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ARTICLE

Estimating the potential effects of climate change on rice production in Thailand

Nirote Sinnarong[1] · Chi-Chung Chen[2] · Bruce McCarl[3] · Bao-Linh Tran[2]

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Abstract
This study estimates the potential effects of climate change on rice production in Thailand based on historical data from 1989 to 2009. An econometric panel data model is applied to examine the impact of the changing climatic conditions on mean and variability of rice yields. The empirical estimation results show that a rise in temperature would lead to a reduction in mean rice production and an increase in production variance. On the other hand, increasing precipitation is found to have region-varying effects on rice production. Under projections of future climate change, the simulation results reveal that the substantial change in mean and variability of rice yields arises as a consequence of fluctuation of temperature and precipitation. For instance, mean rice yield would be decreased by 4.56–33.77% and the rice production variability would be increased by 3.87–15.70% in response to different scenarios over the course of the century. Therefore, it is necessary to take immediate adaptive actions appropriately to mitigate the decrease in rice production.

Keywords Climate change · Rice production · Thailand · Panel data model

Introduction

Agriculture is known as one of the sectors that are most vulnerable to climate change due to its high dependence on climate and weather conditions. As one of the main drivers of agricultural productivity, climate is also a dominant factor in the overall variability of food production (Selvaraju et al. 2011). In recent decades, climate change has increased average temperature, altered precipitation patterns and increased frequency and intensity of some extreme climatic events (such as floods, landslides, tropical cyclones and droughts) that have been observed across Asia and the Pacific (UNFCCC 2007). Climate change is already evident in a number of ways that are observed to continue to adversely affect agriculture (Clements et al. 2011).

Among the regions that have experienced disadvantages and damages in agriculture caused by changing climate conditions, developing countries in the Asia and the Pacific region are most severely affected. Specifically, the slowdown in the rate of agricultural productivity growth, decline in income growth and issues with maintaining food security have already posed challenges to many countries in this region. Based on combining macroeconomic theory with crop models, the scientists from a study conducted by the Asian Development Bank (ADB 2009) estimated yield reductions under climate change compared to no-climate change scenario and found the largest negative impact on rice and wheat yields across all sub-regions: by 2050, irrigated paddy is expected to reduce with a range of 14–20%; irrigated wheat, 32–44%; and irrigated soybean, 9–18%. They also found that food prices are also projected to increase sharply for key crops; for example, rice prices are projected to be 29–37% higher in 2050 compared to a no-climate change case. These adverse impacts of climate change on agriculture are of particular concern for the region

✉ Chi-Chung Chen
mayjune@nchu.edu.tw

Nirote Sinnarong
nsinnarong@hotmail.com

Bruce McCarl
mccarl@tamu.edu

Bao-Linh Tran
linhtran.ymn@gmail.com

[1] Department of Economics, Maejo University-Phrae Campus, Phrae, Thailand

[2] Department of Applied Economics, National Chung Hsing University, Taichung, Taiwan

[3] Department of Agricultural Economics, Texas A&M University, College Station, TX, USA

given the significant role of agriculture in employment, economic development and global food security.

Thailand stands as a world's leading rice producer and exporter with 11 million harvesting hectares, 31.5 million tons of production quantity in 2009 and contributing over 30% of global rice trade volume (FAO 2009). The Thai government has implemented the rice-pledging scheme after the 2011 general election, to give Thai farmers the opportunity to pledge and then provide an unlimited supply of their rice to the government at a higher price than marketing rate. Although Thailand harvested less rice in 2014, continued sales from government granaries are expected to keep the country's exports rising. The FAO report predicts that Thailand will regain the title of the top exporter in 2015 (FAO 2015). However, the sustainability of Thai rice sector's production performance is threatened by low productivity, labour scarcity and water shortage (Southeast Asia Regional Initiatives for Community Empowerment and Rice Watch and Action Network 2005).

Rice in Thailand is predominantly grown in two main cropping periods, the wet season (May through October) and the dry season (November through April). In the wet season, approximately 75% of rice is grown in rain-fed areas and 25% rice in irrigated areas, in which about 6.4%, 5%, 11.7% and 1.4% of irrigated rice area in the northern, north-east, central plain and southern regions, respectively (Soni 2016). The rain-fed systems during the wet season are well-founded alternatives and compete against irrigation (Perret et al. 2013). As climate is an important factor affecting the agricultural sector, Thailand has also experienced difficulties due to dependence of the agriculture on rain-fed cropping systems. Facing climate change which is mainly in changing temperature and precipitation, key components of adaptation measures basically include changes in agricultural practices, changes in agricultural water management, agricultural diversification, agricultural science and technology development, and agricultural insurance and risk management. Generally, these measures intended to increase adaptive capacity by adjusting farming practices, improving crop and livestock through breeding and investing in innovative technologies and infrastructure to increase production (Cruz et al. 2007). Since the rain-fed systems play an important role in rice production in Thailand, the water shortage which is relatively correlated with climate change has been identified as a major constraint to further increases in production. As climate change harms rice yields and continuously growing population threaten food security, rice producers and the Thai government will be forced to further address rice production to adapt to challenges of global climate change (Climate Institute 2008).

There have been a number of studies focusing on climate change and Thailand agriculture (Matthews et al. 1997; Masutomi et al. 2009; Felkner et al. 2009; Babel et al. 2011). The crop simulation model has been adopted in most such papers to estimate rice yield potentials in Thailand under climate conditions and future climate scenarios. For instance, Masutomi et al. (2009) inputted data of cultivation conditions into the M-GAEZ[1] model to simulate rice yields in Southeast Asian countries; Felkner et al. (2009) employed the DSSAT[2] crop growth model to construct measures of intermediate rice production output; or the CERES–rice model which is also another version of DSSAT was adopted by Babel et al. (2011) to examine the impact of climate change on rice production fluctuation in the north-east Thailand.

Despite comprehensively taking cultivation factors as biophysical and management conditions into account, the crop simulation models basically simulate the rice growth through the numerical integration of consistent processes, but they do not always sufficiently address the possible effects of climate change on pets, diseases, variability in climate, climate extremes and so on, and may also encounter simulation errors (Ainsworth and Ort 2010). In contrast to the crop simulation method, the regression model is more flexible since it applies only historical climate and rice yield data for estimation. Furthermore, even though regression model does not require strictly field and management data for its validation and assessment, it provides a good fit to the existing set of observations and therefore lays the foundation for the future relationships between climate and yield that correspond to the past in order to validly predict the effects of future climate change on crop yields (Lobell and Burke 2010).

In this study, we apply regression tool, i.e. the Just–Pope stochastic production function in panel data estimation, as the alternative to the crop simulation models to determine the statistical relationship between climate factors and rice production in Thailand. As climate change not only resulted in reduction in mean yields, but also contributed to a change in crop yield variability (Mearns et al. 1992; Chen et al. 2004), we therefore consider using both mean and variance of climatic conditions as well as corresponding rice productions. Specifically, the panel data set comprising 73 provinces for an 11-year period (1989–2009) was used to examine the impacts of climate variables including temperature and precipitation on average and variation of rice productions. Then, the projections of future changes in climate in the next 80 years will be applied to predict the potential effects of the changes in temperature and precipitation on rice production. Such empirical results have important implications for adaptation strategies for sustaining food security and export earnings in Thailand.

[1] The Global Agro-ecological Zone model.

[2] Decision Support System for Agro-technology Transfer.

Methodology and data set

Theoretical and empirical models

To depict the relationship between climate conditions and both mean and variability of rice production under heteroscedastic disturbances, a stochastic frontier production function approach of the type proposed by Just and Pope (1978, 1979) is applied, while the panel setting approach is followed by Baltagi (1995), Kumbhakar (1997), Chen et al (2004), Isik and Devadoss (2006), McCarl et al. (2008) and Cabas et al. (2010). The estimation equation for rice production can then be formed:

$$y_{it} = f(x_{itk}, \beta_k) + u_{it} = f(x_{itk}, \beta_k) + h(x_{itk}, \alpha_k)^{0.5} \cdot \varepsilon_{it} \quad (1)$$

where y_{it} is the rice production, x_{itk} is a vector of kth explanatory variable, $f(x_{itk}, \beta_k)$ is a function relating the mean level of rice production to x_{itk} and β are estimated parameters, $h(x_{itk}, \alpha_k)^{0.5}$ is a function relating the standard deviation of rice production to the independent variables x_{itk} and α are estimated parameters, and ε_{it} is a random error term with zero mean and variance of σ^2.

The specification allows estimation of the way that explanatory variables such as climate conditions influence both the mean and variance of crop production, as can be seen by noting that $E(y_{it}) = f(x_{itk}, \beta_k)$ and $\mathrm{Var}(y_{it}) = h(x_{itk}, \alpha_k)\sigma^2$.

The stochastic production function given by Eq. (1) can be estimated using maximum likelihood estimation (MLE) or feasible generalized least squares (FGLS) under heteroscedastic disturbances. Given the large sample in this study, applying the FGLS approach could provide more robust estimation results.

The procedure proposed by Just and Pope (1978, 1979) and Chen et al. (2004) is employed to concretize Eq. (1). The rice production and explanatory variables have a log-linear or Cobb–Douglas production function form assumed to reflect the nonlinear relationship between these climate conditions and production (Schlenker and Roberts 2006). The estimated parameters will be represented as elasticities (the percentage change in rice production given a percentage change in an independent variable). The summations of all elasticities of explanatory variables could be either greater or less than one in order to reflect alternative production function characteristics with respect to input variables. Specifically, the panel data model which is used for controlling intertemporal and regional differences is as follows:

$$\ln(y_{it}) = \alpha + \ln\left(x'_{it}\right)\beta + u_{it} \quad i = 1, \ldots, N; \quad t = 1, \ldots, T \quad (2)$$

$$u_{it} = \mu_i + v_{it} \quad (3)$$

where y_{it} is the log of the production observed for province i at time t, x'_{it} is a vector of explanatory variables for province i at time t, β is a vector of estimated coefficients, u_{it} is the model residual, μ_i is the unobservable region-specific effect and ν_{it} is the remanding disturbance.

The estimation procedure consists of four steps as follows:

Step 1 Regressing $\ln(y_{it})$ on $\ln(x_{itk})$ using a fixed effects panel model and obtain a consistent estimator of the unknown variance component, σ_v^2 that is the within residual MSE, call it $\hat{\sigma}_v^2$.
Step 2 Regressing $\ln(y_{it})$ on $\ln(x_{itk})$ using the OLS and obtain the residual $\hat{u}_{it}$, calculate the estimate variance, $\hat{\sigma}_i^2 = \sum_{t=1}^{T} \left(\hat{u}_{it} - \bar{\hat{u}}_{i.}\right)^2 / (T-1)$, where $\bar{\hat{u}}_{i.} = \sum_{t=1}^{T} \hat{u}_{it}/T$ is the group mean of OLS residual, and then obtain $\hat{w}_i^2 = \hat{\sigma}_i^2 - \hat{\sigma}_v^2$ for $i = 1, \ldots, N$. Next, we calculate the weighted value, $\hat{\tau}_i = T\hat{w}_i^2 + \hat{\sigma}_v^2$ and $\hat{\theta}_i = 1 - (\hat{\sigma}_v/\hat{\tau}_i)$
Step 3 Performing FGLS as weighted least squares (WLS) on the transformed model

$$\hat{y}_{it}^* = y_{it} - \hat{\theta}_i \bar{y}_{i.} \quad \text{on} \quad \hat{x}_{it}^* = x_{it} - \hat{\theta}_i \bar{x}_{i.} \quad (4)$$

where $\bar{y}_{i.}$ and $\bar{x}_{i.}$ are the dependent variable and independent variables, respectively.

For empirical model, the mean production equation estimated for rice is constructed as follows:

$$\begin{aligned} \text{Yield}_{it} = \beta_0 + \beta_1 \text{Parea}_{it} + \beta_2 \text{Atem}_{it} + \beta_3 \text{Vtem}_{it} \\ + \beta_4 \text{Tpre}_{it} + \beta_5 T_{it} + \mu_i + \nu_{it} \end{aligned} \quad (5)$$

where Yield_{it} is the rice production in tons, Parea_{it} is the total planted area with rice in hectare, Atem_{it} is the monthly average temperature for the growing season in degree Celsius, Vtem_{it} is the variation of temperature that is used to capture the effects of temperature variability rice yield, Tpre_{it} is the monthly total precipitation for growing season in millimetre and T_{it} is a time–trend variable that represents the effect of technological progress such as a new rice varieties and improved agronomic practices. The natural logarithm of both sides of Eq. (5) is estimated using a panel data approach.
Step 4 Estimating the variance of production model

In order to estimate the marginal effects of explanatory variables on the variance of rice production (α) with the σ^2 is unobservable, this step can use the OLS residuals from Step 2 as a consistent estimator of u_{it}. Then, u_{it}^2 is regress on its asymptotic expectation, $h(x_{itk}, \alpha_k)$ with $h(\cdot)$ assumed to be exponential function, $E\left(\sigma_{it}^2\right) = \exp\left(z'_{it}\alpha\right)$. After taking logs on both sides, it can be rewritten as $\ln \sigma_{it}^2 = z'_{it}\alpha$, where z'_{it}

elements are nonlinear transformations of explanatory variables (x'_{it}) as same as the explanatory variables used in Eq. (5). Hence, Eq. (5) can be rewritten as follows:

$$\ln(u_{it})^2 = \alpha_0 + \alpha_1 \mathrm{Parea}_{it} + \alpha_2 \mathrm{Atem}_{it} + \alpha_3 \mathrm{Vtem}_{it} + \alpha_4 \mathrm{Tpre}_{it} + \alpha_5 T_{it} + e_{it} \quad (6)$$

Equation (6) allows us to model a nonlinear relationship between variance of rice production and climate change. This equation is estimated using the panel least square method.

Description of data

The data used in this study contain rice production data and climate data. The production data are from 73 provinces which are sub-units within four major Thai regions. There are 17 provinces from the north, 17 provinces from the north-east, 25 provinces from the central and 14 provinces from the south over the time period from 1989 to 2009. The rain-fed rice production data are retrieved from the 2010 Office of Agricultural Economics (OAE) reports (Office of Agricultural Economics 2010).

Data of climatic conditions are derived from the Thai Meteorological Department (Thai Meteorological Department 2010). Specifically, monthly measurements of temperature and precipitation at the provincial level are collected from a representative weather station located in the centre of each province. The descriptive statistics across all the data used are presented in Table 1. As can be seen, the north-east region is the predominant rice production area in Thailand. For the rice production, the statistics show that higher means are related to higher standard deviations for all four regions. As for the data regarding climate, the mean temperature for the growing season varies around 27 °C, whereas the variation in temperature is between 0.84 and 4.85 °C in the four regions. In terms of precipitation, the south region has the most with almost twice the precipitation compared with the other three regions. The total precipitation for the growing season varies between 1107 and 2104 mm in these four regions.

Empirical results

Pre-estimation specification test

Before estimating the production function, three specification tests including panel unit root test, heteroscedasticity test, and fixed and random effects test are performed. We use panel unit root test with both the Breitung's and Im, Pesaran and Shin (IPS) methods adopted to examine whether the

Table 1 Descriptive statistics of the date used in the estimations

	North	North-east	Central	South
Total production (tons) (Yield)				
Mean	324,277	504,666	181,765	59,658
SD	247,216	253,856	172,080	69,969
Maximum	1,261,079	1,034,983	768,114	273,401
Minimum	29,889	76,554	825	44
Planted area (hectare) (Parea)				
Mean	118,550	288,862	60,154	28,718
SD	91,512	141,425	52,627	34,158
Maximum	389,488	614,195	238,967	167,756
Minimum	12,808	45,032	203	20
Average temperature (°C) (Atem)				
Mean	27.15	27.29	27.99	27.66
SD	0.90	0.51	0.78	0.56
Maximum	29.27	28.65	30.40	29.51
Minimum	24.89	25.51	24.97	26.33
Variation in temperature (Vtem)				
Mean	4.85	4.42	2.03	0.84
SD	2.54	1.64	1.24	0.42
Maximum	18.78	9.89	6.75	3.48
Minimum	0.77	0.92	0.09	0.10
Total precipitation (mm) (Tpre)				
Mean	1106.95	1273.40	1283.49	2103.61
SD	264.11	361.10	820.32	743.94
Maximum	2141.50	2815.80	6020.50	4870.70
Minimum	522.90	451.40	492.30	801.50
Number of observation	357	357	525	294

Table 2 Unit root test results

	North	North-east	Central	South
Yield (tons)	− 5.13*	− 3.73*	− 5.59*	− 2.42*
	− 2.98*	− 2.73*	− 4.44*	− 4.40*
Planted area (ha)	− 3.12*	− 2.65*	− 6.65*	− 2.17**
	− 3.92*	− 1.34***	− 6.33*	− 1.45***
Average temperature (°C)	− 3.94*	− 4.56*	− 6.78*	− 3.91*
	− 2.50*	− 3.24*	− 5.18*	− 2.00**
Variation in temperature	− 10.41*	− 7.81*	− 10.32*	− 5.24*
	− 9.26*	− 11.77*	− 15.05*	− 4.65*
Total precipitation (mm.)	− 5.96*	− 5.98*	− 6.24*	− 2.41*
	− 6.09*	− 5.27*	− 7.60*	− 2.51*

The top number of each variable is statistic for Breitung's test, and the bottom number is statistic for IPS test

*, ** and *** indicate that the null hypothesis of nonstationary is rejected at the 1, 5 and 10% level of significance

Table 3 Specification test results for the panel data model

	North	North-east	Central	South
Heteroscedasticity[a]				
B-P-G test	13.09*	6.78*	13.72*	5.40*
White's test	5.62*	4.49*	6.39*	2.93*
Fixed versus random effects test[b]				
Mean function	0.00 (1.00)*	7.66 (0.18)*	0.00 (1.00)*	7.98 (0.15)*
Variance function	0.00 (1.00)*	0.00 (1.00)*	6.01 (0.31)*	0.00 (1.00)*

[a]The statistic of B–P–G test and White's test are *F*-statistic

[b]The fixed versus random effects test is performed Hausman test with the Chi-square statistic, and the numbers in parentheses are *p*-value

*The null hypothesis is rejected at the 1% level of significance

variables are stationary and find that they are (see Table 2). Hence, no corrective differential procedures are needed. The heteroscedasticity tests (Breusch–Pagan–Godfrey and White) firmly reject the null hypothesis of homoscedasticity at all conventional significance levels, and thus, we proceed with the Just–Pope estimation approach. To deal with common panel data problems (such as autocorrelation or cross-correlation in cross-sectional units at the same point in time), we run fixed effects model and random effects model which of those both have better estimation than the pooled OLS. As a statistical tool for determining whether a fixed or random effects model is a plausible fit for data, the Hausman test is used and its result indicates that the random effects model is more appropriate (Table 3).

Table 4 Estimated parameters for rice yield mean function and yield variability under Cobb–Douglas functional forms

	North	North-east	Central	South
Mean function				
Planted area	0.96122*	0.96412*	1.05496*	0.96657*
	(0.02795)	(0.03119)	(0.02999)	(0.01419)
Average temperature	− 1.18740**	− 0.67028***	− 0.98538***	− 0.19191
	(0.47407)	(039629)	(0.52076)	(0.49312)
Variation in temperature	− 0.02395	− 0.02166	0.02245	− 0.00394
	(0.02463)	(0.01497)	(0.01713)	(0.01673)
Total precipitation	0.05815	0.08419*	− 0.13961*	− 0.07224**
	(0.04583)	(0.03149)	(0.04105)	(0.02952)
Time trend	0.11684*	0.088688*	0.20951*	0.10865*
	(0.01147)	(0.00708)	(0.01124)	(0.01002)
Constant	2.85141***	0.66238	2.24208	0.18520
	(1.64348)	(1.38503)	(1.80222)	(1.62405)
Adjusted R^2	0.80020	0.77514	0.71131	0.95117
S.E. of regression by OLS	0.17748	0.12550	0.28522	0.12948
S.E. of regression by FGLS	0.14959	0.09664	0.16484	0.10417
Variance function				
Planted area	0.00176	− 0.01254**	− 0.01135	0.00053
	(0.00328)	(0.00515)	(0.01318)	(0.00187)
Average temperature	0.17887***	0.11080	0.59781***	0.24303**
	(0.10458)	(0.09398)	(0.31146)	(0.11194)
Variation in temperature	0.00446	0.00193	− 0.00841	0.00220
	(0.00654)	(0.00358)	(0.01043)	(0.00395)
Total precipitation	0.01272	9.14E−05	0.04151***	− 0.00210
	(0.01174)	(0.00724)	(0.02379)	(0.00640)
Time trend	− 0.02385*	− 0.00460*	− 0.03980*	− 0.00621*
	(0.00338)	(0.00170)	(0.00657)	(0.00231)
Constant	− 0.62635	− 0.16574	− 1.97450***	− 0.76631***
	(0.38818)	(0.33377)	(1.10911)	(0.38964)
Adjusted R^2	0.14524	0.03143	0.07397	0.05791
S.E. of regression by OLS	0.04783	0.02583	0.11898	0.02886
S.E. of regression by FGLS	0.04783	0.02422	0.10737	0.02817

Numbers in parentheses are standard errors

*, ** and *** indicate that the significant at the 1, 5 and 10%, respectively

Estimation of rice production function

The FGLS procedure is used to estimate the parameters of Eq. (5). The estimation results are displayed in Table 4, where the Cobb–Douglas functional form was applied for both mean and variance of rice production. Since the logarithmic form is adopted, the estimated parameters listed in Table 4 show us the elasticities.

For mean rice production, the effects of the time trend (*T*) on rice production are all positive and statistically significant at 95% confidence level. This indicates that the technological progress is significant during the sample period. As expected, the effects of planted area (Parea) on rice yields are all significant and positive. This means that an increase in planted area led to an increase in the per hectare rice yield; then, a 1% increase in rice farmland would induce a 0.96–1.05% increase in rice production across various regions.

For the impacts of climate conditions on rice production, the overall effect of temperature is significant and negative in most rice production regions, whereas the effect of precipitation varies depending on where the crops located. Specifically, increases in average temperature (Atem) reduced mean rice production; for instance, a 1% average temperature increase leads to average production declines by 1.18%, 0.67%, 0.98% and 0.19% for north, north-east, central and south regions, respectively. For the variability in temperature, the estimated elasticities for variation in temperature (Vtem) are negative for all rice production regions excluding the central region. This result indicates that the higher variability in temperature induces a decrease in rice production, which implies a negative effect of more extreme climatic events.

The effect of total precipitation (Tpre) varies across regions. The north-east shows a positive impact where a 1% increase in total precipitation induces an increase in average rice production by 0.08%. The results also show that an increase in precipitation could induce a decrease in rice production from 0.07 to 1.39% for the crops grown in the south and the central regions, respectively. However, no statistically significant effect is found for the north region.

The results for the variance of rice production are given in the last two bottom rows of Table 4. A positive coefficient of α indicates that an increase in the associated variables results in a higher rice production variance, holding all other factors constant. Technological progress is found to cause rice production variance to decrease; in other words, as farmers have adopted more technology, they got rice yield stability increases. In the north and southern regions, rice production variance has a positive relationship with the area of planted paddy rice, while in the central and north-east regions, this relation is negative. For the independent variables related to temperature, an increment in both temperature mean and temperature variation increase rice production variability for all four regions. The overall effect of changes in precipitation on production variability is positive. Higher total precipitation increases the variation in rice production for most of rice-growing regions.

Estimated effects of projected climate change

Two climate scenarios are applied to predict the impacts of climate change on mean rice production and its variance for the coming decades. Climate projections for 2030, 2060 and 2090 are taken from the Thailand Research Fund's Research Development and Coordination Center for Global Warming and Climate Change (THAI-GLOB 2011) and Southeast Asia START Regional Center (Center SASR 2011). This future climate projection is the simulation of future possible climate scenarios in Thailand and surrounding countries at high resolution of grid size 20 × 20 km for the period of 2010–2099, given a baseline period 1960–1999. The simulation was based on the PRECIS (Providing REgional Climates for Impacts Studies) which is a regional climate modelling system, developed by Hadley Centre UK, for the purpose of climate prediction and research. Data from the ECHAM4[3] Global Circulation Model (GCM) were used as initial data for calculation. The simulation data released from the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emission Scenarios (SRES) A2 and B2.

The projected climate change scenarios related to the temperature and precipitation for the four regions in Thailand are presented in Table 5. The simulation reveals a tendency for the average temperature to increase unevenly throughout the country compared to the baseline period in this study (1989–2009). The north and north-east tend to shift towards warmer temperature, with the estimated rises being 2.98–12.49% and 1.96–12.17%, respectively for the A2 and B2 scenarios. The average temperature in the central and south regions is expected to rise by 2.89–12.48% and 3.14–13.05%, respectively. For the projections of precipitation change, the trends described by different scenarios go in either direction, increased or decreased that the precipitation level could be higher or lower, compared to the baseline period. For instance, simulated precipitation levels fluctuate between −2.75 and 55.42%, −9.47 and 37.56%, and −6.90 and 18.49% for the north, north-east and central regions, respectively. In contrast, the precipitation in the south region

[3] The ECHAM climate model has been developed from the ECMWF atmospheric model (therefore the first part of its name: EC) and a comprehensive parameterization package developed at Hamburg University (therefore the abbreviation HAM) which allows the model to be used for climate simulations (IPCC 2015).

Table 5 Climate change scenarios

	SRES	North	North-east	Central	South	Whole country[a]
Temperature						
2030	A2	4.28	4.47	3.87	3.14	3.94
	B2	2.98	1.96	2.89	3.93	2.94
2060	A2	8.16	8.27	6.35	5.91	7.17
	B2	7.46	6.82	6.59	5.54	6.60
2090	A2	12.49	12.17	12.48	13.05	12.55
	B2	7.65	6.71	8.98	10.54	8.47
Precipitation						
2030	A2	1.12	9.29	− 6.90	− 18.20	− 3.67
	B2	26.26	11.49	1.29	− 21.75	4.32
2060	A2	13.59	− 0.96	1.46	− 29.94	− 3.96
	B2	− 2.75	− 9.47	− 4.77	− 24.25	− 10.31
2090	A2	55.42	37.56	18.49	− 3.16	27.08
	B2	27.47	27.27	12.20	− 23.12	10.96

Percentage change in climate variables for the year 2030, 2060 and 2090 were calculated from base year in this study

[a]Since Thailand is normally divided into four regions, the climate scenarios for the *whole* country are calculated as the average values of these parts

Table 6 Results on percentage change in rice average yield and yield variability under projections of climate change

	SRES	North	North-east	Central	South	Whole country[a]
Mean yield						
2030	A2	− 5.02	− 2.21	− 2.85	0.71	− 9.37
	B2	− 2.01	− 0.35	− 3.02	0.82	− 4.56
2060	A2	− 8.89	− 5.62	− 6.46	1.03	− 19.95
	B2	− 9.01	− 5.37	− 5.82	0.69	− 19.52
2090	A2	− 11.61	− 4.99	− 14.88	− 2.28	− 33.77
	B2	− 7.49	− 2.20	− 10.56	− 0.35	− 20.59
Yield variability						
2030	A2	0.78	0.49	2.03	0.80	4.10
	B2	0.87	0.22	1.78	1.00	3.87
2060	A2	1.63	0.92	3.85	1.50	7.90
	B2	1.29	0.76	3.74	1.39	7.19
2090	A2	2.94	1.35	8.23	3.18	15.70
	B2	1.72	0.75	5.88	2.61	10.95

[a]The estimated percentage changes in rice mean and variability for the whole country are calculated as the average values of the four regions

will be significantly decreased for all scenarios by −3.16 to −29.94%.

To identify the link between rice production and future climate change, we now extrapolate the national and regional rice production from combining the estimation results of climate-related elasticities in previous section with the simulated temperature and precipitation levels under IPCC future climate scenarios.

The potential effects of climate change on rice production are represented by the percentage change in mean and variability of yields in rice production. The estimates are shown in Table 6. For the A2 scenario, the mean of countrywide rice production drops by 9.37% in 2030 followed by declines of 19.95% and 33.77% for 2060 and 2090, respectively. Similar results have been obtained for the B2 scenario where mean yields drop by 4.56%, 19.52% and 20.59% in 2030, 2060 and 2090, respectively. In general, future climate change leads to an overall decrease in mean rice production, particularly in the north where the decline in mean rice production ranges from 2.01% in to 11.61%.

As discussed, climate change also significantly impacts rice production variability. As given in Table 6, the variability of rice production increases by 4.10%, 7.90% and 15.70% for 2030, 2060 and 2090 for the whole country for the A2 scenario. For the B2 scenario, variance also increases in almost all regions countrywide. The central area faces the largest possible range of rice yield variability which ranges from 1.78% in 2030 for B2 scenario to 8.23% in 2090 for A2 scenario regionally. Overall, the simulation results of the climate projections reveal an increase in rice production uncertainties in the future. These simulation results are consistent with the literature. For instance, Matthews et al. (1997) found that the simulation results from a crop model predicted an average of 7.4% reduction in Asia rice yields for every 1 °C increase in temperature. Another study by Felkner et al. (2009) showed that rice yields in Thailand will be decreased from 30 to 50% for both low- and high-emission scenarios. Masutomi et al. (2009) assessed the impact of climate change on rice production in Asia and their estimates show that average change in rice production in Thailand ranges from − 2.6 to − 16.2% for A2 climate scenarios for the 2020s and 2080s. Babel et al. (2011) investigated the effects of climate change on rain-fed rice yield using the CERES–rice crop growth model and indicated a decline in the rice yield in north-east Thailand by 17.81%, 27.59% and 24.34% for the 2020s, 2050s and 2080s scenarios, respectively.

Conclusions

In this study, we investigate the effects of climate change on mean and variability in rice yields plus the potential damage compared to current rice production in Thailand, providing useful information for efforts to sustain agricultural productivity in the future.

The empirical estimation results indicate that climate change influences rice production through the effects of both temperature and precipitation. We find that the rise in temperature reduces average yield and increases yield variability. Similarly, an increase in temperature variance would also reduce the mean of rice yields but increase its variability. We also estimate the effect of precipitation level increases and find that an increase in precipitation induces rice yield variability increment for the central region and rice production increases in the north-east and the south.

The combination of estimated effects of climate on rice production and projected climate change scenarios allows us to simulate the possible impacts of future climate change on Thailand's rice yields. Under scenarios, mean rice production falls by 4.56–33.77%, while variance would increase by 3.87–15.70%. The simulation results reveal that the substantial change in mean and variability of rice yields arises as a consequence of fluctuation of temperature and precipitation. Such instability in agricultural production may cause risks to price instability or market uncertainties and threats to food security in the future. As the world's leading rice exporter, Thailand should have adaptation strategies, policies, research programs be taken into consideration for reducing uncertainty in production and managing market risks. Based on estimation results, the study suggests that adaptive actions are necessary to mitigate the decrease in rice production. Some on-farm adaptations include altering planting dates to coping with seasonal change. Public investment in research and development needs to play in producing information about the effects of climate change and appropriate adaptation options. For instance, better invested research could result in new rice varieties with higher tolerance to withstand more frequent and intense climate conditions. Moreover, it could help innovative mechanisms with more comprehensive risk management, for example, to improve the agricultural disaster early warning system and weather index-based insurance.

Besides significantly contributing to the estimates of potential impacts of climate change on rice production to the existing literatures, the study also raises several issues which could be further investigated. Firstly, since the main contribution of this paper focuses on the impacts of climate condition and land use on rice production, other input factors are not considered. Hence, future studies could attempt to collect more data with regard to the conventional rice production factors such as labour force, machinery, fertilizer, irrigation system to result in more persuasive estimates. Secondly, this study relies only on the Cobb–Douglas functional form and future research may try extending functional form since the use of different functional forms for comparison will efficiently support the theoretical foundation and existing empirical evidence.

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