The Effect of Climate Change on Thailand's Agriculture

Attavanich, Witsanu

Kasetsart University

September 2013

The Effect of Climate Change on Thailand's Agriculture

Witsanu Attavanich[1]

Abstract

Agriculture is potentially affected by climate change especially in developing countries where the agricultural sector plays a crucial role including Thailand. The objectives of this study are to analyze the effect of climate change on Thailand's agriculture and investigate implications for greenhouse warming under future climate change scenarios using the Ricardian approach allowing a variety of the adaptations that farmers make in response to changing economic and climate conditions. The study finds that both temperature and precipitation significantly determine farmland values. Summer temperature, precipitation in the early rainy and summer season negatively affect the farmland values, while winter temperature, precipitation in the late rainy and winter season enhance the farmland values. Overall, the projected negative impacts of climate change on Thailand's agriculture during 2040-2049 range from $24 to $94 billion. By downscaling the analysis to the province level, this article finds that western, upper part of central, and the left part of northern regions are projected to be better off, while southern, eastern regions, lower part of central, and the right part of northern regions is projected to be worse off.

Key words: Thailand's agriculture, climate change, Ricardian analysis, regional climate model, farmland value

[1] Witsanu Attavanich is an assistant professor in the Department of Economics, Faculty of Economics, Kasetsart University. Correspondence to be sent to Email: attavanich.witsanu@gmail.com.

1. INTRODUCTION

Recent studies, including those by the Intergovernmental Panel on Climate Change (IPCC) (2001a; 2001b; 2007a; 2007b), indicate that greenhouse gas (GHG) emissions and resultant atmospheric concentrations have led to changes in the world's climate conditions, such as increases in temperatures, extreme temperatures, droughts, and rainfall intensity. Such changes are expected to continue and agriculture is potentially the most sensitive economic sector to climate change, given that agricultural production is highly influenced by climatic conditions (e.g., IPCC 2007b; Mendelsohn, Nordhaus, and Shaw 1994; Deschenes and Greenstone 2007; McCarl, Villavicencio, and Wu 2008; Schlenker and Roberts 2009). Compared with developed countries, developing countries are more vulnerable to climate change since they are already in a hot climate zone, depend on labor-intensive technologies with fewer adaptation opportunities, and a majority of people in these countries rely heavily on the agricultural sector (Mendelsohn et al. 2001).

Thailand is one of developing countries that agriculture plays a crucial role. For example, in 2011 the agricultural sector employed about 14.88 million people, accounting for 38.7 percent of the Thai labor force (National Statistical Office Thailand 2012) and agricultural activities generate about $40 billion, which contributed to 12.8 percent of the gross domestic production (Office of the National Economic and Social Development Board 2012). Thailand is also a major exporter for many agricultural commodities such as rice, natural rubber, and cassava. Therefore, climate change impacts on agriculture are expected to significantly affect the economy and the livelihood of the people in this country.

The objectives of this study are to analyze the effect of climate change on Thailand's agriculture and investigate implications for greenhouse warming under future climate change scenarios on Thailand's agricultural sector using the Ricardian approach firstly proposed by Mendelsohn et al. (1994). Although there are many studies (Office of Environmental Policy and Planning 2000; Buddhaboon, Kongton, and Jintrawet 2005; Pannangpetch et al. 2009; Isvilanonda et al. 2009) analyzing the effect of climate change on Thailand's agriculture, most studies (except for Khamwong and Praneetvatakul 2011) use the traditional production function approach, which potentially overestimates the damage from climate change since the model allows little adaptation of farmers (Mendelsohn et al. 1994).

The current article differs from Khamwong and Praneetvatakul (2011) in several aspects. First, it expands the scope of the previous research from the northeast region to cover entire country. Second, the current paper uses the finer scale of dataset, a farm-level dataset, which could improve the estimated results since it reflects the farmer's decision regarding the climate adaptation strategies more than the use of provincial-level data. Third, the current article employs the land value as a dependent variable similar to the original Ricardian approach, which could address the potential problem from the use of the annual net farm revenue. Fourth, more constructed important explanatory variables determining the farmland values collected from various sources are included to address the problem of endogeneity bias. Lastly, the current article projects the impacts of climate change under climate scenarios using the unique dataset from regional climate models.

2. LITERATURE REVIEW

In view of its importance to economic well-being, effects of climate change on agriculture have been well research and documented, dating back at least 25 years (e.g. Smith and Tirpak 1989; Mendelsohn et al. 1994; Adams et al. 1999; Reilly et al. 2003; McCarl et al. 2008; Attavanich et al. 2013; and various IPCC reports). Overall, the effect of climate change on agriculture is mixed in developed countries, but negative impacts are found in developing countries. Moreover, in a country, the damage is heterogeneous across regions.

Using an agricultural sector model, Adams et al. (1999) find that agricultural welfare strictly increases in the United States (U.S.) with a 1.5°C warming and further warming could decrease this benefit at an increasing rate. The welfare gain from a 1.5°C warming with 7 percent precipitation is $55 billion in 2060. Further warming by 2.5°C could reduce these benefits to $47 billion. With similar approach, Reilly et al. (2003) estimated the net effect in terms of economic welfare of the combined changes in crop yields including adaptation and CO_2 fertilization effects, water supply, irrigation demand, pesticide expenditures, and livestock effects was generally positive. The increase in economic welfare was ranged from $0.8-$7.8 billion in 2030 and $3.2-$12.2 billion in 2090. U.S. producers generally suffered income losses due to lower commodity prices while consumers gained from these lower prices.

Using the Ricardian analysis, Mendelsohn et al. (1994) find that higher temperatures in all seasons except autumn reduce average U.S. farm values, while more precipitation outside of autumn increases farm values. They estimate that a climate change induced loss in U.S. farmland value ranging from -$141 to $34.8 billion. Schlenker, Hanemann, and Fisher (2005) do a similar study and find an annual loss in U.S. farmland value in the range of $5-$5.3 billion for dryland non-urban counties. Mendelsohn and Reinsborogh (2007) find that U.S. farms are much more sensitive to higher temperature than Canadian farms and but are less sensitive to precipitation increases. Deschenes and Greenstone (2007) find that climate change will lead to a long run increase of $1.3 billion (2002$) in agricultural land values. They indicate that agricultural land values in California, Nebraska, and North Carolina will be lowered substantially by climate change, while South Dakota and Georgia will have the biggest increases.

For developing countries, Seo and Mendelsohn (2008) find that in South America climate change will decrease farmland values except for irrigated farms. Moreover, they find small farms are more vulnerable to the increase in temperature, while large farms are more vulnerable to increases in precipitation. Mendelsohn, Arellano-Gonzalez, and Christensen (2010) project that, on average, higher temperatures decrease Mexican land values by 4 to 6 thousand pesos per degree Celsius amounting to cropland value reductions of 42-54% by 2100. Wang et al. (2009) find that in China an increase in temperature is likely to harm rain-fed farms but benefit irrigated farms. A small value loss is found in the Southeast China farms, while the largest damage is discovered in the Northeast and Northwest farms (Wang et al. 2009).

In Thailand, several studies have investigated the effect of climate change on agriculture. By using the Crop Environment Resource Synthesis (CERES) model, Office of Environmental Policy and Planning (2000) reveals that rice grown under rainfed conditions was found to be highly vulnerable to climate change. Moreover, yields of rice and maize are projected to decline as much as 57 and 44 percent as compared to the baseline, respectively, although their magnitudes vary depending on climate conditions, soil types, and crop practices. Their results are different from Pannangpetch et al. (2009) who employ the Decision Support System for Agro Technology Transfer (DSSAT) model to analyze the impacts of global warming on rice, sugarcane, cassava, and maize production in Thailand. They find a little impact of rising atmospheric CO_2 concentration and temperature on the rice, sugarcane and maize production. However, cassava production may drop as much as 43 percent as compared to the baseline.

Buddhaboon, Kongton, and Jintrawet (2005) simulate the effect of climate change on KDML 105 rice yield in Tung Kula paddy field by direct seeding method and set CO_2

concentration at 1.5 and 2.0 times of year 1980-1989 (normal year) in the period of 2040-2049 and 2066-2075, respectively. They reveal that climate change likely enhances overall rice yield. Similar finding is founded in Isvilanonda et al. (2009) who conclude that climate change enhances KDML 105 rice yield in the north-eastern and the northern regions using CropDSS simulation model. Using changes in yields data, they find that the total production of KDML 105 is project to increase approximately 1.4 million ton, which is equivalent about 14,195 million baht. However, Isvilanonda et al. (2009) project that climate change could adversely affect Suphan Buri 1 rice yield in central plain with a reduction of about 0.249 million ton, creating a loss in value approximately 2,029 million baht. Unlike previous studies, Khamwong and Praneetvatakul (2011) apply the Ricardian model with province-level data to analyze the impacts of climate change on agriculture in northeast region. They find that rising temperature in summer and early rainy season and increased rainfall at the end of the rainy season decrease net farm revenue. On the other hand, increased rainfall in summer and early rainy season increases net farm revenue.

According to the above studies, we can classify the model used to analyze the impacts of climate change on agriculture into three categories (Mendelsohn et al. 1994; Wang et al. 2009) consisting of: 1) Traditional production function approach (e.g., Smith and Tirpak 1989); 2) Ricardian approach (e.g., Mendelsohn et al. 1994); and 3) Agro-economic approach (e.g., Adams et al. 1999). Mendelsohn et al. (1994) criticize that the traditional production function approach has a serious drawback since the model tends to overestimate the damage from climate change by omitting a variety of adaptations that farmers can make in response to changing economic and environmental conditions. While the agro-economic approach incorporates the climate change adaptation of farmers, they are difficult to build especially in the developing countries due to data availability and complexity of the model.

Mendelsohn et al. (1994) then introduce the Ricardian approach to bridge the gap between the traditional production function approach and the agro-economic approach. Recently the Ricardian approach is gaining popularity. This approach is applied to both developed countries such as U.S. and Canada (e.g., Mendelsohn et al. 1994, 2001; Reinsborough 2003) and developing countries such as Brazil, India, Sri Lanka, and China (Dinar et al. 1998; Kumar and Parikn 2001; Mendelsohn et al. 2001; Seo, Mendelsohn, and Munasinghe 2005; Wang et al. 2009).

3. THEORETICAL FRAMEWORK

The Ricardian approach developed by Mendelsohn, Nordhaus, and Shaw (1994) is the primary method that we use in this paper. In contrast to the traditional production function approach, the Ricardian approach allows a variety of the adaptations that farmers make in response to changing economic and climate conditions. By not permitting a complete range of adjustments, previous studies could overestimate damages from climate change. Instead of studying yields of specific crops in the traditional production function approach, the Ricardian approach examines how climate in different locations affects the net rent or value of farmland. By directly measuring farmland values, the approach account for the direct impacts of climate on yields of different crops as well as the indirect substitution of different inputs, introduction of different activities, and other potential adaptations to different climates.

The Ricardian approach assumes that each farmer maximizes income subject to the exogenous conditions of their farms. Specifically, the farmer chooses the inputs and the combination of crop and/or livestock, indexed by *j*, which maximizes net revenue for each unit of land:

$$Max\pi_i = \sum_{j\in J} P_{ij} Q_{ij}(X_{ij} \mid C_i, H_i, S_i) - \sum_{j\in J} P_{ij} X_{ij} \qquad (1)$$

where π_i is the net revenue of farm *i*, P_{ij} is a vector of input and output prices, Q_{ij} is the production function for each crop or livestock *j*, X_{ij} is a vector of endogenous input choices such as seeds, fertilizer, pesticides, irrigation, hired labor and capital, C_i is a vector of climate variables, H_i is a vector of economic control variables and S_i is a vector of soil characteristics.

Differentiating equation (1) with respect to each input identifies the set of inputs that maximizes net farm revenue. The resulting locus of net revenues for each set of exogenous variables is the Ricardian function shown in equation (2). It describes how net revenue will change as exogenous variable change.

$$\pi^* = \pi(C_i, H_i, S_i \mid P_{ij}) \qquad (2)$$

If land is traded in the perfectly competitive market, the land value (V) will be equal to the present value of the net revenue of each farm shown in equation (3).

$$V = \int_0^\infty \pi_i^* e^{-rt} dt \qquad (3)$$

where r is the interest rate.

The welfare impact (W) of climate change is calculated by computing the difference between the value of farmland under the new climate (B) and the value of farmland under the current climate (A) as illustrated in equation (4).

$$W_t = \sum_i \left[V_{it}(C_B) - V_{it}(C_A) \right] \cdot L_{it} \qquad (4)$$

where L_{it} is the amount of land at period t of farm i.

4. METHODOLOGY

Empirical Estimation

To answer the first objective and capture the expected non-linear relationship between the farmland value and climate, this article specifies the following model to examine the impacts of climate change on farmland values in Thailand:

$$V = \alpha_0 + \alpha_{1s} T_s + \alpha_{2s} T_s^{\ 2} + \alpha_{3s} P_s + \alpha_{4s} P_s^{\ 2} + \sum_k d_k Z_k + e \qquad (5)$$

where the dependent variable, V, is the farmland value (dollar) per rai[2], T and P represent a vector of seasonal temperature and precipitation variables, s is season including: winter (November-January); summer (February-April); early rainy (May-July); and late rainy (August-October), Z is a vector of relevant control variables capturing characteristics of principal operator (level of education), farm characteristics (irrigation status, whether the farm has main total sales from crop or livestock, whether the farm has the flood problem, and whether the farm has the problem of steep slope), soil conditions (whether the farm has the problem of soil salinity and sandy soil) and location characteristics (district-level population density, whether the farm

---

[2] 1 rai is equal to about 0.395 acre.

locates in the plain area, Euclidian distance of the farm to the city of the province in which farm is located, and percent of agricultural land to total land area for province in which farm is located) , and *e* is an error term.

Uncertainty of Climate Change Impacts

To answer the second objective of the study, this study investigates the implication for greenhouse warming on Thailand's agriculture by employing our estimated coefficients in equation (5) together with future climate projections during 2040-2049 simulated by PRECIS (Providing REgional Climates for Impacts Studies) regional climate model and used Global Circulation Model (GCM) ECHAM4 dataset as initial data for calculation. The simulation covers IPCC emission scenarios A2 and B2[3], which could account for the upper and lower limit of climate change impacts on Thailand's agriculture.

5. DATA

Data used in this study are collected from various sources. For the most part, the data are from the 2011/2012 national agricultural household socio economics survey at the farm level with 6,701 completed farms sampled across 76 provinces from Office of Agricultural Economics. 331 out of 6,701 farms, or about 5%, have been removed from calculation to address the outliner problem[4] and incomplete data on farmland values. In total, we have 6,370 farms. The gathered data consist of: the estimated current market value of farmland including building expressed in dollars per rai; education level of the principal operator; soil conditions; whether the farm has the problem of steep slope and flood problem; irrigation status; whether the farm has main total sales from crop.

---

[3] A2 scenario is characterized by: a world of independently operating, self-reliant nations; continuously increasing population; and regionally oriented economic development. B2 scenario is more ecologically friendly. The B2 scenario is characterized by: continuously increasing population, but at a slower rate than in A2; emphasis on local rather than global solutions to economic, social and environmental stability; and intermediate levels of economic development (IPCC 2007a).

[4] We have found that several farms located in the urban area, especially in large city such as Bangkok, Nonthaburi, and Chiangmai provinces have very high land prices per rai with small income generated from agricultural activities. Including these farms in the estimation could bias the impacts of climate change on overall Thailand's agriculture.

Climate data are obtained from Thailand Meteorology Department, which gathers data from 76 meteorological stations throughout Thailand. The data include information on monthly temperature and precipitation from 1971 through 2012. Since the purpose of this study is to forecast the impacts of climate changes on agriculture, we focus on the long-run impacts of temperature and precipitation on agriculture, not year-to-year variation weather. We consequently analyze the "normal" climatological variables—the 42-year average of each climate variable for every station during 1971-2012. To capture seasonal effects of climate on agriculture, we construct the seasonal climate variables divided into four seasons including: winter (November-January); summer (February-April); early rainy (May-July); and late rainy (August-December). In order to link the agricultural data which are organized in the farm-level and the climate data which are organized by station, we assign these climate variables to each farm that locates close to the climate station using the nearest distance criterion even though the farm locates in different province from climate station.

To account for location characteristics and potential of land for non-agricultural development, we collect several variables including: district-level population density; whether the farm locates in the plain area; Euclidian distance of the farm to the city of the province in which farm is located; and percent of agricultural land to total land area for province in which farm is located from various sources mainly from the National Statistical Office, Ministry of Agriculture and Cooperatives, Ministry of Interior, and Google Earth. Lastly, data of climate projections mentioned in the methodology section are collected from Center of Excellence for Climate Change Knowledge Management, Chulalongkorn University.

Table 1 summarizes variables used in the estimation, their definitions, and summary statistics across the full sample of farms. For example, on average the farmland in Thailand has its value equal to $2,945 per rai. The monthly temperatures averaged during 1971-2012 in the early rainy, late rainy, and summer seasons are around 27.693-28.844 degree Celsius, while in the winter the month temperature drop to 24.778 degree Celsius. Late rainy season has the highest level of monthly precipitation equal to 211.923 millimeters, while winter season has the lowest level of monthly precipitation equal to 44.591 millimeters.

Table 1. Description of variables and summary statistics

Variable	Definition of Variables	Mean (N=6,370)	Std. Dev.
farm value	Estimate of the current market value of farmland including building (dollars per rai)	2,945	2,948
early rainy temperature	Normal monthly mean temperature (°C) from 1971 to 2012 during the early rainy season (May-July)	28.844	0.568
late rainy temperature	Normal monthly mean temperature (°C) from 1971 to 2012 during the late rainy season (August-October)	27.693	0.530
summer temperature	Normal monthly mean temperature (°C) from 1971 to 2012 during the summer season (February-April)	28.358	1.003
winter temperature	Normal monthly mean temperature (°C) from 1971 to 2012 during the winter season (November-January)	24.778	1.428
early rainy precipitation	Normal monthly precipitation temperature (mm) from 1971 to 2012 during the early rainy season (May-July)	182.673	71.772
late rainy precipitation	Normal monthly precipitation temperature (mm) from 1971 to 2012 during the late rainy season (August-October)	211.923	59.194
summer precipitation	Normal monthly precipitation temperature (mm) from 1971 to 2012 during the summer season (February-April)	49.436	18.742
winter precipitation	Normal monthly precipitation temperature (mm) from 1971 to 2012 during the winter season (November-January)	44.591	91.192
education	Whether the principal operator graduated at least grade 9 (equal to 1 if yes)	0.110	0.312
salt soil	Whether the farm has the problem of soil salinity (equal to 1 if yes)	0.011	0.104
sandy soil	Whether the farm has the problem with sandy soil (equal to 1 if yes)	0.018	0.133
steep slope	Whether the farm has the problem of steep slope (equal to 1 if yes)	0.013	0.115
flood problem	Whether the farm has the flood problem (equal to 1 if yes)	0.117	0.321
irrigate	Whether the farm is the irrigated farm (equal to 1 if yes)	0.254	0.435
main sale from crop	Whether the farm has main total sales from crop (equal to 1 if yes)	0.789	0.408
plain	Whether the farm locates in the plain area (equal to 1 if yes)	0.712	0.453
distance	Euclidian distance, in kilometers, of the farm to the city of the province in which farm is located	42.112	31.153
population density	Population density per square kilometer for district in which farm is located	170.852	195.706
agricultural land	Percent of agricultural land to total land area for province in which farm is located	54.271	18.084

Note: Values in Baht are converted with the exchange rate of 32 Baht/US.

6. EMPIRICAL RESULTS

As the Ricardian approach estimates the importance of climate and other variables on farmland values. Table 2 provides the regression results by regressing farmland values on variables of climate, soil, operator characteristics, farm characteristics, and location characteristics to estimate the best-value function across different farms in Thailand. There are 6,370 cross-sectional observations. In order to give a sense of the importance of nonfarm variables in the model, we begin with a model that contains only climate variables. Specification 1 in Table 2 is a quadratic model that includes the eight measures of climate. For each variable, linear and quadratic terms are included to reflect the nonlinearities that are apparent from field studies. For Specification 2, we include variables capturing characteristics of operator, soil, farm, and location to control for other factors influencing farmland values.

Overall we find that all climate variables statistically affect farmland values and their squared terms are significant, implying that the observed relationships are non-linear as found in the field studies. However, some of the squared terms are positive (i.e., early rainy temperature, winter temperature, early rainy precipitation, and summer precipitation) implying that there is a minimally productive level of temperature and precipitation in that season and that either more or less temperature and precipitation will raise farmland values. The negative coefficient of squared terms implies that there is an optimal level of a climate variable from which the value function decreases in both directions.

The overall impact of climate as measured by the marginal impacts evaluated at the mean level of each variable is provided in Table 3. In general, we discover that higher summer temperatures and higher early rainy and summer precipitation are harmful for crops, while higher winter temperatures and higher late rainy and winter precipitation are beneficial for crops. The higher summer temperatures by 1°C decrease the farmland values equal to \$479 per rai, while higher winter temperatures by 1°C increase the farmland values equal to \$299 per rai. For precipitation, higher early rainy and summer precipitation by 1 millimeter decrease the farmland values equal to \$7 and \$28 per rai, respectively. On the other hand, the farmland values will be increased \$11 and \$18 per rai, as late rainy and winter precipitation increase by 1 millimeter, respectively.

Table 2. Regression models explaining farm values

	Specification 1		Specification 2	
farm value	Coef.	Std. Err.	Coef.	Std. Err.
Constant	-471,422.50***	129,626.90	-556,252.10***	136,264.00
early rainy temperature	-23,327.83**	11,453.95	-36,941.65***	11,141.28
early rainy temperature^2	404.93**	198.99	634.68***	193.69
late rainy temperature	56,029.68***	16,266.61	79,825.58***	16,507.53
late rainy temperature^2	-1,014.24***	293.46	-1,440.79***	297.42
summer temperature	15,099.00***	2,819.34	7,444.66**	2,982.07
summer temperature^2	-274.63***	49.14	-139.94***	52.05
winter temperature	-14,180.45***	2,237.70	-9,004.27***	2,292.01
winter temperature^2	292.93***	45.18	188.91***	46.21
early rainy precipitation	-13.78***	4.22	-11.59***	4.18
early rainy precipitation^2	0.02**	0.01	0.01*	0.01
late rainy precipitation	25.58***	6.44	21.61***	6.37
late rainy precipitation^2	-0.03***	0.01	-0.03***	0.01
summer precipitation	-55.08***	11.73	-50.94***	11.57
summer precipitation^2	0.22***	0.09	0.23***	0.08
winter precipitation	25.64***	3.27	21.80***	3.27
winter precipitation^2	-0.05***	0.01	-0.05***	0.01
education			449.55***	116.90
soil salt			-521.69**	237.05
sandy soil			-88.86	251.31
steep slope			-900.84***	251.58
flood problem			-183.36*	106.27
irrigate			223.40**	93.32
main sale from crop			-1,010.18***	95.29
plain			-251.42**	103.08
distance			-5.73***	1.13
population density			1.51***	0.38
agricultural land			1.84	3.01
Adj. R squared	0.1473		0.1851	

Note: Standard Errors are calculated using the Huber/White/sandwich estimator. ***,**,* are significant at 1, 5 and 10 percent, respectively.

Table 3. Marginal effect of climate variables

farm value	Coef.	Std. Err.
early rainy temperature	-388.80	359.32
late rainy temperature	173.81	359.46
summer temperature	-478.78***	182.60
winter temperature	298.64**	151.29
early rainy precipitation	-6.74***	2.43
late rainy precipitation	10.68***	3.44
summer precipitation	-28.38***	5.14
winter precipitation	18.47***	2.81

Note: ***,**,* are significant at 1, 5 and 10 percent, respectively.

7. IMPLICATIONS FOR GREENHOUSE WARMING

This section investigates the implications for greenhouse warming during 2040-2049 on Thailand's agriculture. To project the climate change impacts, the estimated coefficients from Specification 2 in Table 3 are used together with the climate projections from the regional climate model mentioned in the previous sections. In brief, future climate projections in both scenarios shows trend of increasing temperature throughout Thailand, especially in the central plain of Chao Phraya river basin and lower part of northeastern region. Total annual precipitation likely fluctuates in the early part of the century. Since scenarios A2 is assumed to have more carbon dioxide emissions than scenario B2, projected temperatures from scenario A2 is higher than those from scenario B2 while projected precipitation from scenario A2 is slightly lower than those from scenario B2.

By substituting climate projections, this study finds that during 2040-2049 farmland values per rai are projected to decrease from $2,703 per rai to $2,068 and $2,538 per rai in climate scenarios A2 and B2, respectively. By multiplying the farmland values per rai to the total farmland area in Thailand (149 million rai), climate change are projected to adversely affect Thailand's agriculture range from $24 billion to $94 billion as shown in Table 4. By downscaling the analysis to the province level, this article finds that western, upper part of central, and the left part of northern regions are projected to be better off, while southern, eastern regions, lower part of central, and the right part of northern regions is projected to be worse off under both climate scenarios as illustrated in Figure 1. As expected, scenario A2 projects higher negative impacts of climate change on Thailand's agriculture more than scenario B2.

Table 4. Implications for greenhouse warming (national level)

	farmland value/rai ($)	total land values ($1,000)	total change ($billions)
Baseline	2,703	403,361,918	-
A2	2,068	308,674,640	-94.69
B2	2,538	378,838,371	-24.52

Note: Agricultural land is equal to 149,246,428 rai in 2011.

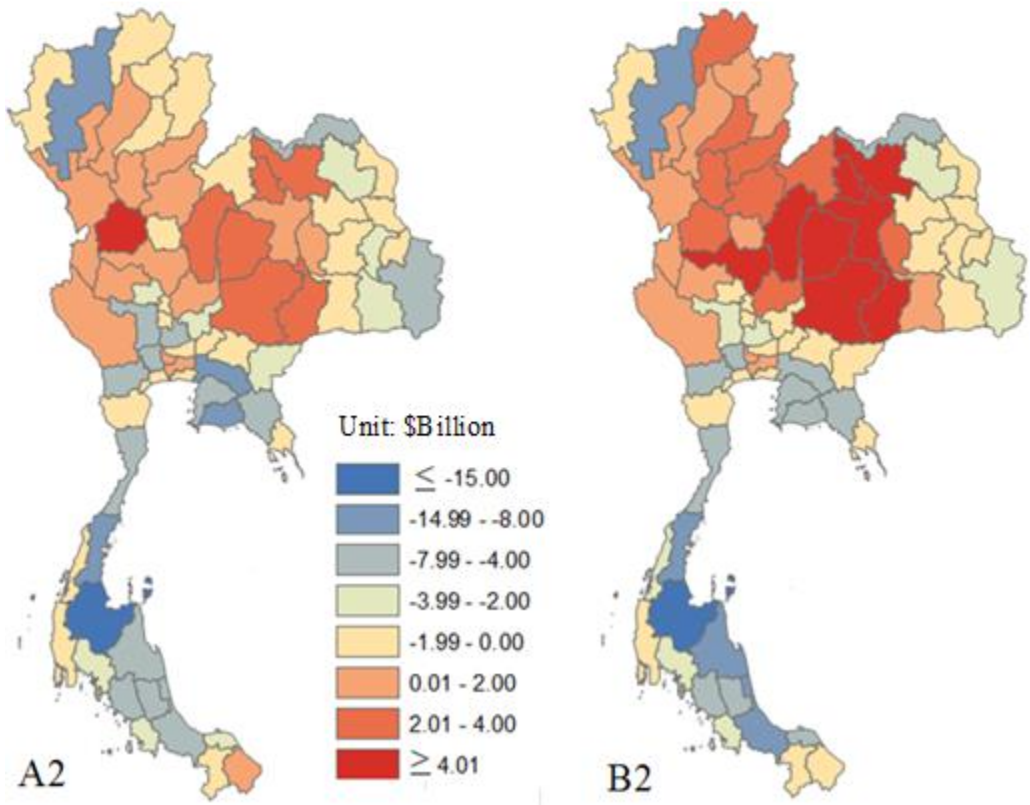

Figure 1. Implications for greenhouse warming (projection of 2040-2049)

Top ten provinces that are projected to adversely affect under both climate scenarios are Surat Thani, Chiang Mai, Chumphon, Rayong, Chachoengsao, Songkhla, Chanthaburi, Nakhon Si Thammarat, Trang, Suphanburi, respectively, with the impacts ranging from $3.48- $19.43 billion. On the other hand, Kamphaeng Phet, Udon Thani, Chaiyaphum, Phetchabun, Nakhon Ratchasima, Nongbua Lamphu, Buriram, Bangkok, Khon Kaen, Sukhothai are top ten provinces that are projected to be better off with the values ranging from $0.27 - $7.80 billion.

8. CONCLUSION

Agricultural sector is potentially the most sensitive economic sector to climate change and Thailand is one of developing countries that agricultural sector plays an important role. This study utilizes the Ricardian approach to analyze the effect of climate change on Thailand's agriculture and investigate implications for greenhouse warming under future climate change scenarios during 2040-2049. A unique farm-level dataset is constructed using data from several sources mainly from the 2011/2012 national agricultural household socio economics survey. The normal climatological variables during 1971-2012 are constructed using climate data from Thailand Meteorology Department. Future climate projections are simulated by PRECIS regional climate model.

The article finds that both temperature and precipitation significantly determine farmland values. Overall, greenhouse warming is projected to adversely affect Thailand's agriculture ranging from $24 billion to $94 billion. For the analysis in the province level, western, upper part of central, and the left part of northern regions are projected to be better off, while southern, eastern regions, lower part of central, and the right part of northern regions is projected to be worse off. Surat Thani, Chiang Mai, Chumphon, Rayong, Chachoengsao, Songkhla, Chanthaburi, Nakhon Si Thammarat, Trang, Suphanburi are top ten provinces adversely affected by climate change, while Kamphaeng Phet, Udon Thani, Chaiyaphum, Phetchabun, Nakhon Ratchasima, Nongbua Lamphu, Buriram, Bangkok, Khon Kaen, Sukhothai are top ten provinces that are beneficial under climate change.

Governmental organizations related to the agricultural sectors should support farmers on several ways such as providing knowledge to farmers regarding adequate cropping techniques, agricultural resource management and encourage farmers to create adaptation plan to reduce the damage from climate change. At the same time, policy makers should develop plans or programs ahead to relief those who are projected to adversely affect by climate change in provinces across Thailand.

9. REFERENCES

Adams, R. M., B. A. McCarl, K. Segerson, C. Rosenzweig, K. J. Bryant, B. L. Dixon, J. R. Conner, R. E. Evenson, and D. S. Ojima. 1999. The economic effects of climate change on u.s. agriculture. In *The impact of climate change on U.S. agriculture.*, eds R. Mendelsohn and J. Newmann: Cambridge University Press, London: 18-54.

Attavanich, W., B.A. McCarl, Z. Ahmedov, S. Fuller, and D.V. Vedenov. 2013. Effects of climate change on US grain transport. *Nature Climate Change* 3**:** 638–643.

Buddhaboon, C., S. Kongton, and A. Jintrawet. 2005. Climate scenario verification and impact on rain-fed rice production. In *The study of future climate change impact on water resource and rain-fed agricultural production.*, eds S. Chinvanna and A. Snidvongs. Proceedings of the APN CAPABLE CB-01 Synthesis Workshop, Vientaine, Lao PDR, 29-30 July 2004. SEA START RC Technical Report No. 13.

Deschenes, O., and M. Greenstone. 2007. The economic impacts of climate change: Evidence from agricultural output and random fluctuations in weather. *American Economic Review* 97 (1): 354–85.

Dinar, A., R. Mendelsohn, R. Evenson, J. Parikh, A. Sanghi, K. Kumar, J. McKinsey, and S. Lonergan (eds) 1998. Measuring the impact of climate change on Indian agriculture. World Bank Technical Paper No. 402, Washington, DC.

IPCC, ed. 2007a. *Climate change 2007: The physical science basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change., eds. S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor and H. L. Miller. Cambridge, UK: Cambridge University Press.

———. 2007b. *Climate change 2007: Impacts, adaptation and vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change., eds. M. L. Parry, O. F. Canziani, P. J. Palutikof, P. J. van der Linden and C. E. Hanson. Cambridge, UK: Cambridge University Press.

———. 2001a. *Climate change 2001: The scientific basis*. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change., eds. J. T. Houghton, Y. Ding, D. J. Griggs, M. Noguer, P. J. van der Linden, X. Dai, K. Maskell and C. A. Johnson. Cambridge, UK: Cambridge University Press.

———. 2001b. *Climate change 2001: Impacts, adaptation, and vulnerability*. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change., eds. J. J. McCarthy, O. F. Canziani, N. A. Leary, D. J. Dokken and K. S. White. Cambridge, UK: Cambridge University Press.

Isvilanonda, S., S. Praneetvatakul, and C. Khamwong. 2009. Economic impact assessment of climate change on rice production in Thailand. Project Code: RDG5130015. The Thailand Research Fund, Thailand.

Khamwong, C., and S. Praneetvatakul. 2011. Impact of climate change on agricultural revenue and adaptation strategies of farmers in Northeasterm Thailand. Kasetsart Journal (Social Science) 32: 214-228.

Kumar, K. and J. Parikh. 2001. Indian agriculture and climate sensitivity. *Global Environmental Change* 11: 147–54.

McCarl, B. A., X. Villavicencio, and X. Wu. 2008. Climate change and future analysis: Is stationarity dying? *American Journal of Agricultural Economics* 90 (5): 1241–47.

Mendelsohn, R (eds.). 2001. Global Warming and the American Economy: A Regional Assessment of Climate Change. Cheltenham: Edward Elgar Publishing.

Mendelsohn, R., J. Arellano-Gonzalez, and P. Christensen. 2010. A Ricardian analysis of Mexican farms. *Environment and Development Economics* 15 (2): 153–71.

Mendelsohn, R., W. D. Nordhaus, and D. Shaw. 1994. The impact of global warming on agriculture: a Ricardian analysis. *American Economic Review* 84: 753–71.

Mendelsohn, R., and M. Reinsborough. 2007. A Ricardian analysis of U.S. and Canadian farmland. *Climatic Change* 81 (1): 9–17.

Office of Environmental Policy and Planning. 2000. Thailand's Initial National Communication under the United Nations Framework Convention on Climate Change. Ministry of Science, Technology, and Environment. Bangkok, Thailand. 100 p.

Pannangpetch K., V. Sarawat, S. Boonpradub, S. Ratanasriwong, S. Kongton, S. Nilpunt, C. Buddhaboon, K. Kunket, I. Buddhasimma, P. Kapetch, K. Ek-un, W. Damrhikhemtrakul. 2009. Impacts of global warming on rice, sugarcane, cassava, and maize production in Thailand. Project Code: RDG5130007. The Thailand Research Fund, Thailand.

Reilly, J., F. Tubiello, B. A. McCarl, D. Abler, R. Darwin, K. Fuglie, S. Hollinger, C. Izaurralde, S. Jagtap, and J. Jones. 2003. U.S. agriculture and climate change: new results. *Climatic Change* 57: 43–67.

Reinsborough, M. J. 2003. A Ricardian model of climate change in Canada. *Canadian Journal of Economics* 36: 21-40.

Schlenker, W., W. M. Hanemann, and A. C. Fisher. 2005. Will U.S. agriculture really benefit from global warming? Accounting for irrigation in the hedonic approach. *American Economic Review* 95 (1): 395–406.

Schlenker, W., and M. J. Roberts. 2009. Nonlinear temperature effects indicate severe damages to U.S. crop yields under climate change. *Proceedings of the National Academy of Sciences* 106 (37): 15594.

Seo, S. N., and R. Mendelsohn. 2008. An analysis of crop choice: Adapting to climate change in Latin American farms. *Ecological Economics* 67: 109–16.

Seo, S., R. Mendelsohn, and M. Munasinghe. 2005. Climate change and agriculture in Sri Lanka: A Ricardian valuation. *Environmental and Development Economics* 10: 581–96.

Smith, J. B., and D. A. Tirpak (eds.). 1989. The Potential effects of global climate change on the United States: Report to Congress, United States, Environmental Protection Agency. Office of Policy, Planning, and Evaluation.

Chinvanno, S., V. Laung-Aram, C. Sangmanee, and J. Thanakitmetavut. 2009. Simulation of future climate scenario for Thailand and surrounding countries. Contract No.RDG5030032. Thailand Research Fund.

Wang, J., R. Mendelsohn, A. Dinar, J. Huang, S. Rozelle, and L. Zhang. 2009. The impact of climate change on China's agriculture. *Agricultural Economics* 40 (3): 323–37.