The impact of climate change on maize yields in the United States and China

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1. Introduction

Global increases in anthropogenic and naturogenic greenhouse gas emissions will change the earth's climate and accelerate global warming has been a widely held and supported view over the decades among scientists (Bolin et al., 1986; Stockle et al., 1992). 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 yields 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 effect of climate change.

In this study, we examine the potential impacts of climate change on maize yields in two important producing regions of the world: the United States and China. Maize (Zea mays L.) is a critical crop in sustaining human life in terms of its role as a major grain commodity, a feed commodity, and a significant bioethanol energy source. Its production in the United States and China accounts for over 50% of total world maize production. While the distribution of maize production in the United States is clustered in the Midwest, maize production regions in China appear to be patchy. Owing to the geological and climatic advantages, Middle China, where its maize production accounts for 38% of China’s total, has been designated as the most important production region, which is known as the “Summer Corn Belt”. Therefore, 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 (Figs. 1 and 2).

Previous studies examining the potential impact of climate change on crop yields have generally either used crop yield simulation models such as CERES-maize or EPIC models (Phillips et al., 1996; Rosenzweig et al., 2002; Tan and Shibasaka, 2003) or statistical models (e.g., Vado and Goodwin).1 One problem with

1 Another approach was taken by Mendelsohn and Nordhaus, who examined the impact of climate factors on land productivity as measured by land price. This Ricardian approach examined the direct impact of climate and climate change on land values using cross sectional data for almost 3000 counties in the 48 contiguous states in the United States for 1982.
Both approaches is that these models are based on climatic, soils, and cultivar variables and virtually ignore the importance of economic variables such as price or profitability on crop yields. In addition, technology improvement is often ignored in these models. In reality, however, technology development that exists whether or not climate change occurs also affects crop yields. Hence, to accurately reflect how crop yields will change in response to climatic change, these models need to consider economic and technology variables in addition to climatic and soils factors.

Analysis of the true effects of climate change on maize yields in the Midwestern United States and Middle China using an econometric model of crop yields that include economic and technology variables in addition to climatic variables is the objective of this research. The model is used to simulate maize yields which are the basis for the examination of climate change effects on these two key important maize-producing regions. The results show that the impacts of climate change may be substantially different, in some cases opposite, for the two countries. These results suggest that greater cooperation and freer international trade in agriculture will be a key component of an effective adaptation strategy to climate change.

2. Empirical 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
The estimated coefficient. TECH is technology improvement. The question is estimated: (Kaiser et al., 1993; Kaiser and Crosson, 1995).

This effect with other environmental factors work is also uncertain. A controversial topic among scientists, and how the interactions of enhancing effects on maize yields in this research since this is a limited number of weather stations are available. As a result, the three climate stations with the closest to the major maize growing regions are chosen for consideration in the model (Table 1). In addition, the “CO2 fertilizer effect” which could possibly enhance yields with elevated atmospheric CO2 concentration is assumed to have no enhancing effects on maize yields in this research since this 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).

In both the United States and China, the following yield equation is estimated:

\[
\ln(Y) = \beta_0 + \beta_1 \ln(\Pi) + \beta_2(0.5 T_p + 0.5 T_v) \\
+ \beta_3(0.5 T_p + 0.5 T_v)^2 + \beta_4(0.5 R_p + 0.5 R_v) \\
+ \beta_5(0.5 R_p + 0.5 R_v)^2
\]  

(1)

where Y is the maize yield expressed as bushels/acre. \(\beta_0-\beta_5\) is estimated coefficient. TECH is technology improvement. \(\Pi\) is average real profit in previous years. \(T_p\) is temperature corresponds to the planting season of maize. \(T_v\) is temperature corresponds to the key growing season of maize (vegetative stage, silking stage, and grain-filling stage). \(R_p\) is precipitation corresponds to the planting season of maize. \(R_v\) is precipitation corresponds to the growing season of maize (vegetative stage, silking stage, and grain-filling stage).

Eq. (1) is estimated with time series and cross sectional data from the 12 regions in the two countries over the time period 1988 to 2007. Since maize yields in areas at different latitudes can be significantly affected by climate change, the importance of temperature and precipitation in colder states/provinces and warmer states/provinces are equally weighted in the model. The 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. In the United States, each state is classified into one climate division and in most cases eight to ten districts comprise one climate division (NOAA, 2009). Thus, time series and cross sectional data on average monthly temperature and average monthly accumulated precipitation that correspond to maize’s planting and subsequent growing season are collected from the district levels for the eight states in the Midwestern United States, and then are pooled and averaged. In Middle China, due to data access limitation, climate data in only a limited number of weather stations are available. As a result, the three climate stations that are the closest to the major maize producing sites in Middle China\(^2\) are chosen for the climate data (China Meteorological Data Sharing Service System 2008).

In Eq. (1), average real profit in the previous two-to-three years is used as the key economic variable effecting maize yields. 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

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**Table 1**

<table>
<thead>
<tr>
<th>Months corresponding to the analysis period of the life cycle stages of maize in the Midwestern United States and Middle China regions.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>US</strong></td>
</tr>
<tr>
<td>Planting</td>
</tr>
<tr>
<td>Growth</td>
</tr>
<tr>
<td>Vegetative stage</td>
</tr>
<tr>
<td>Growth</td>
</tr>
<tr>
<td>Silking stage</td>
</tr>
<tr>
<td>Growth</td>
</tr>
<tr>
<td>Harvesting</td>
</tr>
</tbody>
</table>

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\(^2\) The three sites are: Jinan 54823 in Shandong province (36.49°N, 116.58°E), Taiyuan 53772 in Shanxi province (37.46°N, 112.32°E), and Lushi 57067 in Henan province (34.05°N, 111.03°E).
In the two countries, maize yields are analyzed with consideration of technology improvement over the period 2008–2030, nine climate scenarios are simulated: (1) no change, (2) mild change with adaptation, (3) moderate change with adaptation, (4) substantial change with adaptation, (5) extreme change with adaptation. The consensus estimate of climatologists is that the increase in atmospheric CO₂ concentrations will lead to an increase in mean global temperature. In Eq. (1), changes in 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 2). Based on these projections, temperature changes in the simulated period 2008–2030 increase by 0.46 °C (mild scenario), 0.86 °C (moderate scenario), and 1.46 °C (substantial and extreme scenarios) above 2000 levels. As the relationships between temperature and precipitation are not as clear as those between temperature and CO₂ concentration, a common agreement on future precipitation changes has not been formally set (IPCC, 2007). Accordingly, we conduct sensitivity analysis on the effects of changes in precipitation on maize yields in the simulation by increasing and decreasing each climate change scenario by 2.5% (mild scenario), 5% (moderate scenario), 10% (substantial scenario), and 30% (extreme scenario) above/below 2000 levels. In all scenarios, we assume the trend term is extended out from 2008 through 2030. Maize is a critical food commodity, and average real profits of farmers in the past has tended to be fairly stable due to government support by the government in both countries. Since real profit has been fairly stable over time in each country, we assume real average profit remains constant over the period 2008–2030 for all scenarios.

### 3. Estimated results

The estimation results are presented in Table 3. Not surprisingly, the results indicate that the climatic and economic variables in the two countries have different effects on maize yields. In the Midwestern United States, due to its geographic range, maize is planted beginning in April (Table 1). In Middle China where its latitude range is relatively lower, 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 per year in this region. In June, following the winter wheat harvest, the planting season for maize begins in this region (Table 1). To ensure a good harvest of maize within a shorter growing time, farmers in Middle China often choose early-yielding varieties, known as “summer maize,” for plantation (Liu and Chen, 2005).

In the Midwestern United States, average real profit calculated from the previous 3 years is found to be an important factor influencing maize yields. A 1% increase in average profits in the previous 3 years is found to increase maize yields in the United States by 0.191%. In Middle China, average real profit calculated for the previous 2 years is found to be a significant factor impacting maize yields. A 1% increase in average profits in the previous 2 years is found to increase maize yields in Middle China by 0.188%. The coefficients on the average real profit variable are similar in magnitude for the two countries. While inelastic in magnitude, the positive relationship between profit and maize yield indicates that higher profits provide an economic incentive to farmers to increase yields.

The coefficient on the technology variable is higher in the United States than in China. Since the United States is a leader in agricultural technology, improvement in technology can quickly lead to an increase in maize yields. Thus, it is reasonable that the annual growth rate of technological progress is 1.9% in the Midwestern United States, while it is only 0.7% in Middle China where the mechanization level is still low compared to that in the United States.

### 4. Simulation

When the impacts of climate change on maize yields are analyzed with consideration of technology improvement over the period 2008–2030, the simulation results are quite different in the Midwestern United States and Middle China (Figs. 4 and 5). 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;

### Table 2

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>CO₂ concentration in ppm (IPCC scenario)</th>
<th>Temperature changes (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Staying at 2000 level</td>
<td>368 (IPCC A1 scenario)</td>
<td>No change</td>
</tr>
<tr>
<td>Optimistic</td>
<td>420 (IPCC A2 scenario)</td>
<td>0.46 °C increase</td>
</tr>
<tr>
<td>Moderate</td>
<td>462.5 (IPCC B scenario)</td>
<td>0.86 °C increase</td>
</tr>
<tr>
<td>Pessimistic and extreme</td>
<td>527.5 (IPCC C scenario)</td>
<td>1.46 °C increase</td>
</tr>
</tbody>
</table>

### Table 3

<table>
<thead>
<tr>
<th>Explained variable, ln (yield)</th>
<th>The Midwestern United States</th>
<th>China Middle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explanatory variables</td>
<td>Coefficient (t-values)</td>
<td>Coefficient (t-values)</td>
</tr>
<tr>
<td>Constant</td>
<td>-50.89138 (-4.85)</td>
<td>-33.61903 (-4.85)</td>
</tr>
<tr>
<td>TECH</td>
<td>0.018731 (3.97)</td>
<td>0.00689 (3.21)</td>
</tr>
<tr>
<td>ln(T)</td>
<td>0.190611 (2.13)</td>
<td>0.18756 (2.31)</td>
</tr>
<tr>
<td>(Tp.0.5 + Tn.0.5)</td>
<td>1.786139 (1.81)</td>
<td>1.85333 (1.11)</td>
</tr>
<tr>
<td>(Tp.0.5 + Tn.0.5)²</td>
<td>-0.053987 (-1.83)</td>
<td>-0.03860 (-1.12)</td>
</tr>
<tr>
<td>(Rp.0.5 + Rn.0.5)</td>
<td>0.059630 (1.97)</td>
<td>0.00905 (2.43)</td>
</tr>
<tr>
<td>(Rp.0.5 + Rn.0.5)²</td>
<td>-0.000337 (-2.20)</td>
<td>-0.00004 (-2.14)</td>
</tr>
<tr>
<td>R squared</td>
<td>0.85</td>
<td>0.80</td>
</tr>
<tr>
<td>Adjusted R squared</td>
<td>0.76</td>
<td>0.69</td>
</tr>
<tr>
<td>D.W.</td>
<td>2.91</td>
<td>2.10</td>
</tr>
</tbody>
</table>
however, an increase in temperature with a decrease in precipitation instead is found to have larger negative impacts on maize yields in Middle China. In the Midwestern United States, annual accumulated precipitation amounts at the 2000 level are already at a high level (834.46 mm), and the soil moisture content in the Midwestern United States is abundant. Thus, water is not a limiting factor in this region. A further increase in precipitation in the near future would bring about waterlogging problems to the land and cause damages to maize yields. Such a result corresponds to the result found by Rosenzweig et al. (2002). Thus, the magnitude of the negative impacts of climate change on maize yields can be mitigated under scenarios where a decrease in precipitation accompanies an increase in temperature. Under the extreme scenario where temperature increases by 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 (Fig. 4). 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.

Due to the geographic, climatic, and cultural differences between two regions, the planting schedule of maize in Middle China is behind that in the Midwestern United States. During the growing season of maize in the summer, higher temperatures can quickly increase soil water evaporation rates. Thus, when water is not adequately provided, water deficiency can become a significant problem in Middle China, which affects maize yields (He, 2009). Furthermore, crop agriculture in Middle China is highly dependent on precipitation since there is not much irrigated maize production (He, 2009). Consequently, water availability from precipitation during the hot summer plays an important role in determining maize yields. Thus, an increase in both temperature and precipitation...
tion is found to have a significantly better effect on maize yields in Middle China compared with the Midwestern United States (Fig. 5). 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.

Such 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 decreases 7.44% at a maximum; Middle China yields increases 22.82% (see Figs. 4 and 5).

The results in this simulation show that under severe climate change, changes in maize yields are not uniform throughout the world. This suggests that an important adaptation strategy to combat the negative consequences of climate change on crop production is freer trade in agriculture. 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.

5. Conclusion

This study analyzes the impacts of climate change on maize yields using an econometric model that incorporates climate, economic, and technology variables. The major finding is 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 show that a combination of changes in temperature and precipitation can either bring positive or negative effects on maize yields. Furthermore, variation in regional climatic and economic conditions makes the impacts of climatic change on maize yields substantially different in different regions. In this research, the impacts of climate change on maize yields are not simply examined by climate factors. Economic and technology effects on maize yields are also incorporated. Thus, 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.

In this research, findings gained from the study can be used for early-staged policymaking decisions and advanced problem prevention programs. To ensure the continuous increase in maize yields in the future, further studies and research, as well as efficient environmental policies and actions are required.

References


