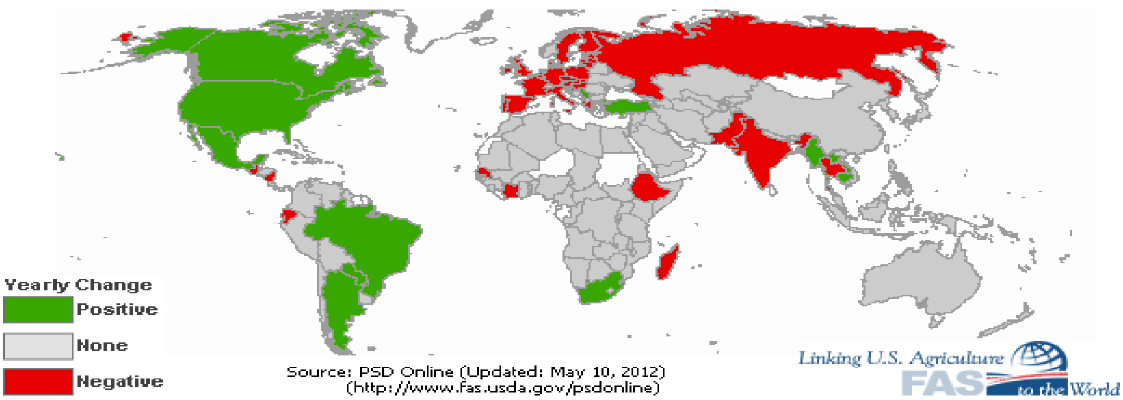


Figure 5.6 2012/2013 maize exports (change from previous year) (Source: USDA)

5.4 Empirical model

Departing from the previous studies where either climatic effects or production input effects are usually focused on separately, this research incorporates climate inputs, production inputs, and technology in a regression function (Cobb-Douglas production function) and uses converted supply functions to analyze the impacts of climate change on maize production in North Central and South regions. As a first part of analysis, a regression model in format of Cobb-Douglas production function is explained here.

For both regions, the following regression function in format of Cobb-Douglas equation is used:

$$\ln(Y)=\beta_0+\beta_1\ln(A)+\beta_2\ln(L)+\beta_3\ln(MA)+\beta_4\ln(CF)+\beta_5 TECH$$
$$+\beta_6 wmT+\beta_7 wmT^2+\beta_8 wmP$$
$$+\beta_9 wmP^2 \qquad (1),$$

where Y is the estimated maize production output (bushels); β_0-β_9 are estimated coefficients; A is land use (in dollars); L represents labor that contributes to the production of maize (labor cost deflated by the overall prices paid indexes for commodities and services) (in dollars); MA is agricultural machinery use (machinery and equipment costs deflated by the overall prices paid indexes for commodities and services) (in dollars); CF refers to the chemical fertilizer use (fertilizer cost deflated by the overall prices paid indexes for commodities and services) (in dollars); $TECH$ is technology (linear trend term); wmT is the weighted mean temperature corresponding to the sensitive seasons of maize's life, including both planting and growing stage (Celsius degree); wmP is the weighted mean precipitation corresponding to the sensitive seasons of maize's life, including both planting stage and growing stage of maize (vegetative stage and reproductive stage) (mm).

For estimation in equation (1), cross-sectional and time series data from the 10 major maize producing states in the two regions (6 states in the North Central region and 4 states in the South region) over the time period 1992 to 2008 are used. Thus, a total of 102 in the North Central and 68 panel data samples in the South for each of variables (climate variables, production variables and output variable) are collected. Given the fact that weather during the sensitive stages of maize development plays a key role in governing the growth and the final outputs of maize, temperature and precipitation in the planting and the growing stage of maize are equally weighted in the equation to reflect their importance to maize (Table 5.2).

5.5 Results

5.5.1 Model analysis Results

The first part uses a regression function (Cobb-Douglas production function) for analysis in the North Central region and the South region (Table 5.5). The results indicate that maize production responds differently to climate and maize production inputs in the two regions. Based on the estimated production function, the contribution of each climatic, production input, and technology in influencing maize outputs in both regions is examined. The input and output links are well represented as the adjusted R-squared values showed 0.96 and 0.98 respectively in the North Central region and the South region.

Table 5.5 Modeling results in the North Central and South of the United States (Data over 1992-2008 are utilized)

Explained variable, (maize outputs)	North Central region in the United States	South region in the United States
Explanatory variables	Coefficients (t-value)	Coefficients (t-value)
Constant	-47.99 (-4.5)	-33.17 (-3.6)
In (A)	4.90×10^{-1} (6.2)	3.60×10^{-1} (5.2)
In(L)	3.20×10^{-1} (2.9)	1.10×10^{-1} (1.3)
In(MA)	2.50×10^{-1} (3.1)	2.10×10^{-1} (2.1)
In(CF)	1.80×10^{-1} (2.8)	3.5×10^{-1} (4.0)
TECH	2.00×10^{-2} (4.5)	2.00×10^{-2} (3.7)
wmT	2.70×10^{-1} (1.5)	6.30×10^{-1} (1.5)
wmT^2	-1.00×10^{-2} (-1.3)	-1.00×10^{-2} (-1.5)
wmP	1.00×10^{-2} (3.7)	1.00×10^{-2} (3.1)
wmP^2	-6.89×10^{-5} (-4.4)	-3.38×10^{-5} (-2.4)
R squared	0.96	0.98
Adjusted R squared	0.96	0.98
D.W.	1.37	1.55

5.5.1.1 Land input

The estimated production functions indicate that among production inputs, land has the largest effect on maize production in both regions (Table 5.5). In the North Central, maize is an important agricultural product produced among farmers. Large land size, fewer farmers and efficient crop producing system make this region strong in maize production. As mentioned earlier, maize production in this region accounts for 49.71% of total maize production in the nation. Given the background of a large share of maize production in this region, it can be considered that its current land use is adequate for maize production. A 1% increase in land is found to increase maize outputs by 0.49% in the North Central region, holding all other factors constant. In the South, a 1% increase in land is found to increase maize outputs by 0.36%.The higher elasticity for the North Central region indicates that its land yields higher output levels for maize than the South region.

In South region, though its current maize production is not high, the region's potential for auxiliary maize production to offset or even outweigh potential climate change-induced reductions in maize production in the North Central region could be significant. Thus, it is worth examining the responses of maize outputs to changing inputs in this region.

5.5.1.2 Agricultural Labor input

Despite the fact that agricultural machinery is critically important for U.S. crop production, labor is still an important input to maize production in the United States. In the two regions, the significance of labor on maize production is found to be different. The labor input in the North Central has the second largest effect on maize production, where a 1% increase in the labor input leads to a 0.32% increase in maize production, holding all other inputs constant. On the other hand, the labor input in the South region is only one-third as large, where a 1% increase in the labor input leads to a 0.11% increase in maize production, holding all other inputs constant.

In the North Central region, there has been a positive trend in self-employment labor and a decrease in hired labor over time, which has been due to decreases in hired labor availability. The larger labor input elasticity in the North Central is likely the result of the relative regional scarcity of hired labor in the North Central region. Given the fact that the South region has been known to be an agricultural producing region in the history, average regional revenue is lower, and more labor population are available and ready to work for the agricultural sector, the availability of hired labor in the South region is more abundant and less expensive.

5.5.1.3 Agricultural Machinery input

Machinery is also an important input for maize production. A 1% increase in the machinery input is estimated to increase maize production by 0.25% in the North Central region and 0.21% in the South region, holding all other factors constant. A higher dependency on machinery input means a higher machinery replacement costs. The large value in the North Central is due to the fact that farmers in this region depend more on maize production.

5.5.1.4 Chemical Fertilizer input

Chemical fertilizer has played its key role in supporting the production of maize since the industrial age. Without this input, the revolution of high yield maize production would not have become real. Despite the key role of the fertilizer input to maize production in the United States, its contribution to maize production is smaller in the North Central region, but is the second largest among production inputs to maize production in the South region. Given the fact that soils in the North Central are specifically rich in nutrients and organic matters, a 1% increase in fertilizer input is found to increase maize production by 0.18% in this region, holding all other factors constant. In the South region, nutrient contents of soils are not as rich the North Central region. Applying this input can greatly improve the growth and development of maize crop, which links to a higher output. A 1% increase in fertilizer input is found to increase maize production by 0.35% in the South, holding all other factors constant. The results are consistent with the regional differences in soil nutrient contents and qualities.

5.5.1.5 Technology improvement input

Over the years, the United States has invested a lot on crop research and development. Due to the practical use of maize, a further increase in maize production has been considered to be important for both farmers and the U.S. government. A 1% increase in technology is found to increase maize outputs by 2% in both regions, holding all other factors constant.

5.5.1.6 Climate inputs

Climate condition directly links to the growth of maize crop and affect the final result of maize output. For both the North Central region and the South region, single cropping is the dominant maize production practice. As stated earlier, April to May corresponds to planting stage, and June to July corresponds to the growing stage (including vegetative and reproductive stage) of maize in both regions (Figure 5.7, Figure 5.8, Figure 5.9 and Figure 5.10). For each region, 50% weight of relative importance is equally applied to temperature and precipitation in corresponding planting and growing season (Table 5.5).

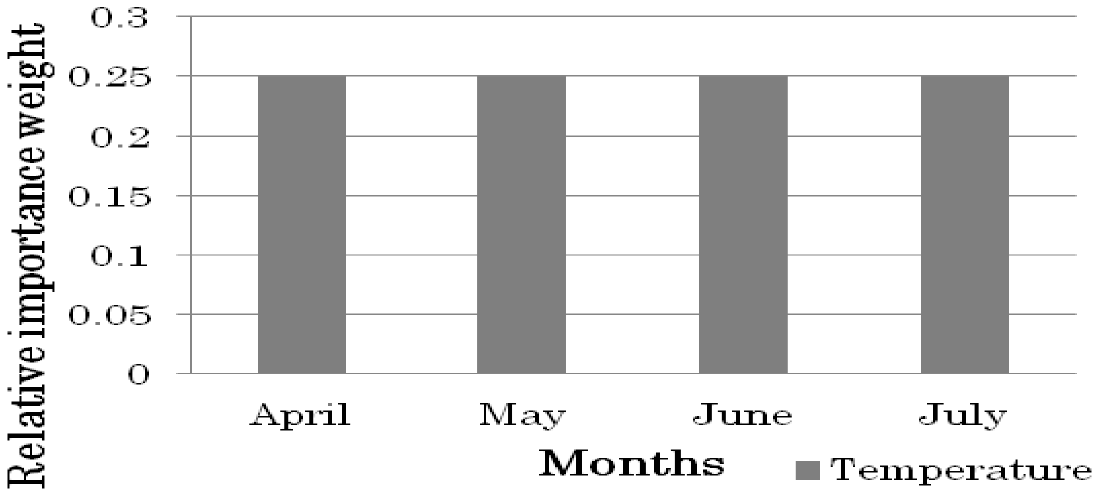


Figure 5.7 Relative importance weight of monthly temperature used in the model for analysis of the North Central region's maize production

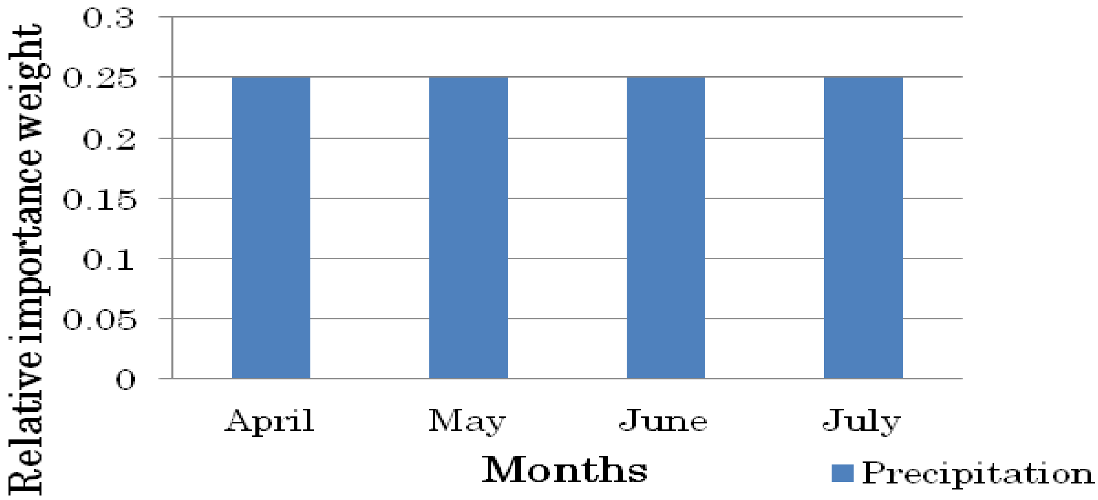


Figure 5.8 Relative importance weight of monthly precipitation used in the model for analysis of the North Central region's maize production

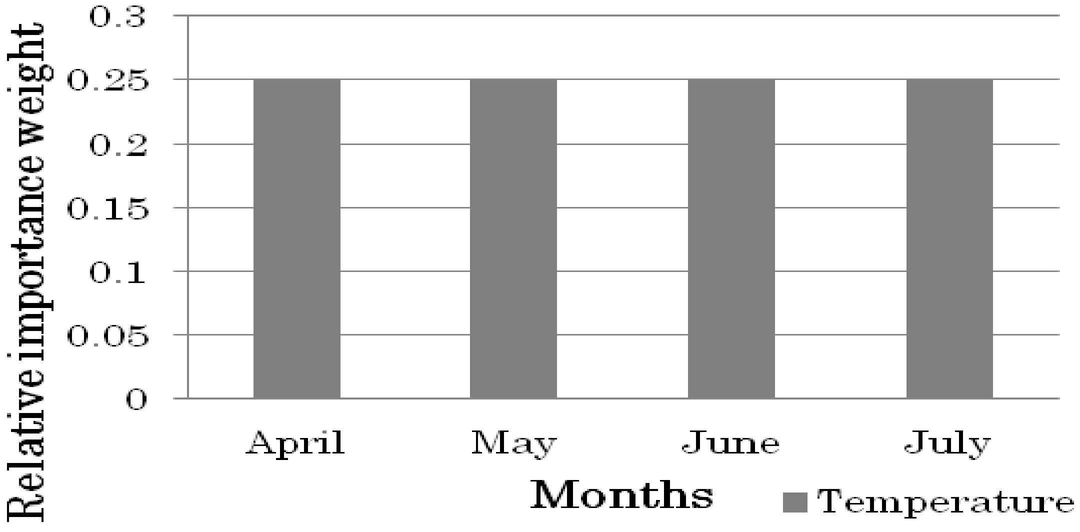


Figure 5.9 Relative importance weight of monthly temperature used in the model of the South region’s maize production

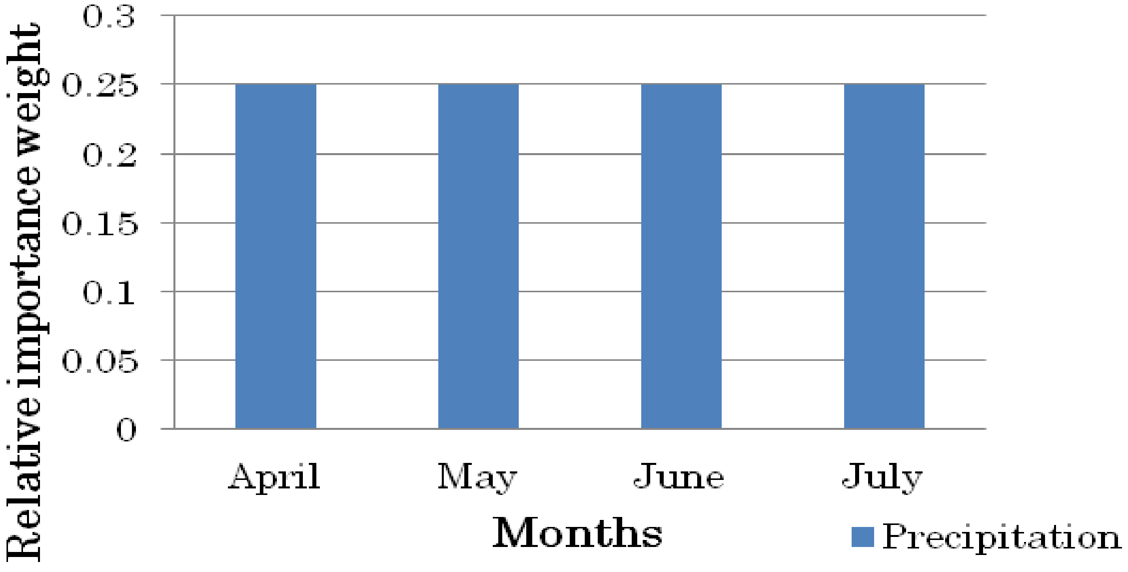


Figure 5.10 Relative importance weight of monthly precipitation used in the model of the South region’s maize production

For both the North Central and the South regions, the estimated results of climate coefficients appear to be relatively inelastic (0<E<1) in the model (Table5.5). In the North Central region, average temperature over the analysis period at the current 2008 level (average of three years’ temperature from 2006 to 2008 is 16.05°C) is below the peak average temperature (16.91°C), holding all other factors constant. A 1°C increase in temperature from the current level is found to increase maize production by 0.58% from the present, but is below the maize production level at the peak temperature. In the South region, average temperature at the current level (average of three years' temperature from 2006 to 2008 is 23.26°C) is slightly over the turning point of average temperature (23.1°C), holding all other factors constant. A 1°C increase in temperature above the current level is found to decrease maize 1.77% from the 2008 level. A positive response to temperature in the North Central region is likely due to its higher latitude range and relatively lower temperature.

On the other hand, in the North Central region, a 1mm increase in precipitation can increase maize outputs by 0.02% from the present level, hold other factors constant. In the South region, a 1 mm increase in precipitation is found to increase maize by 0.28%. This more positive response in the South region is likely the result of the mitigating effects of a relatively warmer climate.

5.5.2 Analysis of precipitation effects on maize outputs

The biophysical link between precipitation and maize output in the North Central and South region are examined where all inputs, excluding temperature input, are controlled at the 2008 level (Figure 5.11 and Figure 5.12).

Average precipitation over the analysis period in the North Central region at the current level (average of three years' precipitation from 2006 to 2008 is 87.93 mm) is found to be slightly below the turning point of average precipitation (89.9 mm), holding that all other factors are constant. Though a 1mm increase in precipitation can increase maize outputs by 0.02% from the present level in this region, a further increase in precipitation can have negative impacts on maize production. This result is consistent with an earlier report that showed precipitation change derived by climate change can decrease maize production (Brown and Rosenberg, 1999; Rosenzweig et al., 2002; Motha and Baier, 2005).

In the South region, average precipitation over the analysis period at the 2008 level (average of three years' precipitation from 2006 to 2008 is 104 mm) is well below the peak turning point (145.87 mm), holding all other factors constant. A 1 mm increase in precipitation is found to increase maize by 0.28%. This more positive response in the South region is likely the result of the mitigating effects of a relatively warmer climate.

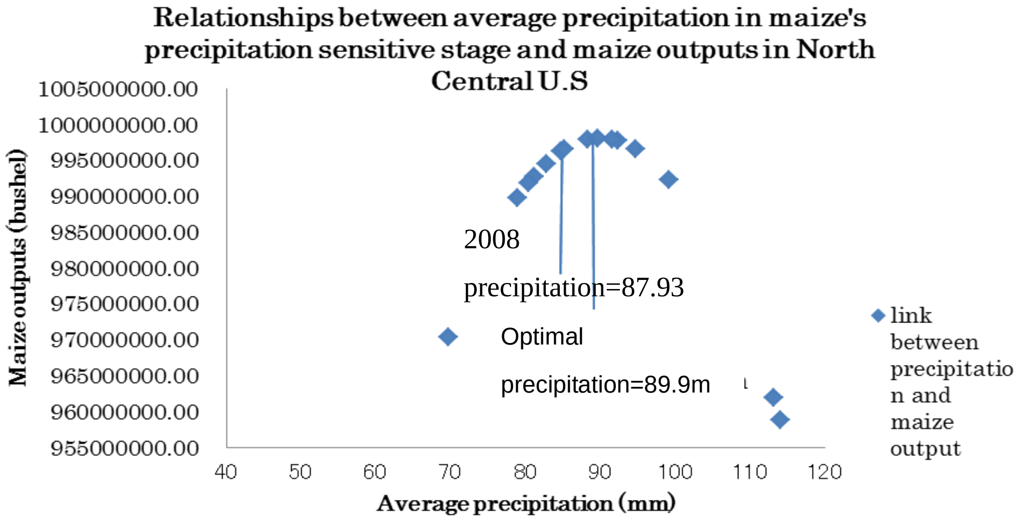


Figure 5.11 Relationship between average precipitation maize's sensitive stages and output in the North Central region

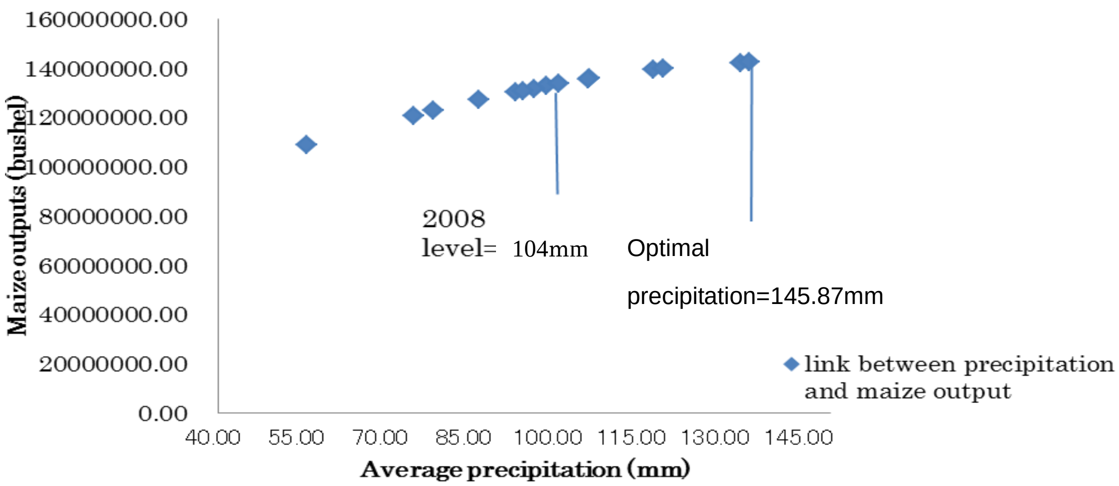


Figure 5.12 Relationship between average precipitation maize's sensitive stages and output in the South region

5.5.3 Projections of climate change effects on maize outputs with varying climate scenarios

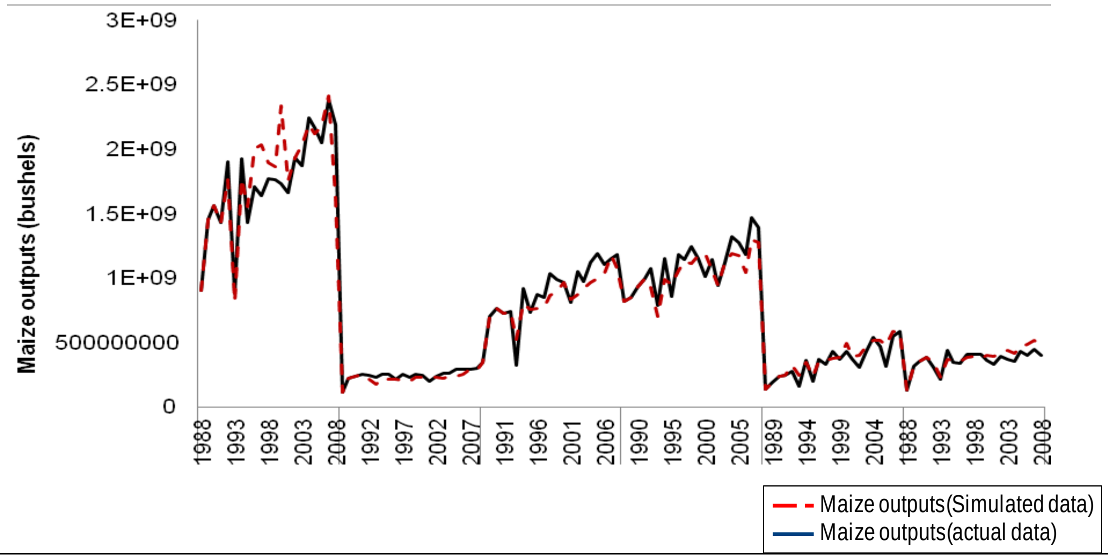
5.5.3.1 Analysis of climate change effects on maize outputs where technology improvement input is controlled to be unchanged from the 2008 level

The impacts of climate change on maize outputs are first analyzed with all variables, excluding climate variables, are controlled to be unchanged from the 2008 (average of 2006-2008) level. Similar to the previous case studies, nine climate scenarios are simulated: (1) optimistic, or no climate change from 2008 level, (2) mild warmer (0.32°C) and wetter (2.5% increase in precipitation), (3) mild warmer (0.32°C) and drier (2.5% decrease in precipitation), (4) moderately warmer (0.72°C) and wetter (5% increase in precipitation), (5) moderately warmer (0.72°C) and drier (5% decrease in precipitation), (6) pessimistic warmer (0.72°C) and wetter (10% increase in precipitation), (7) pessimistic warmer (0.72°C) and drier (10% increase in precipitation), (8) extremely warmer (1.32C°) and wetter (30% increase in precipitation), and (9) extremely warmer (1.32C°) and drier (30% decrease in precipitation). These scenarios are based on the projected changes specified in the Fourth Assessment Report of the Intergovernmental Panel of Climate Change (IPCC, 2007).

The projected results show that the responses in the two regions could be opposite to each other (Figure 5.13 and Figure 5.14).As stated earlier, in North Central U.S., the current precipitation level in 2008 (87.93mm) is already closes to the peak level (89.9mm). A further increase in this input with an increase in temperature could reduce maize output from 2008 levels (Figure 5.13). In the South U.S, the current precipitation level in 2008 (104mm) is still below the peak level (145.87mm). An increase in both temperature and precipitation could have a much better effect on maize output than a decrease in precipitation with an increase in temperature.

Adjusted R^2=0.96

a. Comparison between actual and simulated maize outputs



b. Simulated maize outputs in nine cliamte change scenarios

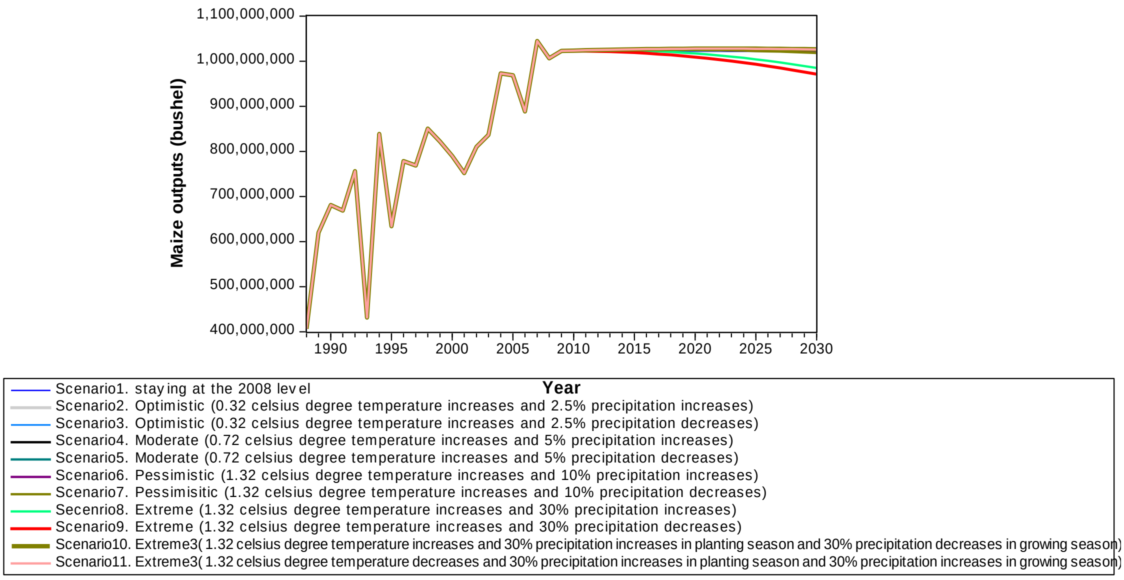
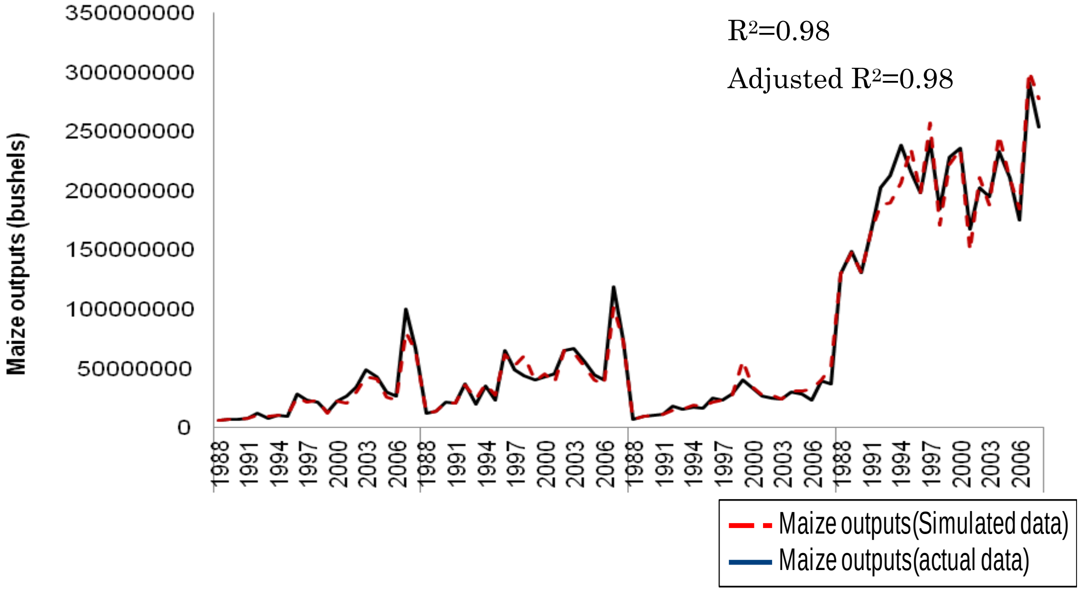


Figure 5.13 Maize outputs under different climate scenarios in North central region where technology and all production inputs controlled to be unchanged from the 2008 level

a. Comparison between actual and simulated maize outputs



b. Simulated maize outputs in nine cliamte change scenarios

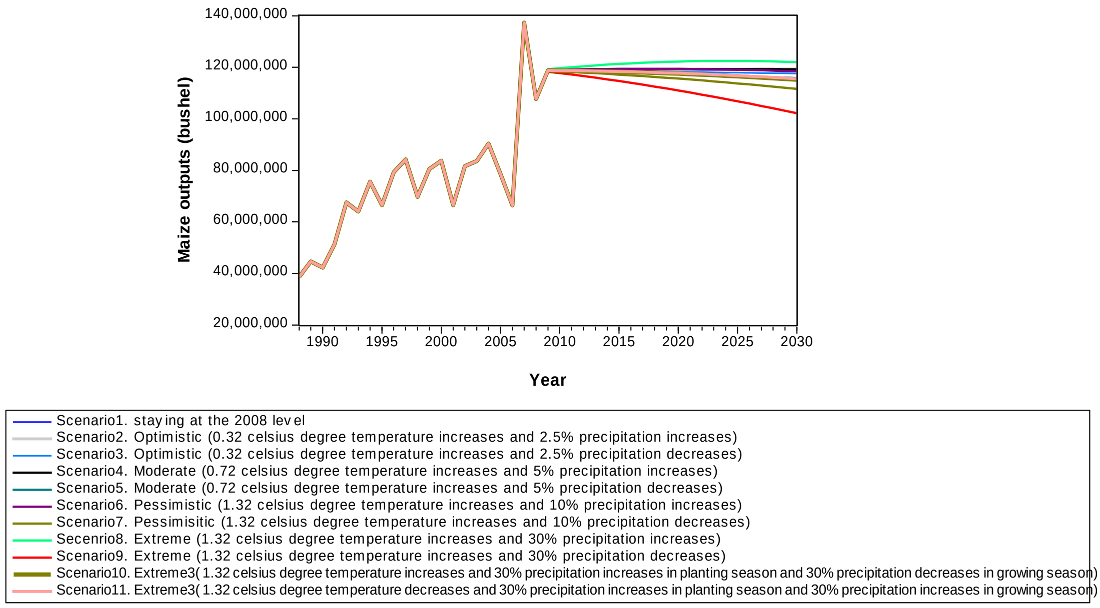


Figure 5.14 Maize outputs under different climate scenarions in the South region where technology and all production inputs are controlled to be unchanged from the 2008 level

5.5.3.2 The effects of climate change on maize output where technology improves over the projected periods

Figure 5.15 and Figure 5.16 illustrate simulated maize outputs in the North Central region and the South region for the nine climate scenarios. Technology improvement is allowed to improve over the 2009-2030 periods.

With technology improvement following past trends, maize production is predicted to increase from just over one billion bushels (2008) to 1.72 billion bushels (2030) under no climate change (Figure 5.15). This represents a 71% increase due to technological improvements when no change in climate is assumed. Under all climate change scenarios, maize production increases over time but at different rates. For example, under both moderate scenarios, maize production actually increases by more than under no climate change. Specifically, by 2030, maize production in the moderately warmer scenarios is 0.6% (wetter) higher and 0.3% (drier) higher than under no climate change. However, maize production suffers slightly under the more extreme scenarios compared with no climate change. For example, under the extreme wetter scenario, maize production is about 4% lower by 2030 compared with the no climate change scenario. Under the extreme drier scenario, maize production is about 5% lower by 2030 compared with the no climate change scenario.

In the South Central region, maize production increases from 107.7 million bushels in 2008 to 166.1 million bushels in 2030 in the no climate change scenario (Figure 5.16). That is, technological progress causes an increase of 54.2% in maize output assuming climate does not change. As is true for the North Central region, maize production is higher under all climate change scenarios in 2030 compared to 2008 due to technological improvements. Located in the lower latitude, the South Central region has a higher average annual temperature (17.32°C) than North Central region (6.71°C). The evaporation rate of soil water in this region is faster during the growing period of maize. While an increase in precipitation mitigates the water deficiency of maize, a decrease in precipitation, even in the moderate scenario, puts pressure on maize. In comparison with the result in the no climate change scenario, maize output decreases by 2.5% and 14% in the moderate and severe scenarios, respectively, where precipitation decreases. However, maize production in this region is higher than under the no climate change scenario for the two scenarios involving an increase in precipitation. In the moderate and severe scenarios where precipitation increases, maize output by 2030 is 0.3% and 2.7% higher than the corresponding no climate change scenario. Hence, it appears that a warmer but wetter climate will increase maize production, while a warmer, but drier climate will decrease maize production relative to no climate change in the South Central region.

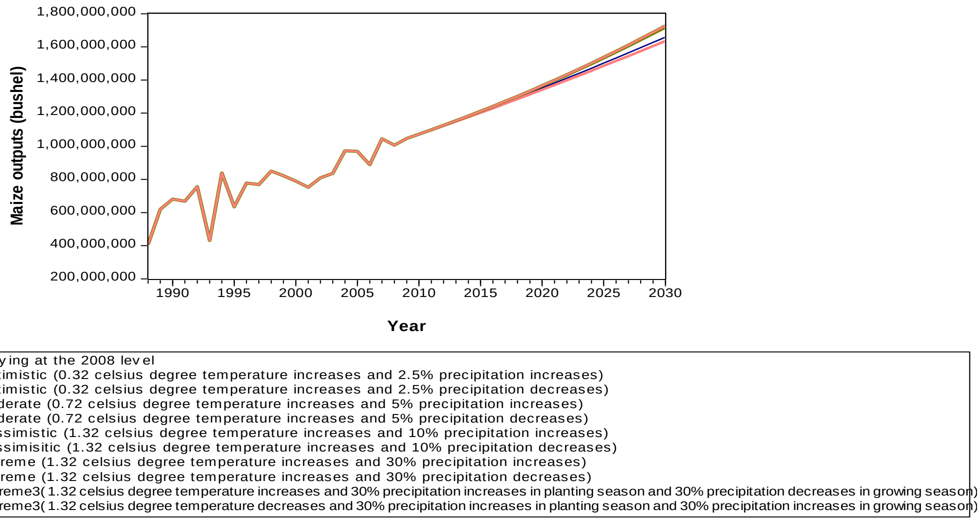


Figure 5.15 Maize outputs under nine climate scenarios in the North central region over the period 2009 to 2030 (with a further technology improvement)

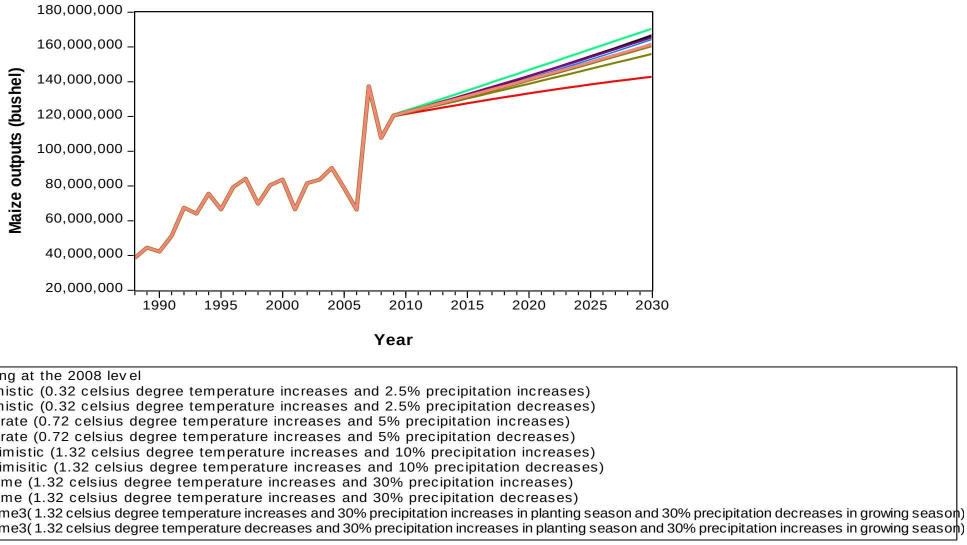


Figure 5.16 Maize outputs under nine climate scenarios in the South U.S over the period 2009 to 2030 (with a further technology improvement)

5.5.4 Production function

5.5.4.1 Conversion of maize production function to supply function

Regression functions in format of Cobb-Douglas production functions in the North Central and the South regions of the U.S. are summarized in Table 5.6, and they are converted to supply functions to examine the changes of maize production outputs corresponding to the changes in technology improvement and input prices.

Table 5.6 The North Central and the South regions' Cobb-Douglas maize production functions

Country, Region	Cobb-Douglas maize production functions
U.S., North Central	$Y = \alpha A^{0.49} L^{0.32} MA^{0.25} CF^{0.18} e^{0.02Tech} e^{0.27T} e^{(8.04 \cdot 10^{-3})T^2} e^{0.01R} e^{(-6.89 \cdot 10^{-5})R^2}$
U.S., South	$Y = \alpha A^{0.36} L^{0.11} MA^{0.21} CF^{0.35} e^{0.02Tech} e^{0.63T} e^{-0.01T^2} e^{0.01R} e^{(-3.38 \cdot 10^{-5})R^2}$

To do so, the original Cobb-Douglas maize production function explained earlier in this chapter is first prepared at the format below. Original Cobb-Douglas Maize production function

$$Y = \alpha A^a L^b MA^c CF^d e^{iT} e^{eT} e^{-fT^2} e^{gR} e^{-hR^2} \quad 1)$$

where *Y* indicates maize output, *A* represents land, *L* represent labor population for maize production, *MA* represents agricultural machinery use in the process of maize production, *CF* indicates the applied amount of chemical fertilizer, *Tech* represents technology improvement, *T* represents average temperature in maize's temperature sensitive periods, and *P* represents average total accumulated precipitation amount in maize's precipitation sensitive periods.

Considering profit maximization:

$$\pi = py - C$$
$$= pf(A, L, MA, CF, Tech, T, P) - C(A, L, MA, CF, W_A, W_L, W_{MA}, W_{CF})$$

where π represents profit, *p* indicates maize price, *py* indicates the revenue, and *C* represents the total cost, and *W* represents the costs of corresponding input variables.

Inserting the production function Y into the profit maximizing function and rewrite the function as follows:

$$\pi = p \cdot \alpha A^{a} L^{b} MA^{c} CF^{d} e^{iTech} e^{eT} e^{-fT^{2}} e^{gR} e^{-hR^{2}} - C \qquad 2)$$

where $C = W_A A + W_L L + W_{MA} MA + W_{CF} CF$

For the purpose of profit maximization $\pi' = 0$, differentiating *A*, *L*, *MA*, and *CF* input variables as below:

$$\frac{\partial y}{\partial A} = p \cdot \alpha a A^{a-1} L^{b} MA^{c} CF^{d} e^{iTech} e^{eT} e^{-fT^{2}} e^{gR} e^{-hR^{2}} - W_A A = 0$$

$$\Rightarrow p \cdot \alpha a A^{a} L^{b} MA^{c} CF^{d} e^{iTech} e^{eT} e^{-fT^{2}} e^{gR} e^{-hR^{2}} = W_A A \qquad 3.1)$$

$$\frac{\partial y}{\partial L} = p \cdot \alpha b A^{a} L^{b-1} MA^{c} CF^{d} e^{iTech} e^{eT} e^{-fT^{2}} e^{gR} e^{-hR^{2}} - W_L L = 0$$

$$\Rightarrow p \cdot \alpha b A^{a} L^{b} MA^{c} CF^{d} e^{iTech} e^{eT} e^{-fT^{2}} e^{gR} e^{-hR^{2}} = W_L L \qquad 3.2)$$

$$\frac{\partial y}{\partial MA} = p \cdot \alpha c A^{a} L^{b} MA^{c-1} CF^{d} e^{iTech} e^{eT} e^{-fT^{2}} e^{gR} e^{-hR^{2}} - W_{MA} MA = 0$$

$$\Rightarrow p \cdot \alpha c A^{a} L^{b} MA^{c} CF^{d} e^{iTech} e^{eT} e^{-fT^{2}} e^{gR} e^{-hR^{2}} = W_{MA} MA \qquad 3.3)$$

$$\frac{\partial y}{\partial CF} = p \cdot \alpha d A^{a} L^{b} MA^{c} CF^{d-1} e^{iTech} e^{eT} e^{-fT^{2}} e^{gR} e^{-hR^{2}} - W_{CF} CF = 0$$

$$\Rightarrow p \cdot \alpha d A^{a} L^{b} MA^{c} CF^{d} e^{iTech} e^{eT} e^{-fT^{2}} e^{gR} e^{-hR^{2}} = W_{CF} CF \qquad 3.4)$$

Since production function in the previous equation 1 is expressed as $Y = \alpha A^{a} L^{b} MA^{c} CF^{d} e^{iTech} e^{eT} e^{-fT^{2}} e^{gR} e^{-hR^{2}}$, equations from 3.1 to 3.4 above can be converted to the following expressions.

$$apY = W_A A \Rightarrow A = \frac{apY}{W_A} \qquad 3.5)$$

$$bpY = W_L L \Rightarrow L = \frac{bpY}{W_L} \qquad 3.6)$$

$$cpY = W_{MA} MA \Rightarrow MA = \frac{cpY}{W_{MA}} \qquad 3.7)$$

$$dpY = W_{CF} CF \Rightarrow CF = \frac{dpY}{W_{CF}} \qquad 3.8)$$

Insertion of results 3.5 to 3.8 to the original production 1) equation can obtain a long-term supply function under a completely competitive condition (4.1-4.4)

$$Y = \alpha \frac{apY^a}{W_A} \frac{bpY^b}{W_L} \frac{cpY^c}{W_{MA}} \frac{dpY^d}{W_{CF}} \quad e^{iTech} e^{eT} e^{-fT^2} e^{gR} e^{-hR^2} \quad 4.1)$$

$$Y = \alpha a^a b^b c^c d^d W_A{}^{-a} W_L{}^{-b} W_{MA}{}^{-c} W_{CF}{}^{-d} p^{(a+b+c+d)} Y^{(a+b+c+d)} e^{iTech}$$

$$e^{eT} e^{-fT^2} e^{gR} e^{-hR^2} \qquad 4.2)$$

$$Y^{1-(a+b+c+d)} = \alpha a^a b^b c^c d^d W_A{}^{-a} W_L{}^{-b} W_{MA}{}^{-c} W_{CF}{}^{-d} p^{(a+b+c+d)} e^{iTech} e^{eT} e^{-fT^2} e^{gR} e^{-hR^2}$$

4.3)

Hence

$$Y = \alpha a^a b^b c^c d^d{}^{\frac{1}{1-(a+b+c+d)}} W_A{}^{\frac{-a}{1-(a+b+c+d)}} W_L{}^{\frac{-b}{1-(a+b+c+d)}} W_{MA}{}^{\frac{-c}{1-(a+b+c+d)}}$$

$$W_{CF}{}^{\frac{-d}{1-(a+b+c+d)}} p^{\frac{a+b+c+d}{1-(a+b+c+d)}} e^{\frac{iTech}{1-(a+b+c+d)}} e^{\frac{eT}{1-(a+b+c+d)}} e^{\frac{-fT^2}{1-(a+b+c+d)}} e^{\frac{gR}{1-(a+b+c+d)}} e^{\frac{-hR^2}{1-(a+b+c+d)}}$$

4.4)

In short-term, medium-term and long-term, a different combination of area planted *A*, agricultural labor for maize production *L* and agricultural machinery use *MA* are fixed in the equations

In the case where area planted *A* is fixed,

$A = \bar{A}$, the price elasticity of supply $= \dfrac{b+c+d}{1-(b+c+d)}$

In the case where area planted *A* and agricultural machinery *MA* are fixed,

$A = \bar{A}, MA = \overline{MA}$, the price elasticity of supply $= \dfrac{b+d}{1-(b+d)}$

In the case where area planted *A*, agricultural machinery *MA* and agricultural labor for maize production *L* are fixed,

$A = \overline{A}, MA = \overline{MA},\ L = \overline{L}$, the price elasticity of supply $= \dfrac{d}{1-(d)}$

For each case where one or two or three inputs are fixed, the fixed input values at the 2008 level are combined with α to produce a new α value in the conversion process of production function to supply function.

Hence, α becomes $\alpha = \alpha \times A_{2008}{}^{a}$ when land *A* is fixed; α becomes $\alpha = \alpha \times A_{2008}{}^{a} \times MA_{2008}{}^{c}$ when land *A* and Agricultural machinery *MA* inputs are fixed, α becomes $\alpha = \alpha \times A_{2008}{}^{a} \times MA_{2008}{}^{c} \times L_{2008}{}^{b}$ when land *A*, agricultural labor for maize production *L*, agricultural machinery *MA* are fixed.

Thus, the North Central and South region's supply functions in different periods (from short-term to long-term) under a completely competitive condition can be obtained with the processes described above (Table 5.7). In the short-term, only chemical fertilizer is adjustable. Since labor is the second easiest variable to adjust, labor in addition to chemical fertilizer are adjustable in the mid-term. In the long-term, more variables become adjustable. Agricultural Machinery, in addition to labor and chemical fertilizer, are allowed to vary. Though a further long-term allows farmers to adjust all variables, including land, the profit maximization problem no longer yields a solution, and therefore an analysis of the price elasticity of supply becomes meaningless in an extremely long-term. Hence, three patterns of supply functions (short-term, mid-term, long-term) in each region are estimated

Table 5.7 Converted supply functions in the North Central and the South regions in different periods (short-term, mid-term, long-term)

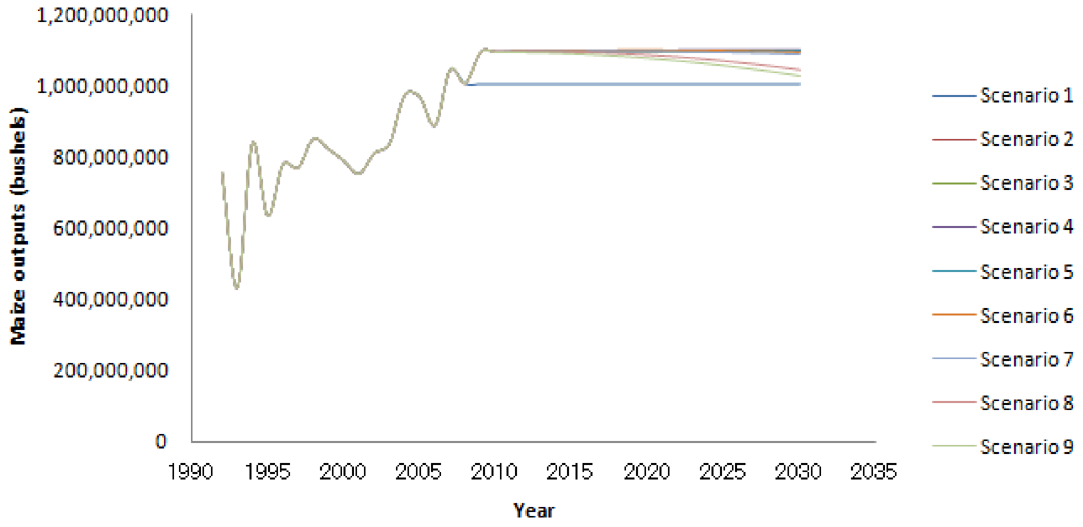
Country, Region	Scenario, periods, (condition)	Maize supply functions
U.S., North Central	Short-term, (Variables *A*, *MA*, *L* are fixed, and only the *CF* is adjustable)	$Y = 4.36 \times 10^{-18} W_{CF}{}^{-0.22} \mathrm{p}^{0.23} \mathrm{e}^{0.03Tech} \mathrm{e}^{0.33T} \mathrm{e}^{-0.01T^2} \mathrm{e}^{0.02R} \mathrm{e}^{(-8.41 \cdot 10^{-5})R^2}$
U.S., North Central	Mid-term, (Variables *A*, *MA*, are fixed, *L* and *CF* are adjustable)	$Y = 3.13 \times 10^{-33} W_L{}^{-0.64} W_{CF}{}^{-0.36} \mathrm{p}^{1} \mathrm{e}^{0.05Tech} \mathrm{e}^{0.54T} \mathrm{e}^{-0.02T^2} \mathrm{e}^{0.02R} \mathrm{e}^{(-.38 \cdot 10^{-4})R^2}$
U.S., North Central	Long-term, (Variable *A* is fixed, and *AL*,*CF*, and *L* are adjustable)	$Y = 2.9 \times 10^{-73} W_L{}^{-1.28} W_{MA}{}^{-1.01} W_{CF}{}^{-0.73} \mathrm{p}^{3.02} \mathrm{e}^{0.1Tech} \mathrm{e}^{1.09T} \mathrm{e}^{-0.03T^2} \mathrm{e}^{0.05R} \mathrm{e}^{(-2.8 \cdot 10^{-4})R^2}$
U.S., South	Short-term, (Variables *A*, *MA*, *L* are fixed, and only the *CF* is adjustable)	$Y = 2.1 \times 10^{-17} W_{CF}{}^{-0.54} \mathrm{p}^{0.54} \mathrm{e}^{0.02Tech} \mathrm{e}^{0.98T} \mathrm{e}^{-0.02T^2} \mathrm{e}^{0.02R} \mathrm{e}^{(-5.22 \cdot 10^{-5})R^2}$
U.S., South	Mid-term, (Variables *A*, *MA*, are fixed, *L* and *CF* are adjustable)	$Y = 4.05 \times 10^{-22} W_L{}^{-0.21} W_{CF}{}^{-0.66} \mathrm{p}^{0.86} \mathrm{e}^{0.03Tech} \mathrm{e}^{1.18T} \mathrm{e}^{-0.03T^2} \mathrm{e}^{0.02R} \mathrm{e}^{(-6.3 \cdot 10^{-5})R^2}$
U.S., South	Long-term, (Variable *A* is fixed, and *MA*, *CF*, and *L* are adjustable)	$Y = 2.37 \times 10^{-40} W_L{}^{-0.34} W_{MA}{}^{-0.66} W_{CF}{}^{-1.09} \mathrm{p}^{2.09} \mathrm{e}^{0.05Tech} \mathrm{e}^{1.95T} \mathrm{e}^{-0.04T^2} \mathrm{e}^{0.03R} \mathrm{e}^{(-1.04 \cdot 10^{-4})R^2}$

As stated earlier, government policies have made labor and mechanization level in the U.S. relatively stable. Thus, the levels of labor and machinery use by 2030 are assumed to be indifferent from the 2008 level. For both the North Central region and the

South region in the U.S., supply functions in the short-term that is estimated in Table 4.7 are used to project the potential changes of maize with/without technology improvement under 9 climate scenarios in three types of time spans (short-term, mid-term, long-term) in both the Northeast and the Southwest regions of China (Figure 4.13 and Figure 4.14). Similar to the results undergone with production functions, significantly positive effects of a further improvement in technology on maize outputs can be observed in the two regions.

As stated earlier, the North Central's average temperature in the 2008 level is below the region's peak level, a further increase in temperature increases maize output (Figure 5.17). Maize outputs under different scenarios of climate change are above the level where technology improvement is unchanged from the 2008 l level (unchanged technology improvement considered situation). In the South region, changes in precipitation could significantly affect the projection of maize outputs (increase above or decrease below the maize production level in technology improvement unchanged situation) (Figure 5.18). In comparison with technology improvement unchanged situation, maize outputs in technology improvement considered situation in both regions increase. The results are in line with the fact that the research and development as well as corresponding application of new technologies in the U.S. are fastest in the world.

a. Short-term maize outputs in the North Central region with technology over 2009-2030 periods unchanged from the 2008 level



b. Short-term maize outputs in the North Central region with technology improves over 2009-2030 periods

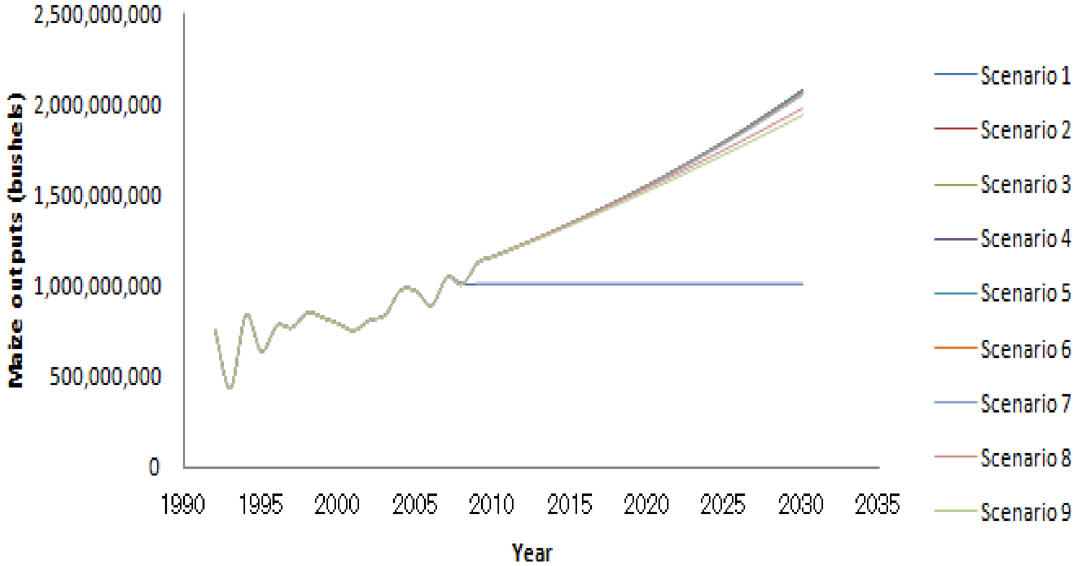
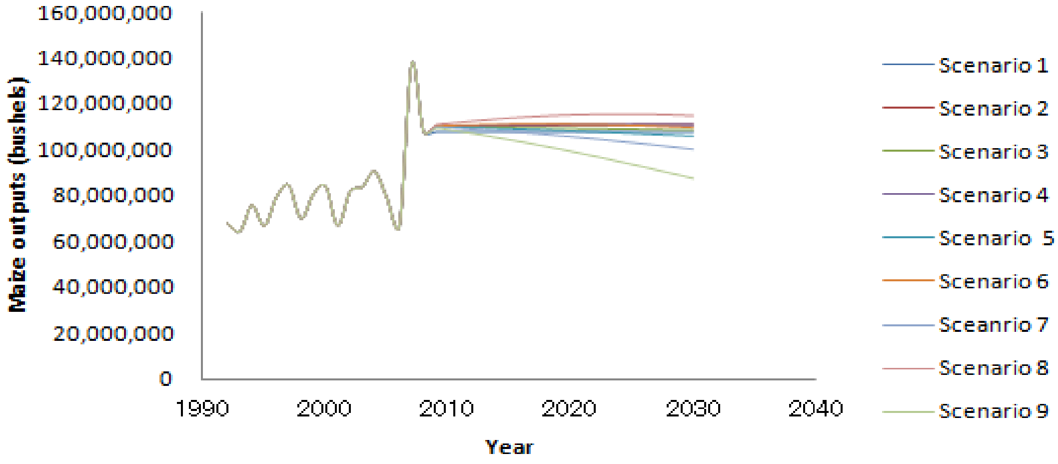


Figure 5.17 Projected maize outputs in the North Central region with/without technology improvement over 2009-2030 periods

a. Short-term maize outputs in the South region with technology over 2009-2030 periods unchanged from the 2008 level



b. Short-term maize outputs in the South region with technology improves over 2009-2030 periods

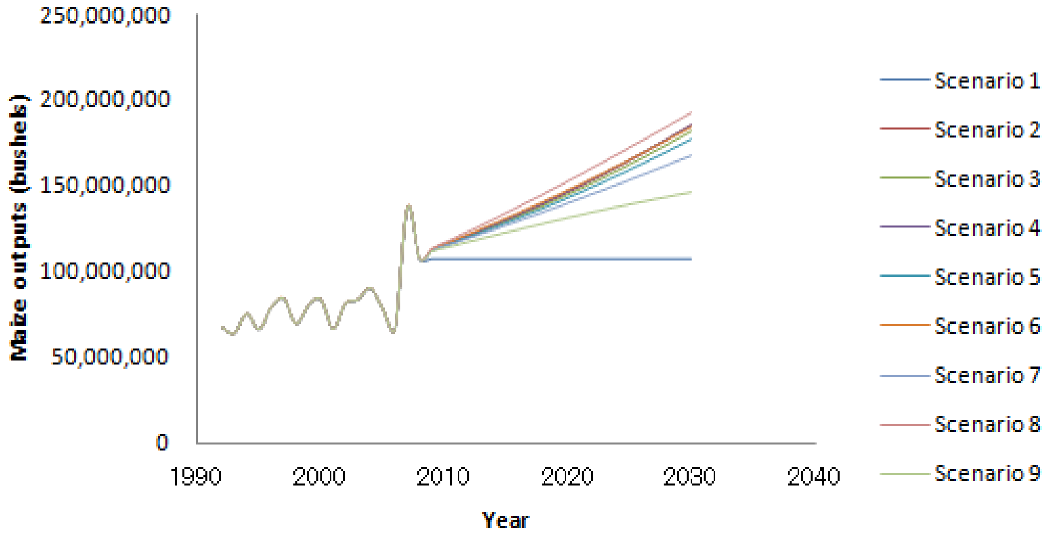


Figure 5.18 Projected maize outputs in the South region with/without technology improvement over 2009-2030 periods

It has been observed that the simulated results under production function utilized case and converted suppply function utilized case are different (Table 5.8 and Table 5.9). Comparatively, differences between two functions are larger in technology imporvement considered case (Table 5.8). The obvious differences are results of the functions' differences. Under the production function utilized case, farmers are assumed to not to respond to the exterior environment in an optimized way, supply function on the other hand does so.

Diverting from past studies that overlooked the importance of price incentives and management in the optimized condition in the maize production process, this case study converts a production function to a supply function to reflect the significance of price incentives and farmers' reactions to the exterior environment under a optimized condition to maize production. With this approach, a more accurate simulating result can be obtained.

While the result differences between two functions are smaller in technology improvement unchanged case, result differences in technology improved case are obvious. In the U.S., farming scale is large. Farms, as business entitities, behave in a profit maximizing condition in the competitive market. Under an profit maximizing condition, farmers respond correspondingly to changes in the exterior environment. Incentive driven structure thus enables farmers to adapt to the changing environment, allow them to apply new technologies to the maize production process, and thus leads to a higher production level (Table 5.9). In either way, a continuous imporvement in technology is a key for a further growth of maize production in the U.S.

Table 5.8 Simulated results of maize production (difference ratios of maize outputs between 2008 and 2030) under two sets of simulating functions (Cobb-Douglas production function and converted supply function in the North Central and the South of U.S. (technology level is unchanged from 2008 level)

Scenario	North Central US		South US	
	Production function	Supply function	Production function	Supply function
Scenario 1	1.00	1.00	1.00	1.00
Scenario 2	1.02	1.09	1.11	1.03
Scenario 3	1.02	1.09	1.09	1.00
Scenario 4	1.02	1.09	1.11	1.03
Scenario 5	1.02	1.09	1.08	0.98
Scenario 6	1.02	1.09	1.10	1.02
Scenario 7	1.01	1.08	1.04	0.93
Scenario 8	0.98	1.04	1.13	1.07
Scenario 9	0.96	1.02	0.95	0.81

Table 5.9 Simulated results of maize production (difference ratios of maize outputs between 2008 and 2030) under two sets of simulating functions (Cobb-Douglas production function and converted supply function in the North Central and the South of U.S. (technology is assumed to improve at a constant rate)

Scenario	North Central US		South US	
	Production function	Supply function	Production function	Supply function
Scenario 1	1.71	1.89	1.54	1.68
Scenario 2	1.72	2.06	1.55	1.73
Scenario 3	1.71	2.06	1.53	1.69
Scenario 4	1.72	2.07	1.55	1.73
Scenario 5	1.71	2.06	1.5	1.65
Scenario 6	1.71	2.05	1.54	1.71
Scenario 7	1.7	2.04	1.45	1.56
Scenario 8	1.65	1.96	1.58	1.78
Scenario 9	1.62	1.93	1.33	1.36

5.5.4.2 Analysis of price elasticity of maize supply in North Central region and South region in the U.S. in three different terms

For both the North Central and the South of the U.S, price elasticity of maize supply in three different terms are examined to analyze the effect of change in price on the change of maize amount in supply (Table 5.10). In the short-term where only the chemical fertilizer variable is adjustable, both the North Central and the South regions have inelastic price elasticity of supply (Pes<1). While the North Central region is 0.22, the South region has a higher value (0.54). Given the fact that maize is a major economic agricultural crop in the North Central region, farmers are more responsive to price changes. As a result, maize output increases with an increase in maize price. Comparatively, in the South region, average revenue is lower. Though the share of regional maize production is not as large, an increase in maize price within a short-term is considered to link an increase in revenue in this region. Thus, farmers in relatively poorer region of the U.S. (the South) is more responsive to changes in maize prices.

Price elasticity of maize supply increases in both regions when labor and chemical fertilizer become adjustable in the mid-term, due to the stimulating effects of flexible changes in labor and chemical fertilizer. In the long-term, farmers are more reactive (Pes>1). When chemical fertilizer, agricultural maize labor, and agricultural machinery use are adjustable, farmers become more efficient to changes in prices. Price elasticity of supply increases further in both regions in long-term (3.02 in the North Central region and 2.09 in the South region). In the long-term, the flexibility of input adjustment increases. Given the fact that farmers in the North Central region are highly relies on maize production to support their family, the flexibility of input adjustment allows farmers to apply optimal inputs to increase maize outputs. Thus, the North Central has a higher value of price elasticity of supply.

When all variables including maize planted area variable become adjustable in an extremely long-term, the summation of coefficients *A, L, MA*, and *CF* becomes larger than 1 (($a+b+c+d$)>1), indicating an increasing return to scale. The original Cobb-Douglas maize production function indicates that maize production outputs increase more than proportionally to the increases in inputs. The profit maximization problem no longer yields a solution, and therefore an analysis of the price elasticity of supply becomes meaningless.

Table 5.10 Price elasticity of maize supply in the North Central and the South regions in three different terms

Scenario	Country	Price elasticity of maize supply	
		North Central region	South region
Short-term, (Variables *A, MA, L* are fixed, and *CF* is adjustable)	U.S.	0.22	0.54
Mid-term, (Variables *A* and *MA* are fixed, *L* and *CF* are adjustable)	U.S.	1	0.86
Long-term, (Variable *A* is fixed, and *L, CF*, and *MA* are adjustable)	U.S.	3.02	2.09

Next to maize price elasticity of supply, labor price elasticity of supply is examined (Table 5.11). In the short-term, only the chemical fertilizer is adjustable (labor variable is fixed). Thus, labor price elasticity of supply is not examined in this term. In mid-term, agricultural maize labor factor becomes adjustable. Labor price elasticity of supply shows elastic results in both regions, (-0.64 in the North Central region and -0.21 in the South region). The results indicate an increase in agricultural labor costs (for maize production) decreases maize supply in both regions. In North Central region, a half of maize production process uses labor. Given the background that farmers are fewer in this region, a further increase in labor cost hence can decrease the efficiency of maize production, which in turn affects the final output. The South U.S., comparatively, is a poorer region and more agriculture population is available. Thus, an increase in labor cost has a smaller effect on maize output. Along with time, the response of maize production to changes in labor price increases (North Central region is -1.28 and the South region is -0.34) (Table 5.11). For the same reason, the profit maximization problem no longer yields a solution, and therefore an analysis of the price elasticity of supply becomes meaningless.

Table 5.11 Labor price elasticity of supply in North Central and South regions in two different terms (mid-term and long-term)

Scenario	Country	Labor Price elasticity of Supply	
		North Central region	South region
Mid-term, (Variables *A* and *MA* are fixed, *L* and *CF* are adjustable)	U.S.	-0.64	-0.21
Long-term, (Variable *A* is fixed, and *L*, *CF*, and *MA* are adjustable)	U.S.	-1.28	-0.34

VI. Conclusion

This study analyzed the impacts of climate on maize production with a multidisciplinary approach (climatic and socioeconomic perspectives). Diverting from the previous researches where either biophysical aspect or economic aspect is focused, maize production models in this thesis included the simultaneous consideration of climatic and socioeconomic elements with/without technology adaptation. Given the fact the IPCC has set its target (starting from 2013) to include both climatic and socioeconomic perspective in climate change analysis and many international institutes such as OECD have noticed the research importance of climate change, this theses did analyses about the impacts of climate change on maize production in China and the U.S. and provided potential solutions to combat climate change.

In this thesis, while the first case study used a semi-optimized supply function, the second and the third case studies used Cobb-Douglas productions and converted supply functions in an optimized condition to examine the impacts of climate change on maize production in the U.S. and China. In the first case study, it has been noticed that the responses of maize production to climate change are different in the U.S. and China. If the same climate change occurs, maize production in China could increase, while maize production in the U.S. could decrease. Differences in responses indicate FTAs and forward contracts could be possible risk mitigation strategies to adapt to climate change. In the second and case study, the Northeast region and the Southwest region in China are analyzed. Climatic, geographic, and economic conditions are found to have different effects on maize production in two regions. Flexibility of producing timing allows farmers to adjust their planting seasons, which in turn lead to a better response in the Southwest region. The opposite responses indicate the potential of advanced regional contracts to adapt to climate change. In the third case study, the north central region and the South region are separately analyzed with Cobb-Douglas production function and converted supply function. For both regions, a continuous improvement in technology is found to reduce the risks of climate change to maize production. An increase in precipitation is found to mitigate droughts, which in turn leads to a better effect on maize production in the South region. Given the different responses in the two regions, technology improvement and emphasize of diversified production style could be meaningful strategies to avoid reduction of maize outputs in the U.S. in the long-term. Difference in climatic, geographic, and socioeconomic conditions could lead to different impacts on maize production. The different impacts in turn could be key strategies to adapt to climate change if used correctly.

In addition to this point, it has also been found that the differences in simulation results between Cobb-Douglas production function and converted supply functions in China are larger than the U.S. The results are in line with different economic conditions of two countries. While the U.S is a developed country where population movements from the agricultural sector to other sectors are not apparent; China is a representative developing country where a further development in economy could push the population movement among different industries further. With a further reduction in labor supply in the agricultural sector as a result of population movement and ageing, the estimated level of maize production in converted supply function utilized case apparently to be lower than production function utilized case. Thus, the method used in this thesis has advantages than past studies to avoid bias in estimations.

In this thesis, due to data availability, projected results by 2030 may not reflect the exact changes in maize outputs in each year. In this thesis, an overall trend in nine scenarios is rather provided.

All in all, climate change does not universally imply damages and disaster. Combination of changes in temperature and precipitation can either bring positive or negative effects on maize's final production. All simulated results indicated that maize production could respond oppositely between countries and regions through 2030. It has been noticed that advanced international and inter-regional contracts and cooperation as well as policies could mitigate the entire-country risk of production reduction and to stabilize regional agricultural labour force. Moreover, the gains in the South may able to outweigh the potential reduction of maize production in the North region in China and the U.S.

The risk mitigation strategies provided in this thesis are expected to impact the stability of food production self-sufficiency in China and the U.S. and the price stability of the international commodity market. They are also expected to be used for early-staged policymaking decisions and advanced risk management programs. To ensure a continuous increase in maize supply in the future, further studies and research, as well as efficient environmental policies and actions are required. Furthermore, the knowledge gained from this thesis can be applied to other countries like Japan to reduce the potential risk of food crisis.

Tables and Figures

References

Brown, Lester. R., 1995. Who Will Feed China? : Wake-Up Call for a Small Planet. Worldwatch Environmental Alert Series. W. W. Norton & Company, New York, USA.

Brown, Elizabeth. A. 1995-1996. Who Will Feed China? A Book Review by Elizabeth A. Brown. The social contract. http://www.thesocialcontract.com/pdf/six-two/lizzy.pdf (Accessed on February 3, 2012)

Chen, Chi-chung., McCarl, Brice. A. and Schimmelpfennig, David, E. 2004. Yield variability as influenced by climate: a statistical investigation. Climate change 66, 239-261.

Chai, L.G. 2005. Maize: New Cultivation Technologies for good and high yields. Beijing: China Agriculture Press.

Carlton, R., Berry, P. & Smith, P., 2010. Impact of crop yield reduction on greenhouse gas emissions from compensatory cultivation of pasture and forested land. International Journal of Agricultural Sustainability 8, 164-175.

China' agriculture department. 2009. New China's agricultural statistics for 60 years. China Agriculture Press.

China Statistics Press.2009. China labor statistical yearbook.

CLIMVIS (Global Summary of the Day). 2010. NOAA Satellite and Information Service. http://www.ncdc.noaa.gov/cgi-bin/res40.pl (Accessed on April 7, 2010)

Corbera, E., Estrada, M. and Brown, Katrina., 2010. Reducing greenhouse gas emissions from deforestation and forest degradation in developing countries: revising the assumptions. Climatic change 100, 355-388.

China Statistical Database. 2012. Annual Data. http://219.235.129.58/reportYearQuery.do?id=1400&r=0.01105760671129341# (Accessed on May 5, 2012)

ChinaGrain. 2012. The country increases the adjustment of industrial maize product consumption. http://www.chinagrain.cn/yumi/2012/4/18/20124188261043425.html (Accessed on April 30, 2012)

Dutton, J.M. and Thomas, Annie. 1984. Treating Progress Functions as a Managerial Opportunity. The Academy of Management Review 9, 235-247.

Department of Population and Employment Statistics of the State Statistics Bureau. 2009. China Population and Employment Statistics. China Statistics Press, Beijing, China .

Den Elzen, Mgj., van Vuuren, Dp. and Vliet, J., 2010. Postponing emission reductions from 2020 to 2030 increases climate risks and long-term costs. Climatic change 99, 313-320.

Gabriele, C. Hegerl and Ulrich, Cubasch. Review articles Greenhouse gas induced climate change. Environmental Science and Pollution research 3, 99-102 (1996).

Godfray, H. Charles. J., Beddington, John. R., Crute, Ian. R., Haddad, Lawrence., Lawrence, David., Muir, James. F., Pretty, Jules., Robinson, Sherman., Thomas, Sandy. M. , Toulmin, Camilla. 2010. REVIEW Food Security: The Challenge of Feeding 9 Billion People. Science 327 (5967): 812-818. http://www.sciencemag.org/content/327/5967/812.full (accessed on February 7, 2011)

Gong, Peng, 2011. Column: World View China needs no foreign help to feed itself. Nature 474, 7. <http://www.nature.com/news/2011/110601/full/474007a.html> (accessed 02.29.12)

GLOBAL CLIMATE CHANGE. 2012. National Aeronautics and Space Administration (NASA). http://climate.nasa.gov/evidence/ (Accessed on February 7, 2012)

Hegerl, Gabriele C. and Cubasch, Ulrich. 1996. Greenhouse gas induced climate change. Environmental Science and Pollution Research 3, 99-102.

Heilig, Gerhard. K., Fischer, Gunther., and Velthuizen, Harrij. van. 2000. Can China feed itself? An analysis of China’s food prospects with special reference to water resources. International Journal of Sustainable Development&World Ecology 7(3): 153-172.

He, Guangwen, 2009. Personal Communication about agricultural practice issues in China. China Agricultural University (15.09.09).

He, Guangwen. 2009. Subsidy issues in China. China Agricultural University. Personal communication (September 15, 2009)

International Pacific Research center. 2005. The Changing Rainfall in China. IPRC Climate 5, 6-9.

IPCC. 1997. The Regional Impacts of Climate Change: An Assessment of Vulnerability: Executive Summary.

http://www.ipcc.ch/ipccreports/sres/regional/index.php?idp=261 (Accessed on April 4, 2012)

IPCC. 2007: Summary for Policymakers. In: Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Kane, S., Reilly, J., and Bucklin, R. 1989. Implications of the Greenhouse Effects for World Agricultural Commodity Markets. Paper presented at the Western Economic Association Conference.

Kaiser, H. M., Riha, S. J., Wilks, D. S., Rossiter, D. G, Sampath, R. 1993. A Farm-level Analysis of Economic and Agronomic Impacts of Gradual Climate Warming. American Agricultural Economics Association 75, 387-398.

Kaiser, H.M., Crosson, P., 1995. Implications of climate change for US agriculture. American Journal of Agricultural Economics 77 (August), 734–740.

Liu, X.H., Chen, F. 2005. Farming Systems in China. Beijing: China Agriculture Press.

Lobell, D.B., Burke, M.B., 2010. On the use of statistical models to predict crop yield responses to climate change. Agricultural and Forest Meteorology 150, 1443–1452.

Li, Xiang., Takahashi, Taro., Nobuhiro, Suzuki., Kaiser, H.M. 2011. The impact of climate change on maize yields in the United States and China. Agricultural Systems 104, 348-353.

Li, Cong., Ziniu, Xiao., Zhang, Xiaoling., 2012. Climatic Characteristics of Precipitation in Various Regions of China for the Past 60 Years. Meteorological monthy 38 (4): 419-424.

Mendelsohn , Robert., Nordhaus, William. D., and Shaw, Daigee. 1994. “The Impact of Global Warming on Agriculture: A Ricardian Analysis. The American Economic Review 84, 753-771.

Ministry of Land and resources P.R.C. 2005. The Law of Land Administration of the People’s Republic of China. <http://www.mlr.gov.cn/zwgk/flfg/tdglflfg/200506/t20050607_638174.htm>

(Accessed 04.30.12)
MOA. 2009. New China’s agricultural statistics for 60 years. China Agriculture Press, Beijing, China .
NOAA. 1984. U.S. Climate Regions national Oceanic and Atmospheric Administration. National Climate Data Center. http://www.ncdc.noaa.gov/temp-and-precip/us-climate-regions.php (accessed on June 5, 2012)

National Bureau of Statistics. 1993-2009. China labour statistical yearbook. Department of Population, Social, Science and Technology Statistics. Ministry of labour and Social Security

National Bureau of Statistics of the Peoples Republic of China. 1993-2009. Price index of agricultural means of production. China Statistics Press.

National Bureau of Statistics of China. 2000. The fifth Population Census data. <http://www.stats.gov.cn/tjsj/ndsj/renkoupucha/2000pucha/html/l0401c1.htm> (accessed on 05.02.12)
National Bureau of Statistics of China. 2003 and 2008. China population statistics year book. Department of Population Social Science and Technology Statistics.
National Bureau of Statistics of China. 2012. Annual Data. (2012). <http://219.235.129.58/reportYearQuery.do?id=1400&r=0.01105760671129341#> (Accessed 05.05.12)
NCDC. 2012. CLIMVIS. NOAA Satellite and Information Service. <http://www.ncdc.noaa.gov/cgi-bin/res40.pl> (Accessed on 04.07.12)
NOAA Research. 2012. Trends in Atmospheric Carbon Dioxide. National Oceanic& Atmospheric Administration. http://www.esrl.noaa.gov/gmd/ccgg/trends/global.html (Accessed on May 11, 2012)

Phillips, D.L., Lee, J.J., Dodson, R.F., 1996. Sensitivity of the US Corn Belt to climate change and elevated CO2: I. Corn and soybean yields. Agricultural Systems 52, 481–502.
Paeth, H., Hence, R. Glowienka-Hense., R. Voss and U. Cubasch. 1999. The North Atlantic Oscillation as an indicator for greenhouse-gas induced regional climate change. Climate dynamics 15, 953-960.
Peng, Gao., Xing-min, Mu., Fei, Wang., and Shuang-yin, Wang. 2010. Trend Analysis of Precipitation in Northeast China in Recent 100 Years. Journal of China

Hydrology 30 (5):80-85.

Piao, Shilong., Ciais, Philippe., Huang, Yao., Shen, Zehao., Peng, Shushi., Li, Junsheng., Zhou, Liping., Liu, Hongyan., Ma, Yuecun., Ding, Yihui., Friedlingstein, Pierre., Liu, Chunzhen., Tan, Kun., Yu, Yongqiang., Zhang, Tianyi and Fang, Jingyun., 2010. The impacts of climate change on water resources and agriculture in China. Nature 467, 43-51.

Peng, Gong. 2011. Column: World View China needs no foreign help to feed itself. Nature 474, 7. http://www.nature.com/news/2011/110601/full/474007a.html (accessed on February, 29, 2012)

Statistics Press.1993-2009.Series. China agricultural products cost-benefit compilation of information.

Shi, Dequan. 2008. Maize: High Yield with New Technologies. Beijing: Jindun.

Setagaya Tokyo Japan. 2012. Future population projection. http://www.city.setagaya.tokyo.jp/kikaku/syouraijinkousuikei_01.pdf (Accessed on July 1, 2012)

South Dakota Climate and Weather. 2012. Climate Division and year-wise variation in season’s rainfall & temperature. South Dakota State University. http://climate.sdstate.edu/ClimateDivisions/Seasonal.cfm (Accessed on June 10, 2012)

Stern, Nicholas. The Economics of Climate Change The Stern Review. New York: Cambridge University Press. 2008.

The central people’s government of the P.R.C. 2005. Law of the People’s Republic of China on Land Contract in Rural Areas (Order of the President No.73). <http://english.gov.cn/2005-10/09/content_179389.htm> (Accessed 05.01.12).

Tao, F. L., Yokozawa, M., Liu, J. Y. & Zhang, Z., 2008. Climate-crop yield relationships at provincial scales in China and the impacts of recent climate trends. Climate Research 38, 83–94.

U.S. Energy Information Administration. 2002. U.S. Climate Zones. http://www.eia.gov/emeu/recs/climate_zone.html (Accessed on June 5, 2012)

USDA. 2012. China Agricultural and Economic Data: Provincial Data. <http://www.ers.usda.gov/data/china/ProvincialForm.aspx> (Accessed on 04.04.12)

United Nations. 2011. Probabilistic Projections. Department of economic and Social Affairs Population Division, Population Estimates and Projections Section. http://esa.un.org/wpp/P-WPP/htm/PWPP_Population-Age_65Plus.htm (accessed on February, 14, 2012)

United Nations. 2012. World Population Ageing 1950-2050 III. CHANGING BALANCE BETWEEM AGE GROUPS. Population Division, DESA. http://www.un.org/esa/population/publications/worldageing19502050/pdf/81chaptreriii.pdf (accessed on February, 29, 2012).

U.S Census Bureau. 2012. U.S. Projected to Remain World's Third Most Populous Country Through 2050. Census Bureau Report. http://www.census.gov/newsroom/releases/archives/international_population/cb11-116.html (accessed on February, 29, 2012).

USDA. 2012. China Agricultural and Economic Data: Provincial Data. http://www.ers.usda.gov/data/china/ProvincialForm.aspx (Accessed on April 4, 2012)

USDA National Agricultural Statistics Service. 2012. Data and Statistics Quick Stats. http://www.nass.usda.gov/Quick_Stats/Lite/ (Accessed on June11, 2011).

USDA. 2012. China: Corn Agricultural Weather Assessments World Agricultural Outlook Board. http://www.usda.gov/oce/weather/pubs/Other/MWCACP/Graphs/chi/Corn.pdf (accessed on April 11, 2012).

USDA. 2012. Commodity Costs and Returns: Glossary. http://www.ers.usda.gov/Data/CostsAndReturns/glossary.htm#lcost (Accessed on June 11, 2012).

USDA. 2012. Crop Calendar. http://www.fas.usda.gov/pecad/weather/Crop_calendar/crop_cal.pdf (Accessed on June 5, 2012).

USDA. 2012. 2012/2012 Corn Production. Foreign agricultural service USDA. http://www.pecad.fas.usda.gov/ogamaps/default.cfm?cmdty=Corn&attribute=Production (Accessed on June 11, 2012)

USDA. 2012. Quick Stats. Data and Statistics. http://www.nass.usda.gov/Quick_Stats/Lite/result.php?15644B2B-35F8-3FC7-BF

4B-D9D349AA3AB8 (accessed on June 1, 2012)

USDA. 2012. Price Paid Surveys and Indexes. National Agricultural Statistics Surveys. http://www.nass.usda.gov/Surveys/Guide_to_NASS_Surveys/Prices_Paid_and_Prices_Paid_Indexes/index.asp (Accessed on June 11, 2011).

USDA. 2012. Agricultural Prices. http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1519 (Accessed on June 11, 2012).

Wigley, T. M. L., R. Richels. J. A. Edmonds. 1996. Letter to nature Economic and environmental choices in the stabilization of atmospheric CO_2 concentration. Nature 379, 240-243.

Wu, BingYi., Zhang, RenHe., D'Arrigo, Rosanne. 2008. Arctic dipole anomaly and summer rainfall in Northeast China. Chinese Science Bulletin 53: 2222-2229.

Wang, Jingxia., Mendelsohn, Robert., Dinar, Ariel., Huang, Jikun., Rozelle, Scott., Zhang, Lijuan. 2009. The impact of climate change on China's agriculture. Agricultural Economics 40, 323-337.

Xiong, Wei., Conway, Declan., Jiang, Jinhe., Lin, Erda., Xu, Yinlong., Ju, Hu., Calsamiglia-Mendlewics, Susana., 2008. National level study: the impacts of climate change on cereal production in China. In The Impacts of Climate Change on Chinese Agriculture-Phase II Final Report. AEA Group. <http://www.uea.ac.uk/polopoly_fs/1.147096!Xiongetal2008Report-Future-cereal-production-Interaction.pdf> (Accessed on 05.08.12)

Yuan, Zaijian. 2011. Analysis of agricultural input-ouput based on Cobb-Douglas production function in Hebei Province, North China. African Journal of Microbiology research 5 (32), 5916-5922. http://www.academicjournals.org/ajmr/PDF/pdf2011/30Dec/Yuan.pdf (Accessed on May 1, 2012).

Appendix

For case study 1: A

Table A1. Temperature in Middle China in June, July and August (Celsius degrees)

Year	June	July	August
1988	24.43	24.77	23.53
1989	23.07	24.77	23.57
1990	23.27	25.87	24.43
1991	23.33	26.37	24.30
1992	22.73	26.13	23.70
1993	23.50	23.63	22.97
1994	24.17	26.30	25.43
1995	23.97	25.87	23.83
1996	23.13	24.90	23.50
1997	24.20	26.97	26.00
1998	23.93	26.07	24.27
1999	24.07	25.20	24.43
2000	23.77	26.13	23.87
2001	24.73	26.00	23.53
2002	24.00	26.17	24.43
2003	23.33	24.27	23.03
2004	22.90	25.00	22.83
2005	25.00	25.87	24.10
2006	23.77	25.73	25.17
2007	23.30	24.73	24.97

Table A2. Precipitation in Middle China in June, July and August (millimeter)

Year	June	July	August
1988	37.43	215.10	131.27
1989	63.77	167.37	81.10
1990	84.43	135.53	123.20
1991	42.57	148.40	88.40
1992	42.20	110.13	149.60
1993	100.17	119.37	119.13
1994	111.80	183.33	126.93
1995	43.23	137.70	179.17
1996	104.80	236.13	167.30
1997	17.67	113.80	73.07
1998	40.07	165.77	239.87
1999	63.77	74.60	113.57
2000	111.10	109.50	139.87
2001	112.03	123.43	48.73
2002	118.60	65.10	49.37
2003	68.20	160.90	164.23
2004	107.60	209.50	117.80
2005	82.67	106.67	151.00
2006	73.67	121.33	145.67
2007	103.00	137.33	278.67

Table A3. Real Profits in Middle China (revenues-costs=real profits) (unit: Yuan)

Year	Real profits (Yuan)
1988	1653.94
1989	1762.05
1990	1429.46
1991	1333.16
1992	1321.03
1993	1609.66
1994	2138.81
1995	2373.77
1996	1972.65
1997	1506.88
1998	1905.51
1999	1199.41
2000	1232.50
2001	1474.14
2002	1426.23
2003	1732.29
2004	2023.42
2005	1775.10
2006	2207.98
2007	2852.14

Table A4. Maize yields over the analysis period in Middle China (unit: bushels/acre)

Year	Maize yields (bushels/acre)
1988	62.84
1989	65.49
1990	69.25
1991	68.02
1992	68.01
1993	76.79
1994	69.39
1995	77.00
1996	79.47
1997	62.86
1998	80.18
1999	73.12
2000	74.43
2001	72.41
2002	73.21
2003	71.81
2004	77.58
2005	80.88
2006	83.02
2007	83.95

Table A5. Temperature in the Midwestern United States in April, May, June, July and August (Celsius degrees)

Year	April	May	June	July	August
1988	8.82	16.91	22.42	23.96	22.80
1989	8.50	14.14	19.38	23.36	21.48
1990	8.74	13.21	20.45	21.91	21.41
1991	10.50	17.44	22.02	22.88	22.19
1992	7.93	14.96	18.39	20.10	18.88
1993	7.37	14.73	18.72	22.03	21.67
1994	9.15	14.91	21.19	21.45	20.24
1995	6.77	13.31	20.70	22.88	23.97
1996	7.07	13.43	20.35	21.09	21.45
1997	6.44	12.07	20.39	22.29	20.30
1998	9.60	17.44	19.23	22.73	22.35
1999	9.65	15.55	20.21	24.25	21.01
2000	8.66	16.16	19.46	21.94	22.03
2001	10.62	15.73	19.70	23.17	22.57
2002	9.26	12.89	21.76	24.53	22.05
2003	9.68	14.16	18.75	22.63	22.97
2004	9.85	15.44	18.73	21.39	19.09
2005	10.61	13.50	21.75	23.43	22.12
2006	11.59	15.13	20.46	24.19	22.16
2007	7.82	17.13	20.93	22.63	22.94

Table A6. Precipitation in the Midwestern United States in April, May, June, July and August (millimeters)

Year	April	May	June	July	August
1988	50.58	55.88	38.35	71.60	85.98
1989	62.64	87.25	87.63	86.74	88.55
1990	61.88	138.72	136.62	110.55	97.95
1991	95.19	116.71	79.44	73.06	66.55
1992	64.45	50.51	74.55	165.80	78.33
1993	95.00	98.93	160.08	166.05	106.62
1994	96.71	50.13	110.33	99.92	86.42
1995	95.00	152.37	84.46	85.41	101.19
1996	79.91	149.45	112.52	94.52	64.29
1997	53.34	98.01	108.20	90.55	92.14
1998	92.58	93.92	164.27	86.71	94.42
1999	115.98	100.55	114.08	104.43	77.88
2000	67.15	101.89	134.62	98.87	77.34
2001	97.63	121.48	93.38	95.15	81.60
2002	92.23	107.35	91.82	73.50	101.98
2003	73.28	122.97	100.84	106.71	59.69
2004	48.16	161.07	94.20	105.09	91.76
2005	72.74	78.11	100.52	79.57	90.81
2006	84.39	81.03	79.03	85.53	106.71
2007	88.07	86.23	84.07	73.03	148.84

Table A7. Real Profits in the Midwestern United States (real profits=revenues-costs) (unit: dollars)

Year	Real profits (dollars)
1988	138.59
1989	169.60
1990	167.11
1991	154.71
1992	172.40
1993	108.67
1994	178.70
1995	189.49
1996	211.18
1997	169.55
1998	107.83
1999	68.29
2000	77.24
2001	86.72
2002	148.44
2003	136.98
2004	151.00
2005	63.15
2006	118.08
2007	187.08

Table A8. Maize yields in the Midwestern United States (unit: bushels/acre)

Year	maize yields (bushels/acre)
1988	70.85
1989	105.30
1990	110.59
1991	98.91
1992	118.96
1993	86.18
1994	131.32
1995	104.47
1996	115.35
1997	118.20
1998	130.75
1999	127.26
2000	128.03
2001	128.40
2002	115.49
2003	133.52
2004	148.47
2005	140.85
2006	137.77
2007	142.98

Case Study 2: B

Table B1. Average temperature in the Northeast region in May (unit: Celsius degrees)

Year	Jilin	Liaoning	Heilongjiang
1992	14.66	16.33	14.49
1993	15.94	16.88	14.76
1994	14.61	15.72	13.77
1995	12.86	14.87	12.81
1996	16.30	16.59	16.14
1997	14.54	15.76	14.17
1998	16.85	16.88	16.74
1999	14.35	16.50	13.44
2000	16.49	16.91	15.78
2001	16.60	17.79	15.74
2002	17.56	18.67	16.47
2003	16.65	17.54	15.84
2004	15.73	16.62	14.88
2005	14.69	15.24	13.71
2006	16.70	17.53	16.74
2007	15.70	17.25	14.79
2008	14.34	15.57	13.57

Table B2. Average temperature in the Northeast region in June (unit: Celsius degrees)

Year	Jilin	Liaoning	Heilongjiang
1992	18.18	19.05	18.48
1993	19.17	20.19	18.55
1994	22.61	22.60	21.87
1995	20.82	20.44	21.03
1996	21.06	21.38	20.22
1997	21.91	22.16	21.24
1998	20.55	20.46	20.05
1999	20.13	21.28	19.60
2000	22.57	23.60	22.29
2001	22.29	22.44	21.60
2002	19.75	20.28	19.25
2003	20.89	20.94	21.17
2004	22.74	22.42	22.36
2005	20.78	20.94	21.40
2006	19.86	20.69	19.51
2007	23.56	23.15	22.39
2008	20.99	20.52	21.90

Table B3. Average temperature in the Northeast region in July (unit: Celsius degrees)

Year	Jilin	Liaoning	Heilongjiang
1992	23.05	23.97	22.83
1993	22.51	22.51	22.59
1994	24.91	25.70	23.74
1995	22.19	22.57	23.00
1996	22.64	23.04	22.89
1997	25.26	25.92	24.44
1998	22.85	23.70	23.34
1999	24.86	25.45	24.82
2000	24.74	25.44	24.22
2001	23.98	24.62	23.76
2002	23.78	24.66	22.78
2003	22.48	23.15	21.67
2004	22.28	23.40	22.61
2005	22.85	24.20	22.20
2006	23.19	23.50	22.41
2007	22.56	23.64	22.86
2008	23.41	24.26	23.52

Table B4. Average precipitation in the Northeast region in May (unit: millimeter)

Year	Jilin	Liaoning	Heilongjiang
1992	56.35	67.52	32.17
1993	31.50	33.27	21.89
1994	66.46	91.06	44.53
1995	74.80	128.06	52.66
1996	38.82	47.03	23.92
1997	84.84	79.71	60.37
1998	77.00	94.91	46.99
1999	7.32	1.65	3.60
2000	65.57	43.73	37.00
2001	62.95	48.47	51.99
2002	25.65	32.26	457.84
2003	36.45	40.01	10.75
2004	55.20	66.29	74.55
2005	53.93	158.16	54.31
2006	35.52	50.55	16.85
2007	59.77	76.50	52.41
2008	83.90	80.77	95.12

Table B5. Average precipitation in the Northeast region in June (unit: millimeter)

Year	Jilin	Liaoning	Heilongjiang
1992	105.11	101.35	115.78
1993	126.28	173.78	110.07
1994	113.03	78.15	108.29
1995	88.39	164.68	57.66
1996	119.34	115.82	110.70
1997	51.39	48.47	54.10
1998	114.85	125.39	82.00
1999	11.26	9.99	8.85
2000	65.74	26.54	37.47
2001	103.17	169.21	37.80
2002	108.12	86.32	99.02
2003	122.05	136.23	60.92
2004	77.55	132.84	17.91
2005	181.74	160.40	103.55
2006	123.11	180.04	131.02
2007	32.94	47.63	79.08
2008	126.07	123.53	82.89

Table B6. Average precipitation in the Northeast region in July (unit: millimeter)

Year	Jilin	Liaoning	Heilongjiang
1992	294.64	484.76	210.86
1993	99.44	152.87	148.67
1994	296.76	247.78	236.47
1995	203.71	336.55	114.17
1996	136.86	379.43	160.66
1997	65.91	113.33	103.25
1998	168.02	326.09	78.11
1999	33.02	21.97	19.94
2000	116.54	135.68	143.98
2001	139.62	213.49	118.11
2002	144.02	228.94	113.11
2003	127.93	180.30	188.81
2004	146.81	319.87	134.58
2005	158.71	183.18	183.94
2006	112.61	186.77	184.95
2007	160.78	196.60	92.12
2008	216.83	313.86	142.37

Table B7. Maize planted area in three provinces of the Northeast region (unit: Acre)

Year	Jilin	Heilongjiang	Liaoning	Northeast maize planted area
1992	5520214	5351938	3420111	4764088
1993	5038369	4390472	3499430	4309424
1994	5189347	4853538	3619026	4553971
1995	5792271	5958075	3749742	5166696
1996	6131292	6582002	3896025	5536440
1997	6064328	6288200	3887871	5413467
1998	5983032	6145871	4047498	5392134
1999	5869860	6552844	4145843	5522850
2000	5429528	4451012	3514997	4465179
2001	6448074	5269901	3871562	5196513
2002	6373944	5647717	3537483	5186382
2003	6491811	5074939	3545637	5037463
2004	7169606	5385544	3950634	5501929
2005	6857519	5486114	4429267	5590967
2006	7118209	8166902	4900240	6728451
2007	7051492	9596375	4938540	7195470
2008	7221497	8880526	4657587	6919871

Table B8. The Northeast region's agricultural labor population in the rural area (unit: persons)

Year	Jilin	Heilongjiang	Liaoning	The Northeast's Average
1992	5590104	4510695	6172530	5424443
1993	5498516	4568835	6019428	5362260
1994	5470852	4556238	5923497	5316862
1995	5309907	4653138	5983575	5315540
1996	5277896	4794612	6098886	5390465
1997	5153408	5610510	6049467	5604462
1998	5107960	7367307	6136677	6203981
1999	5133648	7216143	6232608	6194133
2000	5105984	7210329	6310128	6208814
2001	5081284	7194825	6288810	6188306
2002	5029908	7227771	6387648	6215109
2003	4964700	7120212	6466137	6183683
2004	4907396	6842109	6645402	6131636
2005	4960748	6751023	6651216	6120996
2006	4938024	6682224	6597921	6072723
2007	4862936	6541719	6483579	5962745
2008	4852068	6569820	6417687	5946525

Table B9. The Northeast region's maize production ratio (maize crop is divided by total agricultural crop production)

Year	Jilin	Heilongjiang	Liaoning	The Northeast's maize index
1992	0.7	0.4	0.5	0.5
1993	0.7	0.4	0.6	0.6
1994	0.7	0.4	0.5	0.5
1995	0.7	0.5	0.6	0.6
1996	0.8	0.5	0.6	0.6
1997	0.7	0.4	0.5	0.5
1998	0.8	0.4	0.6	0.6
1999	0.7	0.4	0.6	0.6
2000	0.6	0.3	0.5	0.5
2001	0.7	0.3	0.6	0.5
2002	0.7	0.4	0.6	0.6
2003	0.7	0.3	0.6	0.5
2004	0.7	0.3	0.6	0.5
2005	0.7	0.3	0.7	0.6
2006	0.7	0.5	0.7	0.6
2007	0.7	0.4	0.6	0.6
2008	0.7	0.4	0.6	0.6

Table B10. Agricultural mechanical costs in three provinces of the Northeast region

(unit: Yuan)

Year	Jilin	Heilongjiang	Liaoning	The Northeast's average
1992	193704309	293339771	78901963	188648681
1993	193926822	287049112	81781684	187585873
1994	221118079	479335433	102165121	267539544
1995	251732102	631138906	126778794	336549934
1996	268734541	987695325	191333822	482587896
1997	397213497	779045197	147739113	441332602
1998	464163645	1058749232	243497480	588803452
1999	463542883	910517799	233286631	535782438
2000	451193801	662488671	202077206	438586560
2001	571492842	832380974	245573228	549815682
2002	846969745	975699693	208711532	677126990
2003	954036574	909378463	333183594	732199543
2004	932694110	1073285163	320633520	775537598
2005	1253005908	1327420192	493376107	1024600736
2006	1614765870	2210045377	869792618	1564867955
2007	2044791853	2721532120	940100589	1902141521
2008	2823966597	3441470590	1231000482	2498812556

Table B11. The Northeast region's price index for agricultural means of production (PPI)

Year	Jilin	Heilongjiang	Liaoning	The Northeast's PPI
1992	132	135	139	135
1993	145	168	155	156
1994	174	211	188	191
1995	226	260	243	243
1996	252	287	265	268
1997	252	289	262	268
1998	245	277	251	258
1999	239	268	237	248
2000	236	264	231	244
2001	239	261	232	244
2002	240	260	236	245
2003	242	265	232	246
2004	258	297	263	272
2005	281	322	289	298
2006	273	328	291	297
2007	290	359	332	327
2008	369	441	426	412

Table B12. Applied chemical fertilizer amount for maize production in the Northeast region (unit: bushels)

Year	Jilin	Heilongjiang	Liaoning	The Northeast's average
1992	28613295.08	14298989.85	13346850.82	18753045.25
1993	35615623.23	9904571.53	17361094.14	20960429.63
1994	40341235.15	11366766.41	14408513.57	22038838.38
1995	33304039.33	22040901.02	16631515.49	23992151.95
1996	30549948.87	20920020.44	13919236.48	21796401.93
1997	26361359.50	13945265.44	15395252.18	18567292.37
1998	37975353.53	21736898.49	20902287.51	26871513.18
1999	36962454.86	21954841.69	19844780.16	26254025.57
2000	27637204.5	13402374.43	15203934.95	18747837.96
2001	37290466.82	17555681.60	19521858.97	24789335.80
2002	35033902.83	23349171.95	16738326.42	25040467.07
2003	35371472.15	15766186.32	16353250.81	22496969.76
2004	26437090.27	16499472.19	17409255.91	20115272.79
2005	25597671.97	17817087.30	20418157.28	21277638.85
2006	39924204.84	28533636.85	22776625.08	30411488.92
2007	40291463.67	33252756.15	26129352.78	33224524.20
2008	39347262.24	33064243.83	23552072.56	31987859.54

Table B13. The Northeast region's labor population that participate the process of maize production (unit: persons)

Year	Agricultural Labor	Maize index	Labor for maize production
1992	5424443	0.53	2893018
1993	5362260	0.57	3038632
1994	5316862	0.53	2835642
1995	5315540	0.60	3189324
1996	5390465	0.63	3413943
1997	5604462	0.53	2989028
1998	6203981	0.60	3722389
1999	6194133	0.57	3510029
2000	6208814	0.47	2897467
2001	6188306	0.53	3300409
2002	6215109	0.57	3521916
2003	6183683	0.53	3297944
2004	6131636	0.53	3270185
2005	6120996	0.57	3468585
2006	6072723	0.63	3846038
2007	5962745	0.57	3378909
2008	5946525	0.57	3369717

Table B14. Maize productions in three provinces of the Northeast region (unit: bushels)

Year	Jilin	Heilongjiang	Liaoning	The Northeast's average
1992	522255888	410529504	335887776	422891056
1993	529342128	376594288	377814696	427917037
1994	566662992	451314752	256639992	424872579
1995	582055880	477376368	324667896	461366715
1996	690278512	568867600	381672760	546939624
1997	496154904	458991512	263096344	406080920
1998	757715896	472297896	441275912	557096568
1999	666342768	483596512	387932272	512623851
2000	391002976	311322144	216957048	306427389
2001	522964512	322620760	322305816	389297029
2002	606267200	421434440	337777440	455159693
2003	635911304	327108712	357146496	440055504
2004	712560800	369862360	425056296	502493152
2005	708899576	410568872	447023640	522164029
2006	801965528	597212560	476943320	625373803
2007	708624000	567686560	459739504	578683355
2008	820035440	717284960	468085520	668468640

Table B15. Average temperature in the Southwest region of China in April

(unit: Celsius degrees)

Year	Sichuan	Yunnan
1992	18.06	17.26
1993	17.73	17.00
1994	18.27	18.81
1995	17.15	18.70
1996	16.06	16.86
1997	16.57	15.58
1998	20.18	17.52
1999	18.43	19.23
2000	17.11	17.34
2001	17.43	18.96
2002	17.81	18.30
2003	18.32	19.06
2004	18.58	16.31
2005	18.59	17.86
2006	18.56	18.12
2007	16.67	15.84
2008	18.51	18.52

Table B16. Average temperature in the Southwest region of China in August

(unit: Celsius degrees)

Year	Sichuan	Yunnan
1992	25.45	19.99
1993	23.03	19.85
1994	26.94	19.86
1995	25.24	19.75
1996	26.02	19.95
1997	26.66	20.15
1998	24.67	20.41
1999	24.47	19.36
2000	24.10	20.06
2001	24.17	20.01
2002	23.49	18.84
2003	25.98	20.99
2004	25.04	20.49
2005	23.79	19.98
2006	27.33	20.20
2007	26.19	20.32
2008	23.89	20.12

Table B17. Average precipitation in the Southwest region of China in April (unit: millimeter)

Year	Sichuan	Yunnan
1992	68.50	13.29
1993	62.40	22.52
1994	84.71	9.23
1995	50.33	13.89
1996	40.94	34.50
1997	79.33	61.89
1998	125.43	39.33
1999	37.21	0.64
2000	62.61	25.57
2001	81.53	18.37
2002	93.39	24.77
2003	85.81	18.71
2004	77.89	83.06
2005	88.90	20.79
2006	66.84	39.12
2007	117.86	55.46
2008	88.43	34.76

Table B18. Average precipitation in the Southwest region of China in August

(unit: millimeter)

Year	Sichuan	Yunnan
1992	236.69	212.13
1993	273.73	267.21
1994	137.80	167.98
1995	161.97	225.26
1996	113.83	163.07
1997	85.22	175.30
1998	273.26	154.35
1999	74.38	61.64
2000	210.74	205.44
2001	543.31	165.61
2002	228.18	251.63
2003	143.98	149.86
2004	168.49	171.66
2005	240.58	202.61
2006	76.50	126.45
2007	132.21	187.03
2008	225.09	181.86

Table B19. Maize planted area in two provinces of the Southwest region (unit: acre)

Year	Sichuan	Yunnan	The Southwest's average
1992	4256637.29	2347006.91	3301822.10
1993	4214629.38	2307964.26	3261296.82
1994	4226984.65	2469324.07	3348154.36
1995	4239834.13	2441401.16	3340617.65
1996	4354243.92	2455733.28	3404988.60
1997	3188647.84	2420397.21	2804522.53
1998	3372494.24	2707533.66	3040013.95
1999	3358656.34	2865434.00	3112045.17
2000	3052986.98	2791549.49	2922268.24
2001	2967241.42	2812306.34	2889773.88
2002	2984785.90	2789572.65	2887179.28
2003	2869634.79	2636367.31	2753001.05
2004	2897557.70	2745587.89	2821572.80
2005	2956862.99	2922268.24	2939565.62
2006	3191860.21	3091782.53	3141821.37
2007	3287737.09	3168138.09	3227937.59
2008	3271181.03	3276123.14	3273652.09

Table B20. Agricultural labor in rural area in two provinces of the Southwest region (unit: persons)

Year	Sichuan	Yunnan	The Southwest's average
1992	30156929.60	15430560.00	22793745
1993	28984198.40	15684320.00	22334259
1994	28295550.40	15781920.00	22038735
1995	27976856.00	15928320.00	21952588
1996	27489468.80	16025920.00	21757694
1997	26994812.80	16143040.00	21568926
1998	26544241.60	16221120.00	21382681
1999	25819155.20	16152800.00	20985978
2000	24837300.80	16338240.00	20587770
2001	24380121.60	16484640.00	20432381
2002	23630774.40	16552960.00	20091867
2003	22788065.60	16494400.00	19641233
2004	22344574.40	16533440.00	19439007
2005	21878804.80	16494400.00	19186602
2006	21368006.40	16367520.00	18867763
2007	20772248.00	16240640.00	18506444
2008	20590811.20	16191840.00	18391326

Table B21. The Southwest region's maize production ratio (maize crop production versus total agricultural crop production)

Year	Sichuan	Yunnan	The Southwest's average
1992	0.15	0.25	0.20
1993	0.15	0.26	0.21
1994	0.14	0.29	0.22
1995	0.14	0.29	0.22
1996	0.16	0.30	0.23
1997	0.13	0.29	0.21
1998	0.18	0.32	0.25
1999	0.18	0.33	0.26
2000	0.16	0.32	0.24
2001	0.15	0.32	0.24
2002	0.17	0.32	0.25
2003	0.17	0.27	0.22
2004	0.18	0.28	0.23
2005	0.18	0.30	0.24
2006	0.19	0.31	0.25
2007	0.20	0.34	0.27
2008	0.20	0.34	0.27

Table B22. The Southwest region’s agricultural mechanical costs (unit: Yuan)

Year	Sichuan	Yunnan	The Southwest’s average
1992	4895132.88	11265633.17	8080383.03
1993	1770144.34	9116458.83	5443301.59
1994	2578460.64	11087265.07	6832862.86
1995	17001734.86	30517514.50	23759624.68
1996	25907751.32	25785199.44	25846475.38
1997	20726210.96	87279523.39	54002867.18
1998	1214097.93	21687344.62	11450721.28
1999	50144739.16	63326091.40	56735415.28
2000	63196830.49	51169102.15	57182966.32
2001	16379172.64	33635183.83	25007178.24
2002	15401495.24	59780541.89	37591018.57
2003	10962004.90	38728235.78	24845120.34
2004	17588175.24	53154581.55	35371378.40
2005	66056319.20	40970200.72	53513259.96
2006	230165039.74	88765076.44	159465058.09
2007	299151197.82	103471390.02	201311293.92
2008	594929693.93	147556586.23	371243140.08

Table B23. The Southwest region's price index of agricultural means of production (PPI)

Year	Sichuan	Yunnan	The Southwest's average
1992	130.24	143.42	136.83
1993	149.77	174.11	161.94
1994	175.83	199.53	187.68
1995	229.99	250.41	240.20
1996	262.19	283.71	272.95
1997	264.55	290.52	277.54
1998	245.77	280.35	263.06
1999	233.97	276.71	255.34
2000	225.08	273.66	249.37
2001	220.13	264.36	242.25
2002	229.15	265.42	247.29
2003	230.99	270.46	250.73
2004	256.16	287.50	271.83
2005	274.61	304.46	289.54
2006	283.67	312.99	298.33
2007	309.20	334.90	322.05
2008	360.53	390.49	375.51

Table B24. The Southwest region applied chemical fertilizer amount (bushels)

Year	Sichuan	Yunnan	The Southwest 's average
1992	14841382.04	8536531.13	11688956.59
1993	24071862.76	14433950.43	19252906.60
1994	12879329.76	7995944.90	10437637.33
1995	15755481.04	9299934.10	12527707.57
1996	16804967.94	12206662.54	14505815.24
1997	11567266.37	10052841.22	10810053.80
1998	17214914.59	13827090.14	15521002.37
1999	16526250.18	14770424.00	15648337.09
2000	14737666.65	14409585.57	14573626.11
2001	14742114.49	15921357.50	15331736.00
2002	14693755.61	16199304.07	15446529.84
2003	14058302.93	15120618.88	14589460.91
2004	14922162.84	16232576.32	15577369.58
2005	13277318.98	15244957.62	14261138.30
2006	13455345.42	18863060.65	16159203.04
2007	15195183.82	18632371.05	16913777.44
2008	15759684.33	19251791.68	17505738.01

Table B25. The Southwest region's labor that participates the production process of maize (persons)

Year	Agricultural Labor	Maize index	The Southwest 's agricultural Labor for maize production
1992	22793745	0.20	4558749
1993	22334259	0.21	4578523
1994	22038735	0.22	4738328
1995	21952588	0.22	4719806
1996	21757694	0.23	5004270
1997	21568926	0.21	4529475
1998	21382681	0.25	5345670
1999	20985978	0.26	5351424
2000	20587770	0.24	4941065
2001	20432381	0.24	4801609
2002	20091867	0.25	4922507
2003	19641233	0.22	4321071
2004	19439007	0.23	4470972
2005	19186602	0.24	4604785
2006	18867763	0.25	4716941
2007	18506444	0.27	4996740
2008	18391326	0.27	4965658

Table B26. The Southwest region's agricultural machinery use for maize production

(unit: Yuan)

Year	Agricultural mechanical cost	PPI	The Southwest's agricultural Machinery use
1992	8080383.03	136.83	59054.18
1993	5443301.59	161.94	33613.08
1994	6832862.86	187.68	36406.98
1995	23759624.68	240.20	98916.01
1996	25846475.38	272.95	94693.08
1997	54002867.18	277.54	194580.39
1998	11450721.28	263.06	43528.93
1999	56735415.28	255.34	222195.56
2000	57182966.32	249.37	229309.73
2001	25007178.24	242.25	103230.94
2002	37591018.57	247.29	152014.96
2003	24845120.34	250.73	99093.11
2004	35371378.40	271.83	130123.16
2005	53513259.96	289.54	184824.84
2006	159465058.09	298.33	534525.72
2007	201311293.92	322.05	625093.29
2008	371243140.08	375.51	988637.16

Table B27. Maize production in two provinces of the Southwest region (unit: bushels)

Year	Sichuan	Yunnan	The Southwest's average
1992	248805760	106687280	177746520
1993	244829592	113143632	178986612
1994	225421168	129087672	177254420
1995	247860928	133575624	190718276
1996	282229192	145346656	213787924
1997	228609976	142984576	185797276
1998	245302008	164597608	204949808
1999	251955200	180895960	216425580
2000	215500432	186328744	200914588
2001	178061464	187903464	182982464
2002	206721368	181683320	194202344
2003	203650664	157432632	180541648
2004	219437232	167589576	193513404
2005	228649344	176880424	202764884
2006	217744408	188179040	202961724
2007	237310304	196288848	216799576
2008	250774160	208492928	229633544

Case Study 3: C

Table C1. Average temperature in North Central region of the U.S. in April (unit: Celsius degrees)

year	Iowa	Michigan	Minnesota	Wisconsin	Nebraska	South Dakota	Average
1992	7.88	4.79	4.33	4.91	9.4	6.56	6.31
1993	7.29	4.94	4.94	4.62	7.75	5.98	5.92
1994	9.69	6.68	5.96	6.78	9.3	7.09	7.58
1995	7.21	4.22	3.31	4.01	6.9	3.7	4.89
1996	7.72	3.96	3.14	4.15	8.81	5.54	5.55
1997	6.93	4.89	4.23	5.35	6.28	3.97	5.28
1998	9.81	7.81	8.51	8.38	8.86	7.98	8.56
1999	9.98	7.93	7.37	8.19	8.88	6.84	8.20
2000	9.62	6.01	6.06	6.29	9.63	7.02	7.44
2001	11.49	8.1	6.7	8.53	10.83	7.62	8.88
2002	9.44	6.72	5.23	6.52	10.51	6.81	7.54
2003	10.3	5.58	6.8	6.06	10.68	8.65	8.01
2004	10.64	7.02	7.04	7.27	10.6	8.67	8.54
2005	11.72	8.14	9.00	8.79	10.29	8.80	9.46
2006	12.07	8.68	9.58	9.50	12.19	9.89	10.32
2007	8.16	5.49	5.48	6.12	8.26	5.80	6.55
2008	7.76	7.98	4.52	6.45	7.08	5.33	6.52

Table C2.Average temperature in the North Central region of the U.S. in May (unit: Celsius degrees)

year	Iowa	Michigan	Minnesota	Wisconsin	Nebraska	South Dakota	Average
1992	15.71	12.48	14.37	13.44	15.63	14.70	14.39
1993	15.23	12.37	12.33	12.85	14.71	13.12	13.44
1994	15.97	11.63	14.25	13.06	16.92	15.52	14.56
1995	13.69	11.95	11.96	12.29	11.83	11.06	12.13
1996	13.68	10.78	11.12	10.91	13.94	10.95	11.90
1997	12.43	8.60	10.09	9.74	13.18	11.41	10.91
1998	18.33	15.93	16.23	16.06	17.18	14.90	16.44
1999	15.81	14.36	14.18	14.58	15.03	13.06	14.50
2000	17.06	13.74	14.06	13.98	16.85	14.26	14.99
2001	16.02	14.00	13.89	13.94	15.88	14.12	14.64
2002	13.81	9.89	10.31	10.62	13.83	11.16	11.60
2003	14.41	11.59	12.57	12.04	14.41	12.65	12.95
2004	15.94	12.18	11.14	11.85	16.15	13.06	13.39
2005	14.22	11.04	11.44	11.44	14.74	11.91	12.47
2006	15.81	13.31	13.92	13.47	16.49	14.28	14.55
2007	18.21	14.26	15.18	15.01	17.1	15.39	15.86
2008	14.08	10.58	11.09	11.17	13.77	11.39	12.01

Table C3. Average temperature in the North Central of the U.S. in June (unit: Celsius degrees)

year	Iowa	Michigan	Minnesota	Wisconsin	Nebraska	South Dakota	Average
1992	19.8	15.81	16.83	16.67	18.78	17.33	17.54
1993	19.54	16.56	16.39	16.65	18.99	16.27	17.40
1994	21.68	18.57	19.20	19.33	22.19	19.52	20.08
1995	21.11	19.78	20.35	20.40	19.73	18.38	19.96
1996	20.91	17.93	18.83	18.10	21.24	19.35	19.39
1997	21.44	18.64	19.81	18.98	21.22	19.65	19.96
1998	19.56	17.78	17.07	17.75	19.04	16.20	17.90
1999	20.52	19.26	18.35	18.75	19.72	18.21	19.14
2000	19.85	17.62	16.93	17.41	20.21	17.8	18.30
2001	20.14	17.94	18.58	18.08	20.63	18.65	19.00
2002	22.43	18.73	19.84	19.20	23.76	21.06	20.84
2003	19.55	16.71	17.81	17.30	19.38	17.49	18.04
2004	19.39	16.71	16.35	16.83	18.90	16.62	17.47
2005	22.56	20.86	20.11	20.85	21.55	19.78	20.95
2006	21.14	17.96	19.02	18.37	22.34	20.36	19.87
2007	21.35	19.50	19.86	19.43	20.81	19.88	20.14
2008	20.79	18.31	17.57	18.19	20.19	17.44	18.75

Table C4. Average temperature in the North Central region of the U.S. in July (unit: Celsius degrees)

Year	Iowa	Michigan	Minnesota	Wisconsin	Nebraska	South Dakota	Average
1992	20.35	17.48	17.01	17.78	20.49	17.69	18.47
1993	22.34	20.87	19.41	20.30	22.04	19.10	20.68
1994	21.47	19.98	19.33	19.80	21.74	20.22	20.42
1995	23.40	21.01	20.73	21.48	23.74	21.73	22.02
1996	21.52	18.46	19.41	19.03	22.30	20.59	20.22
1997	23.12	19.89	20.36	20.09	23.86	21.57	21.48
1998	23.34	20.63	20.94	20.99	24.33	22.73	22.16
1999	24.93	22.23	22.35	22.85	24.97	22.78	23.35
2000	22.36	19.04	20.63	19.94	24.13	22.51	21.44
2001	23.98	20.32	21.70	21.35	25.31	23.41	22.68
2002	24.76	22.49	22.72	22.87	26.02	24.91	23.96
2003	22.89	19.88	20.74	20.50	24.91	23.33	22.04
2004	21.41	19.23	19.65	19.56	22.22	21.44	20.59
2005	23.73	21.40	21.67	21.60	24.59	23.39	22.73
2006	24.49	21.85	23.06	22.72	25.35	25.44	23.82
2007	23.21	19.93	21.73	20.88	24.46	24.40	22.44
2008	22.90	20.18	20.72	20.66	23.97	22.44	21.81

Table C5. Average precipitation in the North Central of the U.S. in April (unit: millimeters)

year	Iowa	Michigan	Minnesota	Wisconsin	Nebraska	South Dakota	Average
1992	93.64	82.85	52.66	77.92	22.76	27.12	59.49
1993	91.04	103.99	68.16	123.75	65.72	61.16	85.64
1994	62.48	76.78	95.65	89.35	56.71	56.42	72.90
1995	125.02	82.91	60.51	81.90	79.76	88.05	86.36
1996	43.18	89.61	24.24	66.46	38.89	26.25	48.11
1997	71.20	30.28	38.16	27.52	60.17	71.20	49.76
1998	101.63	56.49	43.91	68.89	63.06	41.29	62.55
1999	160.19	86.33	85.57	115.99	112.43	81.76	107.05
2000	53.34	66.80	38.44	65.98	42.10	70.61	56.21
2001	92.26	76.12	146.5	115.94	90.46	101.71	103.83
2002	92.63	91.44	62.06	105.66	40.42	35.67	71.31
2003	82.92	71.96	58.50	66.18	87.92	60.56	71.34
2004	46.74	51.41	38.02	53.09	44.23	23.93	42.90
2005	92.03	35.1	53.62	40.39	77.66	55.15	58.99
2006	109.76	61.65	81.03	75.66	57.63	66.83	75.43
2007	116.22	82.65	62.77	72.81	104.52	59.49	83.08
2008	147.32	84.73	97.00	141.05	79.82	45.13	99.18

Table C6. Average precipitation in the North Central of the U.S. in May (unit: millimeters)

year	Iowa	Michigan	Minnesota	Wisconsin	Nebraska	South Dakota	Average
1992	45.58	30.96	49.76	48.97	48.20	37.31	43.46
1993	145.15	68.02	119.38	116.28	96.33	84.33	104.92
1994	53.06	48.64	48.51	44.93	36.77	34.29	44.37
1995	156.63	66.62	79.47	93.05	178.97	143.93	119.78
1996	196.74	74.88	78.46	65.98	164.94	139.59	120.10
1997	107.78	94.92	58.00	80.83	71.95	77.16	81.77
1998	109.08	52.76	95.22	88.42	73.22	67.59	81.05
1999	129.09	76.63	125.67	122.2	106.27	93.47	108.89
2000	89.01	130.73	105.04	122.79	65.94	82.49	99.33
2001	182.37	124.51	103.21	126.29	131.29	66.69	122.39
2002	108.32	98.70	58.87	75.44	73.79	46.17	76.88
2003	118.05	104.19	97.45	121.81	85.69	72.39	99.93
2004	199.42	176.66	152.15	209.97	92.39	95.98	154.43
2005	99.40	51.64	106.14	66.83	83.22	97.14	84.06
2006	63.50	117.91	66.91	114.95	34.45	36.32	72.34
2007	137.72	60.38	79.22	62.96	142.62	118.51	100.24
2008	145.63	58.09	77.19	75.13	162.56	110.91	104.92

Table C7. Average precipitation in the North Central of the U.S. in June (unit: millimeters)

year	Iowa	Michigan	Minnesota	Wisconsin	Nebraska	South Dakota	Average
1992	48.49	55.93	97.68	50.18	99.63	107.64	76.59
1993	204.89	119.76	165.13	178.59	141.22	145.34	159.16
1994	161.66	105.38	123.02	96.29	101.76	78.49	111.10
1995	96.35	55.91	63.81	52.58	71.63	86.92	71.20
1996	126.18	125.3	99.48	173.96	82.77	52.97	110.11
1997	110.66	62.99	105.83	111.08	84.87	82.86	93.05
1998	202.16	67.44	137.05	158.19	122.46	124.06	135.23
1999	133.12	97.31	108.94	113.4	149.51	123.50	120.96
2000	172.8	98.25	125.33	168.6	78.80	70.61	119.07
2001	105.55	81.05	99.23	125.31	54.26	84.19	91.60
2002	87.91	76.76	154.69	142.41	40.77	36.60	89.86
2003	114.7	55.88	118.73	80.60	112.46	96.52	96.48
2004	86.39	84.53	81.70	124.74	74.39	67.17	86.49
2005	132.33	72.09	138.99	88.05	132.40	134.17	116.34
2006	64.26	62.03	76.62	61.21	80.90	45.69	65.12
2007	86.84	62.31	87.43	76.91	75.47	85.46	79.07
2008	231.2	125.45	122.88	179.27	113.47	132.08	150.73

Table C8. Average precipitation in the North Central of the U.S. in July (unit: millimeters)

year	Iowa	Michigan	Minnesota	Wisconsin	Nebraska	South Dakota	Average
1992	215.93	120.09	107.81	106.14	151.48	116.39	136.31
1993	277.54	68.71	162.00	133.43	225.52	151.24	169.74
1994	99.14	116.43	105.07	127.03	129.03	94.80	111.92
1995	90.20	86.41	142.07	85.26	53.09	75.04	88.68
1996	80.83	80.87	79.61	99.79	91.95	46.23	79.88
1997	74.11	74.45	137.72	122.77	64.23	107.78	96.84
1998	80.38	47.52	82.18	45.92	113.13	76.88	74.34
1999	134.68	118.97	142.21	189.68	61.79	67.71	119.17
2000	107.05	86.69	101.77	112.52	92.68	65.59	94.38
2001	81.48	46.18	82.01	63.33	97.31	102.16	78.75
2002	106.48	80.16	118.17	83.54	27.81	48.63	77.47
2003	103.94	82.93	76.88	87.12	35.56	40.84	71.21
2004	110.86	78.74	110.97	82.97	108.78	77.30	94.94
2005	82.04	94.16	72.42	84.92	52.67	42.67	71.48
2006	80.60	95.22	51.90	92.96	52.96	20.77	65.74
2007	85.91	54.23	53.40	80.52	70.45	27.35	61.98
2008	149.52	92.68	74.22	107.61	80.33	79.90	97.38

Table C9. Average land costs in the North Central of the U.S. (unit: dollars)

year	Iowa	Michigan	Minnesota	Wisconsin	Nebraska	South Dakota	Average
1992	948948000	194103000	517608000	280371000	407530000	186580000	422523333.33
1993	743040000	148608000	390096000	210528000	321920000	134804000	324832666.67
1994	960147000	186075000	521010000	279112500	439030000	193990000	429894083.33
1995	895594000	184387000	504242000	274699000	414560000	145096000	403096333.33
1996	1161161000	149760000	499200000	224640000	622880000	284160000	490300166.67
1997	1163880000	155550000	492800000	239547000	680672000	283062000	502585166.67
1998	1214625000	149178000	528885000	239982000	682528000	297375000	518762166.67
1999	1177572000	144056000	517874000	235728000	666242000	276012000	502914000.00
2000	1238979000	146960000	538560000	233800000	672265000	338883000	528241166.67
2001	1133730000	148632000	493340000	229704000	597537000	285190000	481355500.00
2002	1205726000	151740000	524520000	246156000	621936000	336242000	514386666.67
2003	1233444000	154980000	534744000	258300000	613980000	338668000	522352666.67
2004	1315466000	156640000	573750000	256320000	646057500	368094000	552721250.00
2005	1342336000	173587500	588380000	293170000	667165000	366368500	571834500.00
2006	1299816000	166980000	578817000	277035000	625482000	364455000	552097500.00
2007	1568816000	215392000	713328000	329184000	761870000	429363000	669658833.33
2008	1644678000	218352000	731885000	345724000	798336000	461177500	700025416.67

Table C10. Price paid index specific for rent in the North Central of the U.S.

year	Iowa	Michigan	Minnesota	Wisconsin	Nebraska	South Dakota	Average
1992	117	117	117	117	117	117	117
1993	118	118	118	118	118	118	118
1994	124	124	124	124	124	124	124
1995	134	134	134	134	134	134	134
1996	137	137	137	137	137	137	137
1997	139	139	139	139	139	139	139
1998	154	154	154	154	154	154	154
1999	135	135	135	135	135	135	135
2000	130	130	130	130	130	130	130
2001	135	135	135	135	135	135	135
2002	137	137	137	137	137	137	137
2003	138	138	138	138	138	138	138
2004	138	138	138	138	138	138	138
2005	146	146	146	146	146	146	146
2006	139	139	139	139	139	139	139
2007	167	167	167	167	167	167	167
2008	173	173	173	173	173	173	173

Table C11. Unpaid labor cost in the North Central of the U.S. (unit: dollars)

year	Iowa	Michigan	Minnesota	Wisconsin	Nebraska	South Dakota	Average
1992	342276000	70011000	186696000	101127000	183845000	84170000	161354166.67
1993	301080000	60216000	158067000	85306000	170160000	71254500	141013916.67
1994	322242000	62450000	174860000	93675000	182578000	80674000	152746500.00
1995	312256000	64288000	175808000	95776000	180480000	63168000	148629333.33
1996	361823000	89154000	210600000	133731000	206380000	99880000	183594666.67
1997	357338000	89675000	205170000	138099500	224547000	98914000	185623916.67
1998	376750000	84663000	219146000	136197000	227216000	103818000	191298333.33
1999	374132000	83468000	219958000	136584000	228416000	99036000	190265666.67
2000	391140000	86394000	227880000	137445000	228735000	119712000	198551000.00
2001	259740000	75988000	176392000	117436000	196344000	82232000	151355333.33
2002	280966000	76882500	189504000	124720500	212772000	99635500	164080083.33
2003	292617000	78300000	194904000	130500000	213678000	102124000	168687166.67
2004	308356000	77792000	206625000	127296000	221265000	109926000	175210000.00
2005	253440000	71505000	177317000	120764000	185130000	91447500	149933916.67
2006	258552000	72468000	183741000	120231000	182817000	95805000	152269000.00
2007	301608000	90365000	218904000	138105000	216764000	109098000	179140666.67
2008	292068000	84624000	207438000	133988000	209792000	108205000	172685833.33

Table C12. Hired labor cost in the North Central of the U.S. (unit: dollars)

Year	Iowa	Michigan	Minnesota	Wisconsin	Nebraska	South Dakota	Average
1992	83028000	16983000	45288000	24531000	79431000	36366000	47604500.00
1993	72600000	14520000	38115000	20570000	75360000	31557000	42120333.33
1994	78303000	15175000	42490000	22762500	80668000	35644000	45840416.67
1995	76993000	15851500	43349000	23615500	80720000	28252000	44796833.33
1996	25146000	9854000	18525000	14781000	25840000	7240000	16897666.67
1997	26474000	10225000	18760000	15746500	29192000	7524000	17986916.67
1998	28375000	9752000	20148000	15688000	29480000	7917000	18560000.00
1999	28314000	10010000	20803000	16380000	29584000	7668000	18793166.67
2000	28905000	10824000	22104000	17220000	29750000	9202000	19667500.00
2001	24570000	7656000	25092000	11832000	34101000	14402000	19608833.33
2002	26718000	8167500	26568000	13249500	35868000	16598500	21194916.67
2003	28290000	8370000	27144000	13950000	35316000	16720000	21631666.67
2004	29210000	8734000	29250000	14292000	36547500	17949000	22663750.00
2005	18048000	6817500	18834000	11514000	23715000	10502000	14905083.33
2006	18396000	6908000	19491000	11461000	23409000	10980000	15107500.00
2007	21442000	8612500	23268000	13162500	27730000	12523500	17789750.00
2008	20748000	8064000	22022000	12768000	26840000	12397500	17139916.67

Table C13. Price paid index (1988=100)

year	Iowa	Michigan	Minnesota	Wisconsin	Nebraska	South Dakota	Average
1992	113	113	113	113	113	113	113
1993	116	116	116	116	116	116	116
1994	119	119	119	119	119	119	119
1995	121	121	121	121	121	121	121
1996	127	127	127	127	127	127	127
1997	130	130	130	130	130	130	130
1998	131	131	131	131	131	131	131
1999	128	128	128	128	128	128	128
2000	132	132	132	132	132	132	132
2001	138	138	138	138	138	138	138
2002	137	137	137	137	137	137	137
2003	142	142	142	142	142	142	142
2004	148	148	148	148	148	148	148
2005	156	156	156	156	156	156	156
2006	164	164	164	164	164	164	164
2007	178	178	178	178	178	178	178
2008	201	201	201	201	201	201	201

Table C14. Mechanical costs in the North Central region of the U.S. (unit: dollars)

year	Iowa	Michigan	Minnesota	Wisconsin	Nebraska	South Dakota	Average
1992	480084000	98199000	261864000	141843000	517256000	236816000	289343666.67
1993	399360000	79872000	209664000	113152000	488000000	204350000	249066333.33
1994	521805000	101125000	283150000	151687500	562870000	248710000	311557916.67
1995	468027000	96358500	263511000	143554500	539200000	188720000	283228500.00
1996	768350000	160940000	444375000	241410000	554030000	231680000	400130833.33
1997	750544000	162825000	427420000	250750500	588824000	224276000	400773250.00
1998	795875000	159229000	467711000	256151000	596904000	239811000	419280166.67
1999	794970000	153692000	464695000	251496000	601828000	227700000	415730166.67
2000	828036000	160314000	478944000	255045000	596785000	272405000	431921500.00
2001	599859000	125422000	366792000	193834000	470367000	199158000	325905333.33
2002	632814000	133717500	391320000	216919500	486360000	230554500	348614250.00
2003	652638000	137227500	402768000	228712500	486324000	235048000	357119666.67
2004	737997000	144496000	447075000	236448000	524535000	263097000	392274666.67
2005	773760000	136192500	462455000	230014000	599250000	288182000	414975583.33
2006	801234000	140096000	486472000	232432000	600696000	306585000	427919166.67
2007	947566000	177099500	587496000	270661500	718160000	353875500	509143083.33
2008	971166000	175512000	589281000	277894000	735768000	371592500	520202250.00

Table C15. Fertilizer cost in the North Central region of the U.S. (unit: dollars)

year	Iowa	Michigan	Minnesota	Wisconsin	Nebraska	South Dakota	Average
1992	574860000	117585000	313560000	169845000	332664000	152304000	276803000
1993	521640000	104328000	273861000	147798000	333040000	139460500	253354583
1994	597012000	115700000	323960000	173550000	381754000	168682000	293443000
1995	652358000	134309000	367294000	200093000	466480000	163268000	330633667
1996	693928000	124410000	325425000	186615000	354705000	164640000	308287167
1997	659044000	114800000	295960000	176792000	366591000	153748000	294489167
1998	613000000	96462000	276816000	155178000	319880000	140049000	266897500
1999	559746000	88792000	253541000	145296000	287154000	120204000	242455500
2000	570105000	89518000	260136000	142415000	291635000	145598000	249901167
2001	660933000	139282000	354212000	215254000	378837000	176624000	320857000
2002	531554000	116865000	290736000	189581000	289716000	153970000	262070333
2003	632589000	132637500	345960000	221062500	349434000	187440000	311520500
2004	711327000	140822000	389400000	230436000	378345000	213295500	343937583
2005	930176000	176310000	480048000	297768000	494530000	264597000	440571500
2006	1043154000	196394000	546916000	325835500	536868000	304830000	492332917
2007	1365046000	274672500	730716000	419782500	691464000	389367000	645174667
2008	1950046000	379416000	1021559000	600742000	987272000	569857500	918148750

Table C16. Maize production in the North Central region of the U.S. (unit: bushels)

year	Iowa	Michigan	Minnesota	Wisconsin	Nebraska	South Dakota	Average
1992	1903650000	241500000	741000000	306800000	1066500000	277200000	756108333
1993	880000000	225500000	322000000	216200000	785200000	160650000	431591667
1994	1915200000	255060000	915900000	437100000	1146750000	361800000	838635000
1995	1426800000	249550000	731850000	347700000	854700000	193550000	634025000
1996	1711200000	211500000	868750000	333000000	1179750000	365000000	778200000
1997	1642200000	255060000	851400000	402600000	1135200000	326400000	768810000
1998	1769000000	227550000	1032750000	404150000	1239750000	429550000	850458333
1999	1758200000	253500000	990000000	407550000	1153700000	367250000	821700000
2000	1728000000	241800000	964250000	363000000	1014300000	425600000	789491667
2001	1664400000	199500000	806000000	330200000	1139250000	370600000	751658333
2002	1931550000	234000000	1051900000	391500000	940800000	308750000	809750000
2003	1868300000	259840000	970900000	367650000	1124200000	427350000	836373333
2004	2244400000	257280000	1120950000	353600000	1319700000	539500000	972571667
2005	2162500000	287430000	1191900000	429200000	1270500000	470050000	968596667
2006	2050100000	286650000	1102850000	400400000	1178000000	312340000	888390000
2007	2376900000	287820000	1146100000	442800000	1472000000	542080000	1044616667
2008	2188800000	295320000	1180800000	394560000	1393650000	585200000	1006388333

Table C17. Average temperature in the South of the U.S. in April (unit: Celsius degree)

Year	Texas	Louisiana	Oklahoma	Arkansas	Average
1992	18.83	18.38	15.47	15.83	17.13
1993	18.11	16.57	13.28	13.45	15.35
1994	19.17	19.70	15.48	17.01	17.84
1995	18.67	19.07	14.10	15.62	16.87
1996	18.81	17.99	14.71	14.62	16.53
1997	16.38	16.69	12.40	13.37	14.71
1998	18.32	18.13	13.78	15.45	16.42
1999	20.57	21.53	15.43	17.41	18.74
2000	19.86	18.27	14.68	15.10	16.98
2001	20.80	21.13	17.40	18.59	19.48
2002	21.61	21.01	16.30	17.62	19.14
2003	20.02	19.26	15.98	16.58	17.96
2004	18.87	18.91	15.40	16.01	17.30
2005	18.76	18.73	15.11	15.98	17.15
2006	22.35	21.75	18.58	19.13	20.45
2007	17.42	17.76	12.89	14.02	15.52
2008	19.48	19.22	14.13	14.86	16.92

Table C18. Average temperature in the South of the U.S. in May (unit: Celsius degree)

Year	Texas	Louisiana	Oklahoma	Arkansas	Average
1992	21.54	21.93	18.73	19.30	20.38
1993	22.02	21.73	18.95	19.47	20.54
1994	22.58	22.23	19.35	19.01	20.79
1995	23.41	23.88	18.19	20.13	21.40
1996	26.16	24.82	22.74	22.30	24.01
1997	22.11	22.33	18.65	18.82	20.48
1998	25.54	24.93	22.18	22.54	23.80
1999	23.51	23.09	19.56	20.06	21.56
2000	25.43	24.74	21.33	21.59	23.27
2001	23.97	23.56	20.54	21.05	22.28
2002	24.11	23.35	19.15	19.47	21.52
2003	25.10	24.71	20.47	20.96	22.81
2004	23.62	23.32	21.49	21.49	22.48
2005	22.63	22.55	19.49	19.54	21.05
2006	24.73	23.48	21.19	20.99	22.60
2007	22.63	23.25	20.42	21.52	21.96
2008	24.16	23.25	20.10	19.98	21.87

Table C19. Average temperature in the South of the U.S. in June (unit: Celsius degree)

Year	Texas	Louisiana	Oklahoma	Arkansas	Average
1992	26.13	25.87	22.34	23.33	24.42
1993	26.48	26.56	23.93	24.56	25.38
1994	28.09	26.90	25.94	26.03	26.74
1995	25.82	25.86	22.65	23.61	24.49
1996	27.68	26.12	24.94	24.64	25.85
1997	25.91	25.85	23.06	23.57	24.60
1998	29.26	28.63	26.11	26.63	27.66
1999	26.83	26.57	23.56	24.69	25.41
2000	26.47	26.51	23.18	24.04	25.05
2001	27.58	25.78	24.50	24.22	25.52
2002	27.39	26.17	24.43	24.75	25.69
2003	26.53	26.42	22.70	22.95	24.65
2004	26.43	26.27	23.60	24.34	25.16
2005	27.40	26.88	24.46	25.19	25.98
2006	27.38	26.71	24.91	24.58	25.90
2007	26.14	26.73	23.48	24.96	25.33
2008	28.57	27.33	25.06	25.28	26.56

Table C20. Average temperature in the South of the U.S. in July (unit: Celsius degree)

Year	Texas	Louisiana	Oklahoma	Arkansas	Average
1992	27.92	27.74	26.46	26.30	27.11
1993	28.75	28.28	28.57	28.41	28.50
1994	28.70	27.02	26.48	25.59	26.95
1995	28.60	28.14	27.28	26.67	27.67
1996	29.11	27.85	26.99	26.28	27.56
1997	28.60	28.36	27.51	27.48	27.99
1998	30.46	29.78	29.97	28.89	29.78
1999	28.03	27.88	27.88	27.54	27.83
2000	29.23	28.41	27.22	26.76	27.91
2001	29.65	28.10	29.81	27.81	28.84
2002	27.62	27.99	26.90	27.02	27.38
2003	28.12	27.49	28.52	26.66	27.70
2004	27.53	27.49	25.51	25.46	26.50
2005	28.49	28.17	26.70	26.73	27.52
2006	28.68	27.93	28.72	27.35	28.17
2007	26.59	26.77	25.90	25.28	26.14
2008	27.84	28.35	27.57	26.87	27.66

Table C21. Average precipitation in the South of the U.S. in April (unit: millimeter)

Year	Texas	Louisiana	Oklahoma	Arkansas	Average
1992	71.35	97.99	80.18	69.85	79.84
1993	60.22	188.16	101.01	151.10	125.12
1994	48.69	117.07	114.92	106.06	96.69
1995	62.33	213.30	108.63	152.06	134.08
1996	36.55	128.67	51.93	116.53	83.42
1997	131.98	201.39	144.22	194.48	168.02
1998	15.29	92.68	63.19	78.18	62.34
1999	42.67	80.97	146.11	146.08	103.96
2000	49.05	121.95	66.38	90.17	81.89
2001	21.06	47.92	33.42	61.19	40.90
2002	46.36	93.39	111.14	85.85	84.19
2003	21.44	95.00	50.91	64.80	58.04
2004	103.89	117.52	95.90	155.96	118.32
2005	17.32	95.19	34.85	103.60	62.74
2006	34.87	117.77	85.74	120.03	89.60
2007	56.64	103.74	75.13	107.39	85.73
2008	48.79	85.01	118.79	211.38	115.99

Table C22. Average precipitation in the South of the U.S. in May (unit: millimeter)

Year	Texas	Louisiana	Oklahoma	Arkansas	Average
1992	136.88	75.92	117.94	88.45	104.80
1993	102.87	116.95	192.28	131.18	135.82
1994	112.85	152.57	103.89	101.57	117.72
1995	114.38	170.01	176.13	126.52	146.76
1996	29.57	62.54	64.18	92.51	62.20
1997	95.20	161.49	95.62	100.41	113.18
1998	15.67	11.51	65.56	91.33	46.02
1999	92.53	116.95	137.27	120.85	116.90
2000	86.72	114.61	108.82	171.22	120.34
2001	72.52	47.84	191.32	147.60	114.82
2002	49.43	59.66	91.98	158.24	89.83
2003	31.32	68.10	93.98	171.37	91.19
2004	73.91	245.14	41.80	129.79	122.66
2005	70.00	83.03	73.32	54.53	70.22
2006	62.15	60.90	85.82	98.10	76.74
2007	137.36	124.01	180.93	94.06	134.09
2008	55.70	154.18	116.28	115.43	110.40

Table C23. Average precipitation in the South of the U.S. in June (unit: millimeter)

Year	Texas	Louisiana	Oklahoma	Arkansas	Average
1992	108.03	195.55	182.85	176.73	165.79
1993	135.23	182.06	91.58	106.34	128.80
1994	60.02	132.87	52.83	96.38	85.53
1995	80.57	63.56	164.06	94.71	100.73
1996	77.09	160.78	99.17	110.04	111.77
1997	111.48	143.99	114.64	131.04	125.29
1998	30.43	69.26	45.97	49.13	48.70
1999	99.52	179.61	162.96	136.34	144.61
2000	122.66	136.57	187.68	174.1	155.25
2001	79.38	314.93	58.65	80.94	133.48
2002	65.91	120.82	97.06	67.14	87.73
2003	112.5	216.89	136.82	148.96	153.79
2004	173.81	302.66	170.21	143.71	197.60
2005	28.12	76.14	109.73	49.36	65.84
2006	59.77	59.15	70.27	64.74	63.48
2007	130.73	134.73	244.91	90.71	150.27
2008	46.86	91.38	149.38	104.25	97.97

Table C24. Average precipitation (millimeter) in the South of the U.S. in July

Year	Texas	Louisiana	Oklahoma	Arkansas	Average
1992	62.31	122.68	111.56	134.17	107.68
1993	26.54	96.18	43.10	38.95	51.19
1994	46.00	178.39	114.16	164.51	125.77
1995	49.50	161.97	82.97	98.61	98.26
1996	54.76	146.11	149.69	136.82	121.85
1997	31.67	117.15	67.03	48.54	66.10
1998	28.78	94.49	62.51	81.65	66.86
1999	60.35	107.16	33.87	45.13	61.63
2000	15.90	67.06	64.09	41.15	47.05
2001	27.74	111.05	25.4	66.86	57.76
2002	125.25	135.78	89.01	98.19	112.06
2003	72.42	150.09	24.38	88.65	83.89
2004	56.26	106.71	129.00	122.15	103.53
2005	86.87	144.61	72.76	101.49	101.43
2006	79.22	149.21	42.53	66.94	84.48
2007	174.40	218.19	120.14	148.22	165.24
2008	91.92	60.56	61.69	72.11	71.57

Table C25. Average land costs in the South of the U.S. (unit: dollars)

Year	Texas	Louisiana	Oklahoma	Arkansas	Average
1992	85925000	16123250	7365000	5209050	28655575
1993	80480000	10368400	6840800	4508000	25549300
1994	109757500	16928000	9699500	5290000	35418750
1995	108822000	13576900	8291200	5607850	34074488
1996	114303000	16643850	12050000	8863200	37965013
1997	114860000	14787700	12820000	7801400	37567275
1998	136080000	23261000	16702200	9021650	46266213
1999	110116500	11512400	26999700	4218900	38211875
2000	120099000	13197400	17285400	7480800	39515650
2001	95264000	15075900	15205000	9338500	33720850
2002	124537500	29278400	14364000	13138700	45329650
2003	114192000	26686400	14214000	18512800	43401300
2004	118950000	22419600	16070000	16851200	43572700
2005	128658000	18594600	19372000	14095200	45179950
2006	108662400	16140000	17741700	10978200	38380575
2007	136847500	42638800	21728000	37746800	59740275
2008	163852000	33540000	28120000	30474400	63996600

Table C26. Price paid index for rent (1988=100) in the South of the U.S.

Year	Texas	Southeast pprenti88	Oklahoma	Arkansas	Average
1992	117	117	117	117	117
1993	118	118	118	118	118
1994	124	124	124	124	124
1995	134	134	134	134	134
1996	137	137	137	137	137
1997	139	139	139	139	139
1998	154	154	154	154	154
1999	135	135	135	135	135
2000	130	130	130	130	130
2001	135	135	135	135	135
2002	137	137	137	137	137
2003	138	138	138	138	138
2004	138	138	138	138	138
2005	146	146	146	146	146
2006	139	139	139	139	139
2007	167	167	167	167	167
2008	173	173	173	173	173

Table C27. Unpaid labor cost in the South of the U.S. (unit: dollars)

Year	Texas	Louisiana	Oklahoma	Arkansas	Average
1992	38762500	6704750	3322500	2166150	12738975
1993	42540000	4636800	3615900	2016000	13202175
1994	45644500	6499200	4033700	2031000	14552100
1995	47376000	4434400	3609600	1831600	14312900
1996	74886000	25899350	7608000	12189600	30145738
1997	73880000	21603200	7884000	10016800	28346000
1998	91800000	36596000	11037600	12903850	38084363
1999	76420500	18261400	18085800	5940900	29677150
2000	84525000	21071000	11685600	10526400	31952000
2001	50608000	10650150	9520000	7651300	19607363
2002	66768500	19685200	9448800	10796100	26674650
2003	62128500	18278000	9338000	15260650	26251288
2004	63702300	15300600	10352500	13769600	25781250
2005	50163500	8394600	8990000	7492800	18760225
2006	44633600	7677000	8672400	6148400	16782850
2007	55491500	19602600	10499200	20428900	26505550
2008	61364000	14242800	12550400	15237200	25848600

Table C28. Hired labor costs in the South of the US (unit: dollars)

Year	Texas	Louisiana	Oklahoma	Arkansas	Average
1992	16747500	5235750	1435500	1691550	6277575
1993	18840000	3675400	1601400	1598000	6428700
1994	20167000	5238400	1782200	1637000	7206150
1995	21189000	4110100	1614400	1697650	7152788
1996	15687000	5050400	806000	1440000	5745850
1997	15840000	4278500	848000	1191300	5539450
1998	20184000	7567000	1182600	1593300	7631725
1999	16945500	3845400	1935000	747600	5868375
2000	18900000	4476400	1244700	1330200	6487825
2001	8928000	1924650	1112500	948100	3228313
2002	12156500	3775800	1113600	1383300	4607300
2003	11181300	3499600	1115500	2000200	4449150
2004	11309400	2843400	1277500	1827200	4314375
2005	10024500	2077400	701800	873600	3419325
2006	8905600	1899000	675000	716300	3048975
2007	11115500	4847000	806400	2379000	4786975
2008	12305000	3520400	965700	1773200	4641075

Table C29. Price paid index (1988=100) in the South of the U.S.

Year	Texas	Louisiana	Oklahoma	Arkansas	Average
1992	113	113	113	113	113
1993	116	116	116	116	116
1994	119	119	119	119	119
1995	121	121	121	121	121
1996	127	127	127	127	127
1997	130	130	130	130	130
1998	131	131	131	131	131
1999	128	128	128	128	128
2000	132	132	132	132	132
2001	138	138	138	138	138
2002	137	137	137	137	137
2003	142	142	142	142	142
2004	148	148	148	148	148
2005	156	156	156	156	156
2006	164	164	164	164	164
2007	178	178	178	178	178
2008	201	201	201	201	201

Table C30. Mechanical costs in the South of the U.S. (unit: dollars)

Year	Texas	Louisiana	Oklahoma	Arkansas	Average
1992	109060000	12476750	9348000	4030950	33728925
1993	122000000	8335200	10370000	3624000	36082300
1994	140717500	13488000	12435500	4215000	42714000
1995	141540000	9549600	10784000	3944400	41454500
1996	159873000	38824950	14656000	16732800	57521688
1997	156540000	32718700	14658000	13510900	54356900
1998	178632000	47831000	20376900	16301950	65785463
1999	154791000	25598600	32955200	7618800	55240900
2000	175959000	31787000	21602700	14376600	60931325
2001	101888000	18254250	14500000	9933200	36143863
2002	127264000	31354800	13696800	13000900	46329125
2003	118620600	29307200	13924200	19009200	45215300
2004	124055700	24360000	16192500	17593600	45550450
2005	149240000	21630800	20123100	14452800	51361675
2006	134780800	20079000	19710000	12036500	46651575
2007	168216000	51977600	23833600	40558900	71146525
2008	196903000	39967200	30155000	32010000	74758800

Table C31. Fertilizer costs in the South of the U.S. (unit: dollars)

Year	Texas	Louisiana	Oklahoma	Arkansas	Average
1992	70140000	17930250	6012000	5792850	24968775
1993	83260000	12068100	7077100	5247000	26913050
1994	95438500	17971200	8434100	5616000	31864950
1995	122451000	14858000	9329600	6137000	38193900
1996	117411000	36882900	8576000	13418400	44072075
1997	110460000	29149700	11324000	13144200	41019475
1998	121248000	44660000	14212800	15491200	48903000
1999	91474500	20539400	20584100	6444900	34760725
2000	100296000	22914000	12884400	10848600	36735750
2001	90736000	20802600	13547500	12070700	34289200
2002	92086000	32224800	12050400	16125250	38121612
2003	93494700	30134000	11490800	20739300	38964700
2004	104053800	28505400	13772500	21155200	41871725
2005	132409500	25007000	18052500	17092800	48140450
2006	129500800	25137000	20428200	16317200	47845800
2007	172709500	71994600	26172800	60237500	82778600
2008	281796000	77162800	39405000	58242800	114151650

Table C32. Maize production in the South of the U.S. (unit: bushels)

Year	Texas	Southeast	Oklahoma	Arkansas	Average
1992	202500000	67538750	18225000	12350000	67538750
1993	212750000	64028750	15225000	8190000	64028750
1994	238680000	75581250	17655000	10800000	75581250
1995	216600000	66457500	16250000	9775000	66457500
1996	198240000	79253750	24650000	28750000	79253750
1997	241500000	84218500	23460000	23125000	84218500
1998	185000000	69710000	28600000	21500000	69710000
1999	228330000	80465000	40600000	13000000	80465000
2000	235600000	83717500	33600000	22750000	83717500
2001	167560000	66517750	26250000	26825000	66517750
2002	202270000	81620000	24700000	34170000	81620000
2003	194700000	83612500	23750000	49000000	83612500
2004	233520000	90392500	30000000	42700000	90392500
2005	210900000	78665000	28750000	30130000	78665000
2006	175450000	66357500	23100000	26280000	66357500
2007	291560000	137352500	39150000	99710000	137352500
2008	253750000	107660000	36800000	66650000	107660000