

**Impact of Climate Change on Agricultural Production in Asian Countries:  
Evidence from Panel Study**

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## Abstract

Global warming has been an issue lately in many aspects because it has been in increasing trend since 1980s. Climate change might be a major concern to humanity since it affects many economic sectors as well as different aspects of human life. Negative impacts of climate change on agricultural sector will be especially dangerous since agriculture is directly related to food security and human life. This paper analyzes the impact of climate change on agricultural production in 13 Asian countries from 1998 and 2007. This study estimates a country-level fixed effect (FE) panel model for agricultural production using seasonal climate variables and other input variables. The results show that higher temperatures and more precipitations in summer increase agricultural production while higher fall temperature is harmful in South and Southeast Asia. On the other hand, overall increase in annual temperature decreases agricultural production in Asian countries.

## Introduction

According to previous studies, global warming has been in increasing trend since the 1980s although the Earth's average surface temperature has increased by about 1.2 to 1.4°F in the last 100 years (Mendelshon, 2007). Based on the NOAA and NASA data, the eight warmest years on record have all occurred since 1850 with the warmest year being 2005 since 1998. NASA's Goddard Institute for Space Studies (GISS, 2010) has released the report on "Global Surface Temperature Change" recently and concluded that global temperature continued to rise rapidly in the past decade and the global warming trend of 0.15-0.20°C per decade that began in the late 1970s has not decreased or reversed. However, there is surprising absence of the impacts study on climate change (Mendelshon, 2007). A broad consensus among climate scientists based on their research is that there would be drastic temperature increases and change in precipitation patterns. Therefore, climate change might be a major concern to humanity since it affects so many economic sectors as well as different aspects of human life. Negative impacts of climate change on the agricultural sector will be especially dangerous since agriculture is directly related to food security and human health. This paper examines whether increase in temperature negatively affects the agricultural production in Asian countries. If climate change negatively impacts agricultural production, it will cause big problem in world food security because the major agricultural product of the most Asian countries is paddy rice and it is an important dietary component more than half of the world's human population.

## Climate Change

Global warming has been an issue lately in many aspects and the impacts of future climate change on many sectors such as agriculture, forestry, water, energy, ecosystem, and health have been controversial [Pearce et al. (1996); Watson et al. (1996); McCarthy et al. (2001)]. The Intergovernmental Panel on Climate Change (IPCC) defines climate change as follows: "climate change refers to a change in the state of the climate that can be identified by changes in the mean or variability of its properties and that persists for extended periods, typically decades or longer". According to the estimation by the NASA's Goddard Institute for Space Studies and the National Climatic Data Center, warming has been in increasing trend since the 1980s. The analysis also

shows that 2005 was the warmest year since reliable, widespread instrumental measurements became available in the late 1800s. It exceeded the previous record set in 1998 by a few hundredths of a degree. Figure 1 shows the annual average global surface temperature anomalies degrees in Fahrenheit between 1901 and 2010.<sup>4</sup> As it is shown in the graph, temperature especially has been rapidly increasing in last 25 years. However, there is surprising absence of impact studies on climate change effects partially due to the slight temperature increase on average over the globe which has warmed only by 0.5°C over the last hundred years [Houghton et al. (2001)]. Mendelsohn (2007) addresses the absence of research in past climate change impact on global agriculture over the last 40 years. Mendelsohn (2005) especially stresses that there is very little empirical research on Asia in spite of the general interest in the economic impact of climate change. Although there have been extensive debates over the concerns about the impacts of climate change, a broad consensus among climate scientists is that there would be drastic temperature increases and change in precipitation patterns due to greenhouse gas effect (Houghton *et al.*, 2001). Mendelsohn (2007) argues that future climate change may have very different effects from the past climate change since future climate changes are expected to be much larger. Houghton et al. (2001) predicted that further emissions of greenhouse gases will cause temperatures to increase 1.5°C to 5.8°C and precipitation patterns to shift by 2100.

\*\*\*Place Figure 1 Here\*\*\*

## **Agriculture in Asia**

Table 1 shows the list of countries included in the analysis with GDP share of agriculture and their major agricultural products. In Asia, agriculture is a crucial part of economy in most countries although many countries have become less dependent on agriculture in terms of the GDP share of agriculture especially in East Asian countries such as China, Japan, and South Korea due to the fast economic growth. According to the FAOSTAT, the share of agricultural output in GDP fell from 35% to 19% in East Asia from 1970 to 1991. The agricultural share of GDP also declined from 44% to 31% in South Asia although the decline rate is smaller than that of East Asian countries. In rapidly growth economies in Southeast Asia such as Indonesia, Thailand, and Malaysia, by 1991 the share of agricultural output in GDP was less than half of its 1970 level. However, some countries still heavily rely on agriculture such as Cambodia with 33%, Laos with 44%, Myanmar with 53%, and Nepal with 36% in 2005 for instance. Figure 2 shows the major agricultural products in Asia in 2008 and China and India are the 2 biggest agricultural producers in most products. As it is shown in both Table 1 and Figure 2, paddy rice is the most important agricultural product in Asia since it is the major product in almost all Asian countries and 9 out of top 10 world rice producers are Asian countries. The reason that mass rice production is limited to certain areas such as Asian countries is due to the fact that most Asian countries have the ideal climate condition for rice production such as availability of water, suitable soil types, and high average temperatures especially for the growing season (USDA ERS). That is, rice cultivation is well suited to regions or countries with high average

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<sup>4</sup> The unit of temperature is degrees in Fahrenheit in Figure.1 in order to show variation although degrees in Celsius is used as the unit of temperature variable in the analysis.

temperatures and high rainfall. In addition, low labor cost is another factor since the cultivation is mostly labor intensive in many regions. This explains why Asian countries are major rice producers and rice is the most important crop in Asia. According to Mendelsohn et al., (2000;, 2004), high latitude countries that are currently cool will likely benefit from warming on the other hand, regions that are already hot such as low latitude countries will be vulnerable to climate change. Based on his logic, temperature change will negatively impact especially the Southeastern Asian agriculture since the most countries are located in the tropical region.

\*\*\*Place Table 1 Here\*\*\*

\*\*\*Place Figure 2 Here\*\*\*

### **Literature**

Mendelshon (1996) has examined the impacts of the climate change on agriculture for all countries in the world between 1960 and 2000. For the analysis, cross-sectional model, experimental (crop simulation) model, and response functions for temperature, precipitation, and carbon-dioxide are used. In the results, temperature and precipitation has the effect from a loss of 0.05% to a gain of 0.9% of global agricultural GDP. When carbon fertilization is included in the models, historic climate change increases the global agriculture production from 2% to 4%. The interesting finding is that the climate change impacts vary by locations. The results suggest that the positive effect is larger in the mid to high latitude countries while is smaller in the low latitude countries. Mendelshon stresses that most developed countries lay on the mid to high latitudes while most less-developed and developing countries are located in the low latitudes.

Deressa and Hassan (2009) have analyzed the economic impact of climate change on crop production in Ethiopia by using the Ricardian method. For the estimation, county-level survey data are used and the net crop revenue was regressed on climate (rainfall and temperature), household, and soil variables. They analyzed the seasonal marginal impact of climate variables which are temperature and precipitation on the crop net revenue. The analysis indicates that marginal increase in temperature during summer and winter has a negative significant effect on net crop revenue per hectare and marginal increase in precipitation during spring has a positive significant effect on net crop revenue per hectare.

Horie et al (1995b) have analyzed the impacts of elevated CO<sub>2</sub> level and high temperature on Japanese rice production and growth by using the rice crop simulation model SIMRIW and field experiments. The analysis indicates that enhanced CO<sub>2</sub> levels in a warmer atmosphere will substantially increase rice yields and yield stability in northern and north-central Japan. On the other hand, rice yields are expected to decline by at least 30% due to the increase in CO<sub>2</sub> level and temperature in south central and southwestern Japan (Matsui and Horie, 1992).

Basak (2009) has analyzed climate change impacts on rice production in Bangladesh by using simulation model. The model is specifically focused on Boro rice production which accounts for 58% of the total rice production during 2008 in Bangladesh to estimate the effects of future climate change. Soil and hydrologic characteristics of the locations, typical crop management

practices, traditional growing period and climate data in 2008 were used for the analysis and temperature and CO<sub>2</sub> levels are controlled in the simulation model called DSSAT (Decision Support System for Agrotechnology Transfer). The simulation results show that rice production varies in different locations for different climatic conditions and hydrological properties of soil although same Boro rice was used in all areas. The model also indicates that rice production decreases drastically from 2.6 % to 13.5 % and from 0.11% to 28.7% when the maximum temperature was increased by 2°C and 4°C. Although the simulation model shows that a drop in minimum temperature also reduces the rice yield, it suggests that increase in maximum temperature causes more damage in the production. The model also found some positive effects of CO<sub>2</sub> concentration on the rice yield but the impact was little compared to that of temperature change.

Mathauda et al. (2000) analyzed the effects of temperature change on rice yield in the Punjab region in India by using the CERES RICE simulation model between 1970 and 1990. They categorized the weather scenario by 5 different conditions which are normal weather, slight warm (0.5°C increase in temperature), moderate warm (1°C increase), greater warm (1.5°C increase), and extreme warm (2°C increase) in the simulation model. The model predicted that temperature increase decreases rice yield by 3.2% in slight warm, 4.9% in moderate warm, 8.2% in greater warm, and 8.4 % in extreme warm condition compared to normal condition scenario. The result also showed that an increase in temperature negatively affects not only rice production but also other rice attributions such as biomass, crop duration, and straw yield.

Seo et al. (2005) examined the climate change impacts on Sri Lankan agriculture using the Ricardian method and five AOGCM experimental models. The model analyzed the net revenue per hectare of the four most important crops (rice, coconut, rubber, and tea) in the country. This paper focused more on the precipitation effect on crop production while most literatures usually analyze the temperature effect. It is mainly due to the greater range of precipitation across the country although the limited range of temperature variation allows only a simple test of temperature impacts in the study. Both the Ricardian method and five AOGCM experimental models showed that the effects of increase in precipitation are predicted to be beneficial to all crops tested and the benefit ranges from 11 % to 122 % of the current net revenue of the crops in the model. On the other hand, the impacts of increase in temperature are predicted to be harmful to the nation and the loss ranges from -18 % to -50 % of the current agricultural productivity.

Mendelsohn and Dinar (1999) have analyzed the impacts of climate change on agriculture in developing countries with India and Brazil. They used 3 different methods for the analysis which are the Ricardian method, agro-economic model, and agro-ecological zone analysis. Farm performance, land value or net income, was regressed on a set of environmental factors, traditional economic inputs which are land and labor, and support systems such as infrastructure in the models. Unlike most studies, this analysis pointed out the importance of the farmers' adaptation. They argue that farmers will adapt to new condition for instance due to climate change by making production decisions which are in their own best interests. Crop choice is one of the examples of farmers' adaptation to warmer weather in the paper. Wheat, corn, and rice are three crops as examples since the regions they grow depend on the temperature. As temperature gets warmer wheat farmers switch wheat to corn for making profits. Later, if temperature gets warmer again enough to lose profits, farmers adapt to warmer weather thus switch to rice from corn. The results of the Ricardian method, agro-economic model, and agro-ecological zone

analysis showed that increase in temperature will decrease the crop production especially the crops grown in cool areas such as wheat. However, the authors argue that the result of the Ricardian method suggests that farmers' ability to adapt to new condition will mitigate the impacts of climate change in the long run while the agro-economic model and agro-ecological zone analysis would be more suitable for short run analysis since the adaptation is not included in the models.

Mendelshon (2005) examined the impact of climate change on Southeast Asian agriculture for 2100 by using 3 different climate simulation models from AOGCM's: the PCM model (Washington et al., 2000), the CCSR model (Emori et al., 1999), and the CCC model (Boer et al., 2000). According to the results, the mild and wet warming of PCM, will increase agricultural revenues in Southeast Asia by \$35 billion per year, a 6% benefit. On the other hand, the CCSR scenario and the CCC scenario would cause net revenues to fall by about \$60 billion per year, 11% loss and \$219 billion, 39% loss to Southeast Asian agriculture.

## **Data & Methodology**

For the analysis, cross-sectional time series (panel) data are used in the paper. The empirical analysis is based on the cross-section data with 13 Asian countries for the time period between 1998 and 2007. Due to the unavailability of the data for few countries, some observations are missing thus the panel data in the model are unbalanced. Countries in the model are following: China, India, Indonesia, Thailand, Philippines, Japan, Pakistan, South Korea, Nepal, Sri Lanka, Laos, Malaysia, and Myanmar. Temperature and precipitation data are obtained from NOAA Satellite and Information Service, National Environmental Satellite, Data, and Information Services (NESDIS). For economic variables such as production, labor, irrigation, machinery, and fertilizer data in the model are obtained from Food and Agriculture Organization of United Nation Statistics Division (FAOSTAT).

### **Conceptual model**

$$Y=Y(L, M, F, I, C)$$

where Y represents agricultural production which is the net production. According to the FAO, production quantities of each commodity are weighted by 1999-2001 average international commodity prices and summed for each year. The unit of production is "international dollars" rather than using production quantity or local currency.<sup>5</sup> FAO explains that the international commodity prices are used in order to avoid the use of exchange rates for obtaining continental and world aggregates, and also to improve and facilitate international comparative analysis of productivity at the national level. L represents the total number of economically active population in agriculture, M represents the total number of machines in use in agriculture, I represents the total area equipped for irrigation in 1000 Ha, and F represents the total consumption of fertilizer in agriculture in 1000 ton. C represents climate variables which are temperature and precipitation. For temperature and precipitation, mean temperatures of winter

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<sup>5</sup> FAO explains that the international prices, expressed in "international dollars" in data, are derived using a Geary-Khamis formula for the agricultural sector. This method assigns a single price to each commodity. For example, one metric ton of wheat has the same price regardless of the country where it was produced.

season (December, January, and February), spring season (March, April, and May), summer season (June, July, and August), and fall season (September, October, and November) are included in the model.

### Econometric Model

In previous literatures, the cross-section model (also known as the Ricardian model), the experimental model (also known as Agronomic-Economic model), and the simulation model are 3 most widely used methods for the climate impact study. However, due to the characteristics of country-level panel analysis, a production model is used for the analysis. Agricultural production model in this analysis has following specification form;

$$Y_{it} = e^{\beta_1 T_1 + \beta_2 T_2^2 + \beta_3 P_3 + \beta_4 P_4^2} * \beta_0 * L_5^{\beta_5} * I_6^{\beta_6} * M_7^{\beta_7} * F_8^{\beta_8} * e^{\mu_{it}}$$

After taking log on both sides, the fixed effect (FE) panel model becomes as

$$\ln Y_{it} = \beta_0 + \beta_1 C_1 + \beta_2 C_2^2 + \beta_3 \ln L_3 + \beta_4 \ln I_4 + \beta_5 \ln M_5 + \beta_6 \ln F_6 + \mu_{it}$$

where C1 is a vector of climate variables and C2 is a vector of squared climate variables. L, I, M, and F represent labor, irrigation, machinery, and fertilizer respectively.  $\mu$  is error term.

For climate variables, both the linear and quadratic terms are estimated in the model in order to capture the non-linear relationship between the agricultural production and climate variables.

Table 2 shows the lists of countries with their geographical and climate zones. Table 3 shows the definition of the variables used in the model.

\*\*\*Place Table 2 Here\*\*\*

\*\*\*Place Table 3 Here\*\*\*

\*\*\*Place Table 4 Here\*\*\*

\*\*\*Place Table 5 Here\*\*\*

### Result

Table 5 shows the regression results of fixed effect panel analysis.<sup>6</sup> The model 1 analyzes the impacts of seasonal climate variables and production input variables on agricultural production

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<sup>6</sup> For the model 1, Hausman test rejects the null hypothesis that random effect model is appropriate;  $\chi^2(15) = 84.70$  and  $\text{Prob} > \chi^2 = 0.000$ . Therefore, the test suggests using Fixed Effect (FE) model over Random Effect (RE) model. Modified Wald test is done in order to test the existence of heteroskedasticity. The test rejects the null hypothesis that variance is homoskedastic with the following result;  $\chi^2(10) = 152.45$  and  $\text{Prob} > \chi^2 = 0.0000$ . For testing autocorrelation, Wooldridge test is done and the test rejects the null hypothesis that there is no first-order autocorrelation with following result;  $F(1, 9) = 6.171$  and  $\text{Prob} > F = 0.0348$ . Due to the presence of heteroskedasticity and autocorrelation, robust standard errors are used in the fixed effect model.

For the model 2, Hausman test also rejects the null hypothesis that random effect model is appropriate;  $\chi^2(8) = 51.61$  and  $\text{Prob} > \chi^2 = 0.000$ . Therefore, the test suggests using fixed Effect (FE) model over random effect (RE)

in Southeastern Asian countries. In the model 1, China, Japan, and Korea are not included because they are in temperate region while other countries included in the model are located in tropical region in Asia. Major distinctive characteristics of tropical Asian countries are year-around warm weather and two monsoon seasons that are Southwest monsoons (occur from June through September) and Northeast monsoons (occur from December to early March). These two factors enable to cultivate crops more than twice a year in most tropical Asian countries. Monsoons are especially very important in South Asian agriculture since most crops are heavily dependent on rainfall and most countries have insufficient irrigation system. As mentioned earlier, the model includes a quadratic term of each climate variables to capture the non-linear relationship with agricultural production. The regression results show that the coefficients of summer and fall temperature are significant at 10% with a positive sign and summer precipitation is also significant at 10% with a positive sign respectively. Square terms of these significant variables are also significant at 10% with a negative sign. The coefficients of other climate variables are insignificant in the model. In order to avoiding complexity of the analysis and interpretation of climate variables due to quadratic terms, marginal impacts and elasticities of climate variables are calculated in Table 5 and Table 6 below. The impacts of climate variables are analyzed later with the results of marginal impacts and elasticities. The coefficients of all production input variables indicate the elasticities since both production and input variables are log-forms. As expected, most input variables are significant in the model. Irrigation is significant at 1% and has positive impact on production. Irrigation has bigger effect on production than any other input variables in the model. It shows that providing sufficient water is crucial on agricultural production in tropical Asian countries. It also shows the characteristic of rice-based Asian agriculture since rice is mostly cultivated in flooded field thus requires sufficient water all the time. The coefficient of irrigation is 0.904 that agricultural production increases by 0.904% when irrigation equipped area increases by 1% holding other variables constant. The result shows machinery is significant at 10% and has positive impact as expected. When machinery is increased by 1%, production increases by 0.121%. Fertilizer is significant at 5% and has a positive effect on production. 1% increase in fertilizer use will lead 0.158% increase in production. Although agriculture is very labor intensive in most Asian countries, labor is insignificant in the model. Maybe it is due to the reason that there is already sufficient labor force in agricultural sector since agricultural population is very high and labor cost is very low in most developing Asian countries.

Model 2 estimates the impacts of annual climate change instead of seasonal climate effects in all Asian countries included in the analysis. It enables to capture the overall climate change effects on agricultural production regardless of region. In this model, temperature is expected to have a negative impact on agricultural production. Precipitation is expected to have a positive impact since agriculture in most countries heavily relies on rainfall because of insufficient irrigation. The regression result shows that the coefficient of temperature is positive while precipitation is negative. Annual temperature is significant at 5% and its square term is also significant at 5%. Annual precipitation is significant at 10% while its square term is insignificant. Because of quadratic formation of climate variables, sign of a linear term and a quadratic term is always

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model. Modified Wald test is done in order to test the existence of heteroskedasticity. The test rejects the null hypothesis that variance is homoskedastic with the following result;  $\chi^2(13) = 3780.58$  and  $\text{Prob} > \chi^2 = 0.0000$ . For testing autocorrelation, Wooldridge test rejects the null hypothesis that there is no first-order autocorrelation with following result;  $F(1, 12) = 13.533$  and  $\text{Prob} > F = 0.0032$ . As for the model1, robust standard errors are used in the fixed effect model due to the presence of heteroskedasticity and autocorrelation.

opposite each other. Due to this reason, the interpretations and signs of climate variables are further explained under the marginal impacts and elasticity analysis as mentioned earlier. Similar to the results in model 1, the regression results indicate that most input variables of agricultural production have significant impacts. Since both production and input variables are also log-forms as in model1, the coefficients of input variables indicate the elasticities. As expected, irrigation is the most important agricultural production input in Asian countries. It is significant at 1% and has positive effect on production. When irrigated area is increased by 1%, agricultural production increases by 0.852%, holding other variables constant. Irrigation has bigger effect on production than any other input variables in this model as in model1. This result shows that irrigation plays a crucial role in Asian agriculture regardless of climate zone. Machinery is also significant at 1% and has positive impact. Production increases by 0.141% when machinery use increases by 1%. Most countries in the model are developing countries therefore additional machinery will be helpful for production regardless of an agricultural product. Fertilizer is significant at 10% with positive impact on production as well. If fertilizer is increased by 1%, production will be increased by 0.062%. Compared to the magnitude of the fertilizer effect in model1, the impact becomes smaller when China, Japan, and South Korea are included in the model. Labor is also insignificant as it is in model1.

### Marginal Impact Analysis

The expected marginal impacts of climate variables on agricultural production evaluated at the mean are calculated using following formula;

$$E \left[ \frac{dY}{dX_i} \right] = [\beta_{1,i} + 2 \times \beta_{2,i} \times E(X_i)] * E(Y_i)$$

where  $\beta_{1,i}$  are linear term coefficients and  $\beta_{2,i}$  are quadratic term coefficients for temperature and precipitation variables.  $E(X_i)$  and  $E(Y_i)$  are mean values of temperature and precipitation variables.

Following is the formula for elasticities of climate variables and notations in the formula are same as in the marginal impacts formula above;

$$E \left[ \frac{dY}{dX_i} \right] = [\beta_{1,i} + 2 \times \beta_{2,i} \times E(X_i)] * E(X_i)$$

Table 5 shows the marginal impacts of seasonal and annual climate variables on agricultural production. They are evaluated at the mean. Increase in temperature and precipitation marginally during the summer season increases agricultural production in tropical Asian countries. However, marginal increase in temperature during the fall season reduces agricultural production.

\*\*\*Place Table 6 Here\*\*\*

Table 6 shows the elasticities of climate variables in the model. Elasticities of seasonal temperature and precipitation are calculated using the regression coefficients and mean values of climate variables from model 1. Elasticities of annual climate variables come from model 2. The results indicate that increase in temperature and precipitation during the summer increase agricultural production in tropical Asian countries. When the summer temperature and

precipitation are increased by 1%, production increases by 1.031% and 0.002%, respectively. However, increasing temperature during the fall season reduces production. If temperature is increased by 1% in the fall, production is reduced by 0.892%. Elasticities of annual climate variables suggest that warmer temperature significantly decreases agricultural production in Asia. When annual mean temperature increases by 1%, average agricultural production decreases by 0.346%. Since mean agricultural production is I\$ 13,072,221,000 and mean annual temperature is 22.982°C, about 0.23°C increase in annual temperature decreases agricultural production by I\$ 45,229,885 in Asian countries. On the other hand, more rainfall increases production. Since mean annual precipitation is 144.238mm, agricultural production increases by I\$ 4,052,389 when rainfall increases by about 1.44mm.

\*\*\*Place Table 7 Here\*\*\*

### **Conclusion**

This paper analyzes climate impacts on agricultural production using fixed effect country-level panel analysis in selective Asian countries from 1998 and 2007. One model examines the impacts of seasonal climate variables and production input variables on agricultural production in South and Southeastern Asian countries. The other model examines overall climate impacts on agricultural production using annual temperature and precipitation. The results show that increase in temperature and precipitation during the summer increase agricultural production in tropical Asian countries while increasing temperature during the fall season reduces production. By using annual climate variables, the results suggest that increase in annual temperature significantly decreases agricultural production in Asia while more rainfall increases production. Climate impacts on Asian agriculture have been previously analyzed. However, most studies used simulation models using different climate change scenarios since the methods have advantages to control climate variables and experimental variables such as CO<sub>2</sub> level and radiation. Iglesias et al. (1996) found from crop simulation study that climate change will be harmful on crop production in South and Southeastern Asian countries. Matthews et al. (1997) also found from their simulation models that rice production will be declined under warming scenarios. This panel study also confirms that increasing temperature significantly decreases agricultural production in Asian countries.

As many studies indicate, Asian agriculture will be very vulnerable to climate change. Since many countries are developing countries they are poor and heavily rely on agriculture. Moreover, irrigation is the one of the most crucial factors in the agriculture because rice is the major crop in Asia. For rain fed rice, rainfall is even more important. Since Asian countries are major rice producers to the world, climate change might be the major concern to human being in near future. If climate change negatively affects an agricultural production, a crop yield will decline. Consequently, price of agricultural products will increase and it may cause malnutrition for the poor. Therefore, adaptation to climate change will be necessary such as developing new varieties that are more tolerant to higher temperature, increasing investment in agricultural productivity, and developing proper adaptation programs or policies.

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- NASA. [www.nasa.gov](http://www.nasa.gov)
- Monthly Climatic Data for the World, National Oceanic and Atmospheric Administration (NOAA)

## Tables & Figures

Table 1. The list of Countries and Agricultural Commodities

Country	GDP Share of Agriculture in 2005 (%)	Major Products by Rank in 2008
Asia	100	Rice, Pork, Milk, Wheat, Vegetables, Eggs, Chicken, Beef
China	15.2	Rice, Pork, Vegetables, Wheat, Eggs, Chicken, Beef, Cotton
India	16.2	Rice, Milk, Wheat, Sugar, Vegetables, Cotton, Potatoes
Indonesia	16.0	Rice, Palm Oil, Chicken, Coconuts, Rubber, Maize, Cassava
Japan	1.5	Rice, Eggs, Milk, Chicken, Pork, Beef, Vegetables
Laos	44.4	Rice, Vegetable, Tobacco, Maize, Beef, Pork, Coffee
Malaysia	8.7	Palm Oil, Chicken, Palm Kernels, Rubber, Rice, Eggs, Pork
Myanmar	57.2	Rice, Chicken, Beans, Vegetables, Sesame Seed, Pork
Nepal	36.3	Rice, Milk, Vegetables, Potatoes, Wheat, Maize, Ginger
Pakistan	19.3	Milk, Wheat, Cotton, Rice, Beef, Sugar, Chicken, Cottonseed
Philippines	14.3	Rice, Pork, Coconuts, Bananas, Chicken, Sugar, Eggs, Fruits
South Korea	3.0	Rice, Pork, Vegetables, Milk, Chicken, Beef, Eggs, Cabbages
Sri Lanka	11.8	Rice, Tea, Coconuts, Chicken, Plantains, Pepper, Rubber
Thailand	10.2	Rice, Cassava, Rubber, Sugar, Chicken, Pork, Beef, Mangoes

Sources: Food and Agriculture Organization of United Nation Statistics Division (FAOSTAT),  
World Development Indicators, The World Bank

Table 2. Geographical and Climate Zones of Countries

Country	Geographical Region	Climate Zone
China	Eastern	Extremely Diverse tropical in south to subarctic in north
India	Southern	Varies from tropical monsoon in south to temperate in north
Indonesia	South-Eastern	tropical; hot, humid; more moderate in highlands
Japan	Eastern	varies from tropical in south to cool temperate in north
Laos	South-Eastern	tropical monsoon; rainy season (May to November); dry season (December to April)
Malaysia	South-Eastern	tropical; annual southwest (April to October) and northeast (October to February) monsoons
Myanmar	South-Eastern	Tropical; southwest (June to September) and northeast (December to April) monsoons
Nepal	Southern	varies from cool summers and severe winters in north to subtropical summers and mild winters in south
Pakistan	Southern	mostly hot, dry desert; temperate in northwest; arctic in north
Philippines	South-Eastern	tropical marine; northeast monsoon (November to April); southwest monsoon (May to October)
South Korea	Eastern	temperate, with rainfall heavier in summer than winter
Sri Lanka	Southern	tropical monsoon; northeast monsoon (December to March); southwest monsoon (June to October)
Thailand	South-Eastern	tropical; rainy, warm, cloudy southwest monsoon (mid-May to September); dry, cool northeast monsoon (November to mid-March)

Source: Climate-zone.com

Table 3. Variable Definitions

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<i>Production</i>	Net agricultural production (base: 1999-2001 average international commodity prices)
<i>Labor</i>	Total number of economically active population in agriculture
<i>Irrigation</i>	The total area equipped for irrigation in 1000 Ha
<i>Machinery</i>	Total number of machinery in use in agriculture
<i>Fertilizer</i>	Total consumption of fertilizer in agriculture (unit: 1000 ton)
<i>Winter Temp</i>	Mean temperature of December, January, and February (unit: degrees in Celsius)
<i>Spring Temp</i>	Mean temperature of March, April, and May (unit: degrees in Celsius)
<i>Summer Temp</i>	Mean temperature of June, July, and August (unit: degrees in Celsius)
<i>Fall Temp</i>	Mean temperature of September, October, and November (unit: degrees in Celsius)
<i>Winter Rain</i>	Mean precipitation of December, January, and February (unit: mm)
<i>Spring Rain</i>	Mean precipitation of March, April, and May (unit: mm)
<i>Summer Rain</i>	Mean precipitation of June, July, and August (unit: mm)
<i>Fall Rain</i>	Mean precipitation of September, October, and November (unit: mm)
<i>Annual Temp</i>	Annual mean temperature (unit: degrees in Celsius)
<i>Annual Rain</i>	Annual mean precipitation (unit: mm)
<i>Temp*Rain</i>	Interaction variable of annual mean temperature and precipitation

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Table 4. Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Winter Temp	92	22.612	5.208	11.1	27.689
Spring Temp	92	27.115	2.451	19.133	30.492
Summer Temp	92	27.860	1.755	23.8	31.875
Fall Temp	92	25.899	2.286	16.133	28.311
Winter Precip	92	107.854	114.020	0	475.945
Spring Precip	92	123.264	64.597	6.567	280.419
Summer Precip	92	223.358	134.300	27.771	690.983
Fall Precip	92	187.502	87.649	16.917	398.901
Irrigation	92	2583.757	5.496	189.995	63831.37
Labor	92	13266.54	4.267	1662.371	258590.2
Machinery	92	53530.13	9.403	1069.557	3150274
Fertilizer	92	695.061	8.559	4.563	22561.5
Production	92	9830497	4.242	616614.9	170000000
Annual Temp	122	22.982	5.512	13.012	28.703
Annual Precip	122	144.238	67.354	16.249	286.688
Temp*Precip	122	3494.224	2017.392	219.435	7694.334
Irrigation	122	3053.366	5.755	189.995	63831.37
Labor	122	13226.8	6.025	1526.908	498819.7
Machinery	122	103156.2	10.095	1069.557	3150274
Fertilizer	122	1046.284	8.802	4.563	52944.53
Production	122	13072221	4.840	616614.9	355000000

Table 5. Regression Analysis Results

Dependent Variable: Agricultural Production (1,000 I\$)

Variables	Model 1		Model 2	
	Coefficients	Robust S.E.	Coefficients	Robust S.E.
Constant	-9.247	5.923	4.763***	1.289
Winter Temperature	0.073	0.052		
Winter Temperature Squared	-0.001	0.001		
Spring Temperature	0.216	0.148		
Spring Temperature Squared	-0.005	0.003		
Summer Temperature	0.737*	0.382		
Summer Temperature Squared	-0.012*	0.006		
Fall Temperature	0.138*	0.070		
Fall Temperature Squared	-0.004*	0.002		
Winter Precipitation	0.000	0.000		
Winter Precipitation Squared	-1.40e-07	1.13e-06		
Spring Precipitation	0.001	0.001		
Spring Precipitation Squared	-2.95e-06	2.16e-06		
Summer Precipitation	0.001*	0.000		
Summer Precipitation Squared	-1.90e-06*	8.83e-07		
Fall Precipitation	0.000	0.000		
Fall Precipitation Squared	-9.26e-07	9.37e-07		
Irrigation	0.904***	0.146	0.852***	0.097
Labor	0.023	0.410	0.172	0.131
Machinery	0.121*	0.057	0.141***	0.039
Fertilizer	0.158**	0.066	0.062*	0.034
Annual Temperature			0.120**	0.051
Annual Precipitation			-0.003*	0.002
Annual Temp. Squared			-0.003**	0.001
Annual Precip. Squared			-2.32e-06	4.64e-06
Annual Temp*Precip			0.000	0.000
No. of Obs	92		122	
No. of Countries	10		13	
R <sup>2</sup> : within	0.7576		0.6387	
R <sup>2</sup> : between	0.9029		0.8782	
R <sup>2</sup> : overall	0.8959		0.8792	
Adjusted R <sup>2</sup>	0.8666		0.8695	

\*\*\* significant at 1% \*\* significant at 5% \*significant at 10%

Table 6. Marginal Impacts of Climate Variables on Agricultural Production (1000I\$)

Seasons	Winter	Spring	Summer	Fall	Annual
Temperature	0.187	-0.548	1.031*	-0.892*	-0.247**
Precipitation	0.006	-0.001	0.002*	-0.003	0.003*

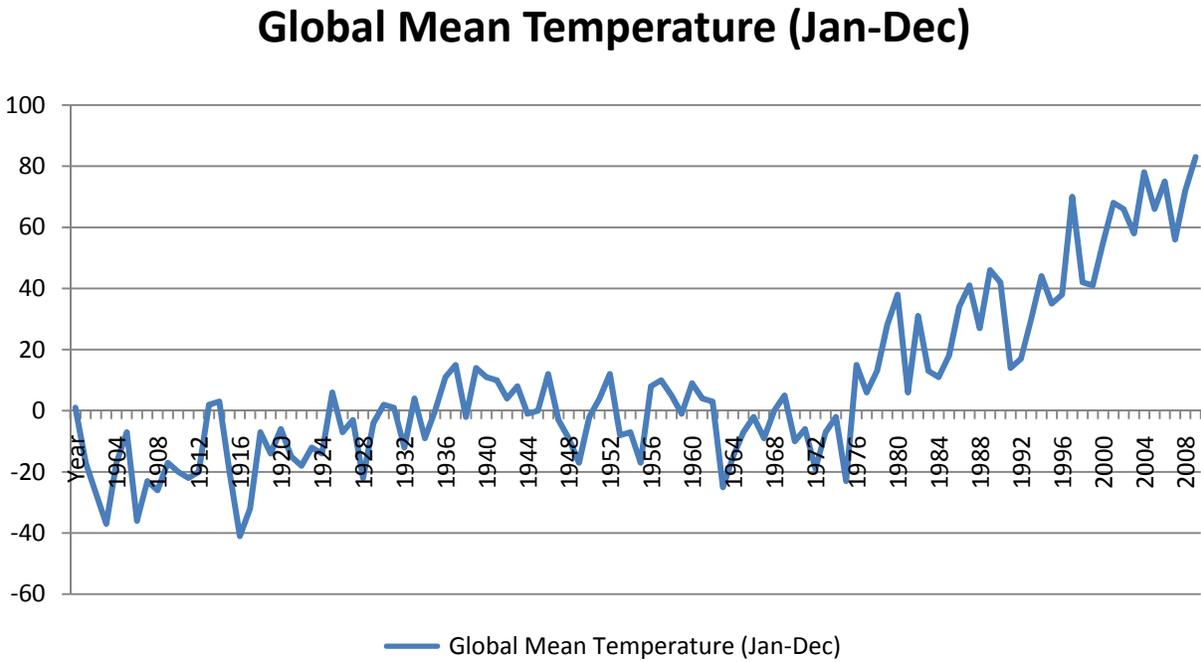
\*\*\* significant at 1% \*\* significant at 5% \*significant at 10%

Table 7. Elasticities of Climate Variables on Agricultural Production (1000I\$)

Seasons	Winter	Spring	Summer	Fall	Annual
Temperature	0.262	-0.923	1.784*	-1.434*	-0.346**
Precipitation	0.040	-0.010	0.028*	-0.036	0.031*

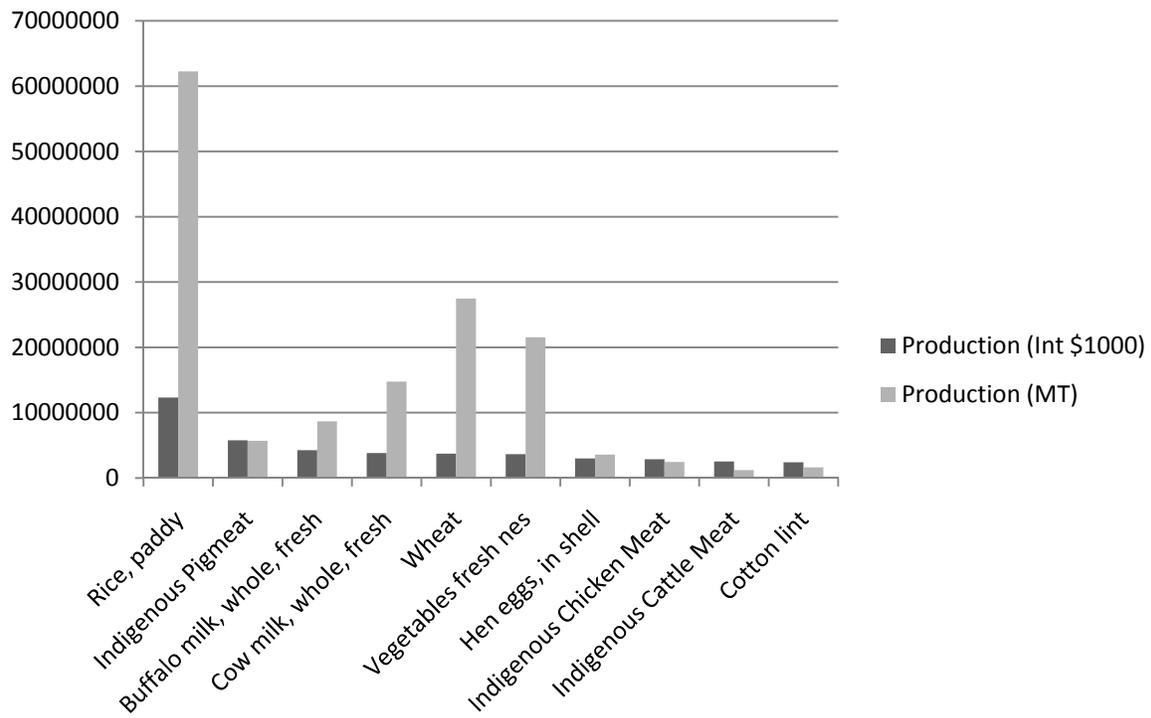
\*\*\* significant at 1% \*\* significant at 5% \*significant at 10%

Figure 1. Annual Average Global Surface Temperature Anomalies 1901-2010 (Degrees in Fahrenheit)



Data source: Goddard Institute for Space Studies, National Aeronautics and Space Administration (NASA)

Figure 2. Major Agricultural Products in Asia in 2008



Source: FAOSTAT