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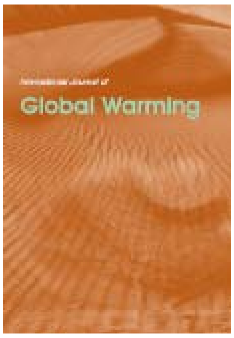

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The association of weather variables with rice production and simulation of agro-adaptation measure for northeast Thailand: evidence from panel data model

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Abstract: Climate change poses a significant threat to agriculture and global food supply. This study aims to estimate the potential impacts of weather on rice production and agro-adaptation in northeast Thailand. Based on the rice production and weather data from 17 provinces over the 1989–2014 periods, the feasible generalised least squares are explored to obtain reliable estimates. The results showed that an increase in the temperature during the crop-growing season has adverse effects on the rice production. The rainfall increases are found to increase rice production levels. The numerical simulations provided evidence that altering planting can reduce the impact of weather on rice production risk by 25.16 to 57.95% for the possible adaptations. Applying a new rice variety can reduce rice production risk by 35.50 to 44.56%. Simulation results revealed that the decrease in impact of weather on rice production can be mitigated significantly using proper agro adaptations practices.

Keywords: rice production; weather; climate change; panel data; agro-adaptation; Thailand.

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1 Introduction

Life on Earth is affected by climate as it has an ability to produce an impact on food production and the future of sustainable development (Nikolinka and Uwe, 2010). There is a close relationship between the change of climate and sustainable development as the change in climate generally produces an impact on the standard living condition of human, social, and economic development. These aspects constitute sustainable development influencing Greenhouse gas (GHG) emissions (Know Climate Change, 2015). The change in climate introduced risks to sustainable development by adversely affecting ecosystem services, deter land and water management. Such change in climate also created negative effects on human health including the risk in food security, rural development, and poverty (Denton et al., 2014). Climate change will have a generally negative impact on crop production. Past studies indicate that increased atmospheric CO_2 leading to those higher temperatures could enhance photosynthesis and increase rice yields (Hijioka et al., 2014).

Thailand agricultural industry relies heavily on climate as most agricultural production is rain fed. Matthews et al. (1997) reported that the change in climate produced negative impact to Thailand rice yield. Future rice yield estimation, which is calculated by two rice crop models, resulted in the growth of –11.6% with climate change. It was also found that there was a loss of 0.2 million tons in the production of Jasmine rice from an impact of climate change in the year 2007 (Isvilanonda et al., 2008). Felkner et al. (2009) also predicted that there will be a 30 to 40% decrease in rice yield in 2080s compared to the yield during 1997 to 2006 prior to the change in climate. Moreover, Babel et al. (2011) indicated a decline in the rice yield in the northeast Thailand by 17.81, 27.59 and 24.34% for the 2020s, 2050s and 2080s, respectively, compared to the average yield during 1997–2006 under climate change scenario.

To assess the vulnerability of agriculture to climate change, it is necessary to consider the role of adaptation, as appropriate adaptation can greatly reduce the magnitude of the impacts of climate change (Reidsma et al., 2010). Adaptation refers to the adjustment in ecological, social, or economic systems in response to actual or expected climate stimuli and their effects or impacts, specifically, the change in processes, practices and structures to moderate potential damages or to exploit beneficial opportunities associated with climate change. Green Climate Fund (2013) argued that the importance of climate change issue is becoming inevitable and there should be a long-term implementation plan in place that involves governmental integration. The transformation and adaptation policy should be introduced to the public. Incremental adaptation refers to actions where the central aim is to maintain the essence and integrity of the existing technological, institutional, governance, and value systems, such as through adjustments to cropping systems via new varieties, changing planting times, or using more efficient irrigation. In contrast, transformational adaptation seeks to change the fundamental attributes of systems in response to actual or expected climate and its effects. Transformational adaptation includes changes in activities such as changing livelihoods from cropping to livestock or by migrating to take up a livelihood elsewhere, and also changes in citizens' perceptions and paradigms about the nature of climate change, adaptation, and their relationship to other natural and human systems (Noble et al., 2014). Pannangpetch et al. (2009) suggested that there should be adaptation measures such as crop management, cultivar, zoning policy, and crop calendar to battle against the issue of climate change. With the particular issue of rice production, nutrient management, planting date alternation together with proper management can reduce the impact of climate change. Agarwal (2008) also claimed that the method of hybrid rice cultivar can result in the high temperature tolerance in rice, which in turn, will make rice more tolerant to the change in climate. Shorter maturity varieties could also help in better risk management due to the fact that they could also be used for second crop planting if water availability is sufficient (Matthews et al., 1997). The study in Henan Province, China found that most common strategies employed by farmers' were as follows: changing crop varieties, crop type, water and soil management, and planting dates (Kibue et al., 2014). According to a study conducted in central Vietnam, Shrestha et al. (2016) found that late transplanting of rice also increase the rice production yield by 20 to 27%. Deb et al. (2015a) reported that in the summer to autumn seasons, shifting the transplanting date by 45 days resulted in the maximum yield in rice production. It was noted that there was an increase of 2.89%. During the winter season as the transplanting date was shifted backward for 30 days the results showed an increase of 3.23% in rice yield. Similarly, simulation of maize yield in the Himalayan foothills of India suggested early shift of planting date could enhance yields by 11.0 and 22.5% compared to yields for the initial sowing date for 2055s and 2085s, respectively. The simulated maize yield under future climate with current management practice for the two new cultivars illustrated an increase of 17.18 to 66.07% and 17.54 to 44.14% for climate change scenario (Deb et al., 2015b).

According to FAO (2015), Thailand is considered to be one of the leading rice producers in the world with 12.37 million hectares in agricultural land area employing the rice production output of roughly 36 million tons. With the annual overseas export shipment reaching 6.7 million ton valued over 4.6 billion USD, Thailand is clearly one of the leading contender in rice export. These schemes represented the rice production in Thailand, which is a significant proportion of the Thai economy, labour force, and world rice market. In northeast Thailand, rice production represents a significant portion of the regional economy and labour force. Rice-based (*Oryza sativa L.*) rain-fed lowlands are the major cropping areas in northeast Thailand (Haefele et al. 2006). As a result of the poor physical endowment of the region, for example, generally poor soils, highly uneven distribution of rainfall, and very limited irrigation facilities, average rice yields in northeast Thailand (2.07 t/ha) are the lowest in the country (average of 3.82 t/ha in the central region). Combined with the fact that farming is the major occupation for 80% of the population in northeast Thailand, this leads to very unfavourable socioeconomic development indicators, including the lowest average income in the country (OAE, 2014). Because of the importance of the rice-based system in this region, rice is the key to agricultural development. Moreover, income from rice farming does constitute an important share of total income, especially for poor farmers, therefore any improvement of productivity will directly benefit these households (Wijnhoud et al., 2003). Climate change mitigation and adaptation are of great concern to ensure food security for the growing population and improve the livelihoods of poor smallholder producers. Without adaptation, climate change is generally problematic for agricultural production, economies, and communities dependent on agriculture; however, with appropriate adaptation, vulnerabilities can be reduced, and there are numerous opportunities to be realised (Smit and Mark, 2002; Wilk and Wittgren, 2009).

Nevertheless, understanding of the weather variables that affect regional rice production is limited to econometric estimation of production functions to identify rice production average and variability has received little attention in Thailand, especially in the regional level. This study has two major purposes. The first is to adapt stochastic production function for assessing the potential impact of observed weather conditions on rice production. The second purpose is to simulate agro-adaptation measures for calculating risk reduction performance (RRP) of the selected adaptation measures in the northeast Thailand. Given the above background, this study aims to test the following hypothesis based on the methodologies applied. First, the changing in weather variables has the impact on mean rice production and its variability. This study applied the panel data econometric models to estimate statistical relationship between rice production and weather conditions. Second, agro-adaptation measure can be reducing the risk of rice production. This study simulated the empirical results for the evaluation of adaptation scenarios that predicted the effect of change in planting date and rice varieties on rice production. The innovative of this study is estimating the mean and variance of rice production function and proposing RRP of altering planting date. This study contributes to an understanding of the development of an econometric model to determine potential impacts of weather conditions on the mean and variance of rice production, and by examining the implications of the agro-adaptation on agriculture. These results have important implications for adaptation patterns to mitigate the effect of risky climate change on food security and sustainability in the future.

2 Materials and methods

There are many different approaches that have been employed to estimate the effect of climate on crop production. Hertel and Rosch (2010) grouped the approaches into three categories; crop growth simulation model, hedonic approach, and a statistical or econometric approach. According to a past study in Thailand, a number of studies on climate change and crop production are predominantly applied crop simulation models. An example of previous studies was done by Matthews et al. (1997), Felkner et al. (2009), and Babel et al. (2011). Although the study was used by Chen et al. (2004), Mendelsohn (2009), Wang et al. (2009), and Weersink et al. (2010) and others, the hedonic approach and econometric approach have received little attention in Thailand. The econometric approach estimates statistical relationship between crop productions and weather variables such as temperature and rainfall. The advantages of a statistical approach are that it requires relatively less data, can be applied at national or global spatial resolution, the model's goodness-of-fit provide future responses based on past relationships, and out-of-sample prediction can test the model's validity. Moreover, statistical models provide a transparent way to access the model uncertainties. For instance, if a model performed poorly in representing crop production responses to climate conditions, it would be reflected in a low goodness of fit test statistic (R^2) between model fitted and observed variables (Lobell and Burke, 2010).

2.1 Just and pope production function estimation

This study employed a statistical approach to estimate impacts of weather conditions by running models with observed historical climate, then simulating weather condition incorporation with agro-adaptation scenarios. This numerical simulation model can be used to investigate a larger number of possible environmental and management conditions via physical experiments (Porter et al., 2014). In order to examine the effect of weather variables on both average and variability of rice production under heteroscedastic disturbances, a stochastic production function approach of the type proposed by Just and Pope (1979) was applied in equation (1).

$$y_{it} = f\left(x_{itk}, \beta_k\right) + u_{it} = f\left(x_{itk}, \beta_k\right) + h\left(x_{itk}, \alpha_k\right)\varepsilon_{it} \tag{1}$$

where y_{it} was the rice production, x_{itk} was a vector of K explanatory variables, $f(x_{itk}, \beta_k)$ was the deterministic term of production (or mean function) with β representing the vector of estimated coefficients, u_{it} was the heteroscedastic disturbance term; $h(x_{itk}, \alpha_k)$ was the stochastic term of production (or variance function) with α representing the vector of estimated coefficients, and ε_{it} was a random error term with zero mean and variance of σ^2. This specification allowed explanatory variables such as weather to influence both mean and the variance of rice production. Thus, the advantage of this Just and Pope specification is the proposed estimation method corrects for heteroscedasticity.

The stochastic production function given by equation (1) can be estimated using maximum likelihood estimation (MLE) or a feasible generalised least squares (FGLS) under heteroscedastic disturbances. MLE is more efficient and unbiased than FGLS estimation in the case of small sample (Saha et al., 1997). Due to the large sample in this study, the FGLS was used. To estimate production function, the procedure proposed by Just and Pope (1979) was used and adapted to the case of panel data by assuming that rice production and explanatory variables have relationship in form of log-linear model as we called Cobb-Douglas production function. This procedure consists of three steps. The first step, regress y_{it} on x_{itk} by ordinary least square (OLS) and obtain the residuals, u_{it}. The fact that production variance appear as heteroscedasticity in the Just-Pope formulation, the OLS regression coefficient estimates of the mean production function are still unbiased and consistent, but not asymptotically efficient (Asche and Tveteras, 1999). The second step, uses the OLS residual from the first step as a dependent variable to estimate the marginal effect of x_{itk} of the variance of production. The third and final step, perform FGLS by re-estimating the mean production in the first step using the predicted value from the variance function in the second step as weights for generating the FGLS estimators.

2.1.1 Estimating the mean production model

In general, crop production is significantly impacted by climatic properties (such as rainfall, temperature, solar radiation, etc.) (e.g., Chen et al., 2004; Tao et al., 2009; Wang et al., 2009; Ayinde et al., 2013; Chiueh et al., 2013). Chiueh et al. (2013) indicated that precipitation, temperature, sunlight, radiation, and El Ninõ should be major climatic factors. The econometric estimations of this study applied the panel data model; the production equation estimated for rice in form of one-way error component model was constructed as equation (2).

$$\begin{aligned} Prod_{it} &= \beta_0 + \beta_1 Area_{it} + \beta_2 Atem_{it} + \beta_3 Vtem_{it} \\ &\quad + \beta_4 Trai_{it} + \beta_5 Vrai_{it} + \beta_6 Tren_{it} + \mu_{it} + v_{it} \end{aligned} \tag{2}$$

where $Prod_{it}$ was the natural logarithm of rice production (tons), $Area_{it}$ was the natural logarithm of planted area (ha), $Atem_{it}$ was the natural logarithm of seasonal mean of monthly average temperature for growing season (Celsius degrees), $Trai_{it}$ was the natural logarithm of sum of monthly total rainfall for growing season (mm.), $Tren_{it}$ was the time-trend variable to represent the effect of technological progress during the study period. Coping with the effects of extreme climatic events on rice production, added $Vtem_{it}$ and $Vrai_{it}$ were the natural logarithm of variation of mean temperature and total rainfall, respectively. μ_i was the unobservable province-specific effect, and v_{it} is the remainder disturbance.

2.1.2 Estimating the variance production model

This step used the OLS residuals from equation (2) as a consistent estimator of u_{it}. Then, $\ln\left(u_{it}^2\right)$ was regressed on explanatory variables as same as the explanatory variables used in equation (2), and hence estimated the following regression model:

$$\begin{aligned}\ln\left(u_{it}^2\right) &= \alpha_0 + \alpha_1 Area_{it} + \alpha_2 Atem_{it} + \alpha_3 Vtem_{it} \\ &\quad + \alpha_4 Trai_{it} + \alpha_5 Vrai_{it} + \alpha_6 Tren_{it} + \mu_{it}\end{aligned} \tag{3}$$

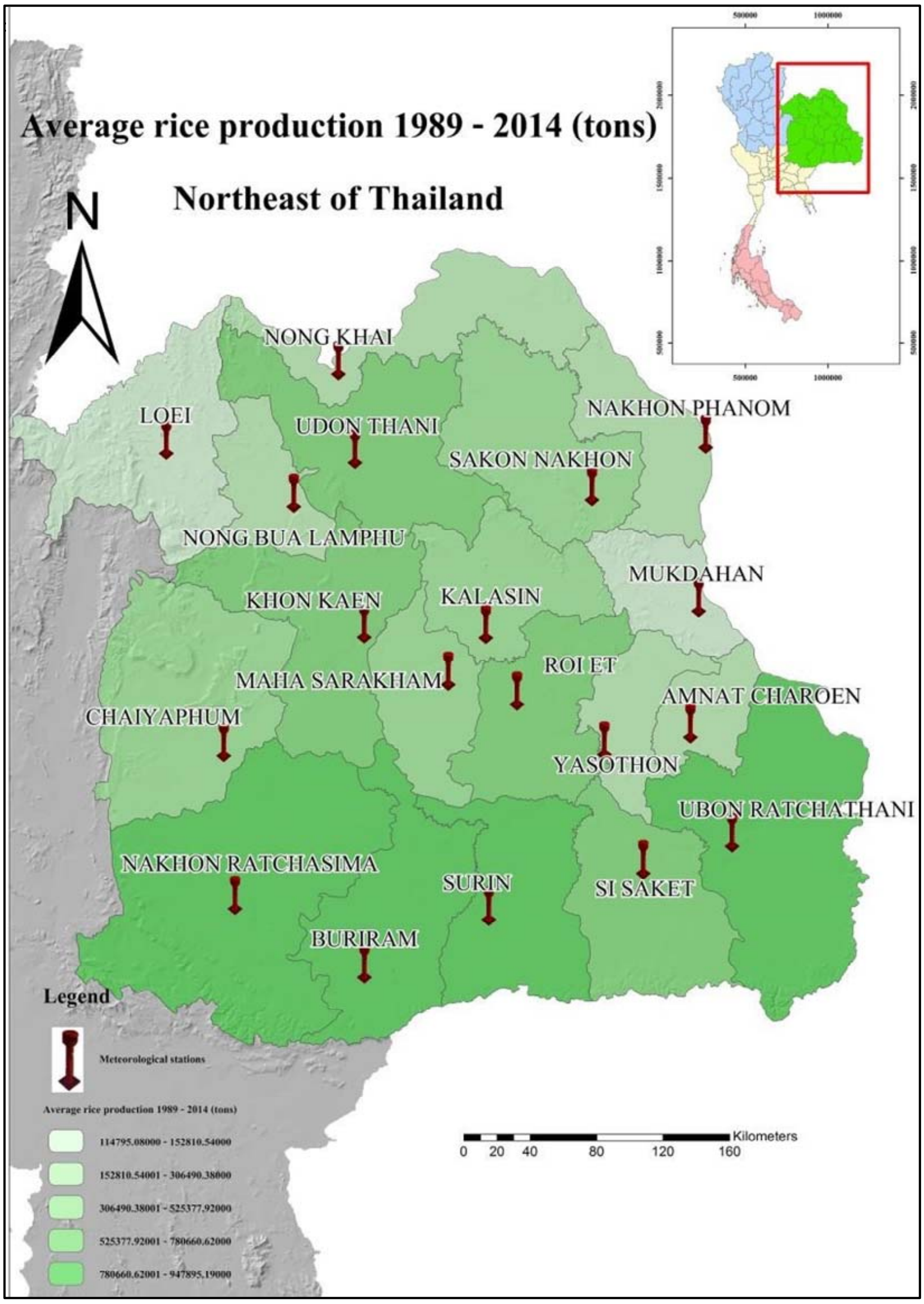
where e_{it} was the white noise error terms.

2.1.3 Simulation of agro-adaptation measure

In the agriculture sector of Southeast Asia, most commonly used adaptation techniques involve changes in cropping patterns and cropping calendar, improved farm management, and use of climate-resilient crop varieties (ADB, 2009). Shrestha et al. (2016) stated that the alternation in planting date together with supplementary irrigation, nutrient management, and the adoption of cultivars has produced a positive result in combating against adverse effects from climate change with the case study from Central Vietnam. Deb et al. (2015a) also confirmed that early seed planting in the Himalayan foothills of India can help reduce the decline in the maize yield. In similar case study performed by Deb et al. (2015b) changing the rice transplanting date in Ca Mau, Vietnam resulted in a yield increase as the flowering and the reproductive stage received more rainfall, thus producing the boost in rice yield. In addition, by planting the seeds early, the production of rice would be less exposed to the risk of heat stresses resulting in the reduction in the chilling injury within the anthesis and maturity stage of rice.

Therefore, change in cropping pattern and crop calendar consists of change in cropping pattern and change in cropping technique/calendar to response with changing of climate. Farmers will change the cropping pattern, which include addition of new crops to replace existing crops, or changes cropping cycle within a season to respond the weather variability. For example, the changing cropping pattern of farmers in northern Philippines shifted from irrigated rice to tobacco and drought tolerant vegetable crops. Also, farmers changed timing of farm activities to suit weather variations changing (Lasco et al., 2011). Changing crop varieties is switching from one-crop variety to another in response to climatic change. This is an adoption, which measures climate-resilient crop varieties that are able to withstand a single or a range of climate stresses. For example, Vietnamese farmers adapt rice type by using climate-resilient rice varieties and also adapt their rice cultivation to use short-cycle rice varieties (Action Aid, 2008).

Figure 1 The location map of the study area in northeast Thailand (see online version for colours)



2.2 Study area

Northeast Thailand, comprising 19 provinces, lies between latitude 14.50–17.50°N and longitude 102.12–104.90°E (Figure 1). The region has about 10.22 million ha of agricultural land, up to 67% is devoted to rice. It occupies the largest amount of agricultural land area of 5.9 million hectares employing the rice output of 12.3 million tons (OAE, 2014). The region has a tropical climate, with average temperature ranging from 19.6 to 30.2°C. October–February is the cool season, while March–May is the hot season, with highest temperatures observed in the month of April. Rainfall in the region is highly unpredictable, mainly concentrated in the rainy season, i.e., May–October. The average annual rainfall varies from 1,270 to 2,000 mm. within the region (Babel et al., 2011). Rain-fed rice is grown under poor conditions, i.e., poor crop management with low inputs, and is highly subject to climatic variability. The main variety is Jasmine rice, namely KDML105 (KhaoDok Mali 105) and RD6 (Rice Department 6), are medium-maturing varieties covering almost 80% of the rice fields in northeast Thailand (Miyagawa, 2001).

2.3 Panel dataset

This study applied the panel data analysis by blending the inter-individual differences and intra-individual dynamics. Panel data usually contain more degrees of freedom and more sample variability than a single cross-section or time series data. The study obtained balanced panel data of rice production in 17 provinces over 26 year periods (1989–2014) including 442 observations. Rice in Thailand is predominantly grown under rain-fed conditions, with the rain-fed ecosystem accounting for over 80% of total rice area (Isvilanonda et al., 2000). Therefore, rain-fed rice production data was used in the study. Rice production and planted area were obtained from Office of Agricultural Economic (OAE) reports (2014). Weather variables were taken from the Thai Meteorological Department (2014). Monthly data on temperature and rainfall with provinces measures for rice-growing season (May to October) based on values from a representative weather station located centrally within the province. The symbol in Table 1, NE-O is the original scenario without agro-adaptations, whereas LPD1, LPD2, and LPD3 are agro-adaptation scenarios with later planting dates of one to three month, respectively. Thus, SPD1, SPD2, and SPD3 are adaptation scenarios with shorter planting date by using short-term rice varieties within one to three months, respectively. At each increment or decrement, a new weather dataset was constructed for the time panels corresponding to the new growing period. For the sample period, the average planted area was 299,799 ha/province/year with average production of 548,447 ton. The mean temperature was 25.83–28.86°C and varied about 0.52–5.12°C across scenarios. Total rainfall was about 636.15–1,259.18 mm and varied around 10,190–24,469 mm across scenarios. The summary statistics were presented in Table 1.

Table 1 Descriptive statistics of the data used in the estimations

Variables	*NE-O*	*LPD1*	*LPD2*	*LPD3*	*SPD1*	*SPD2*	*SPD3*
Production (ton)	548,447.40	548,447.40	548,447.40	548,447.40	548,447.40	548,447.40	548,447.40
	308,629.60	308,629.60	308,629.60	308,629.60	308,629.60	308,629.60	308,629.60
Planted area (ha)	299,799.70	299,799.70	299,799.70	299,799.70	299,799.70	299,799.70	299,799.70
	150,877.10	150,877.10	150,877.10	150,877.10	150,877.10	150,877.10	150,877.10
Average temperature (°C)	28.21	27.54	26.63	25.83	28.44	28.63	28.86
	0.47	0.44	0.52	0.68	0.50	0.55	0.64
Temperature variance	1.02	1.83	4.14	5.12	0.69	0.62	0.52
	0.70	1.11	1.93	5.78	0.49	0.53	0.52
Total rainfall (mm)	1,259.18	1,096.28	895.92	666.53	1,174.29	914.81	636.16
	360.57	329.11	264.79	199.32	361.54	337.25	259.34
Rainfall variance	14,812.88	20,958.92	24,469.08	23,652.77	12,780.15	11,808.83	10,189.81
	14,715.19	18,643.02	19,913.74	18,605.34	13,615.70	14,586.21	15,522.99

Note: The top number of each variable is mean value, and the bottom number is standard deviation.

Table 2 Pre-estimation specification test results

Variables	*NE-O*	*LPD1*	*LPD2*	*LPD3*	*SPD1*	*SPD2*	*SPD3*
Panel unit root test[a]							
Production	–5.1160***	–5.1160***	–5.1160***	–5.1160***	–5.1160***	–5.1160***	–5.1160***
	–3.7759***	–3.7759***	–3.7759***	–3.7759***	–3.7759***	–3.7759***	–3.7759***
Planted area	–2.6312***	–2.6312***	–2.6312***	–2.6312***	–2.6312***	–2.6312***	–2.6312***
	–2.4191***	–2.4191***	–2.4191***	–2.4191***	–2.4191***	–2.4191***	–2.4191***
Average temperature	–11.0602***	–8.4234***	–17.1071***	–16.2584***	–13.8445***	–13.3855***	–15.4655***
	–11.2235***	–7.9068***	–14.4313***	–15.1318***	–12.2494***	–11.5580***	–12.8070***
Temperature variance	–14.4941***	–8.4376***	–17.5951***	–41.2333***	–14.3108***	–14.8156***	–14.8097***
	–12.0329***	–11.5314***	–17.6927***	–22.8838***	–13.6084***	–12.8712***	–13.2331***
Total rainfall	–14.7668***	–13.2306***	–13.3485***	–11.9135***	–13.8848***	–16.1001***	–15.6247***
	–14.7343***	–13.5323***	–12.3584***	–12.1399***	–14.6885***	–14.1310***	–14.7043***
Rainfall variance	–14.2926***	–14.6862***	–14.5269***	–14.4687***	–13.4602***	–12.4143***	–11.3993***
	–12.1117***	–13.9455***	–13.8069***	–13.3779***	–11.9399***	–11.1138***	–12.8373***
Heteroscedasticity test[b]							
Glejser test	17.7609***	12.5000*	12.7800**	16.9953***	26.8597***	27.2309***	21.1654***
ARCH test	3.1305*	2.1644	2.1163	2.5150	3.0239*	3.8293*	2.9559*

Notes: [a]The top number of each variable is statistic for LLC's test, and the bottom number is statistic for IPS test.
[b]Statistic value of heteroscedasticity test is LM-statistic.
***, **, and * indicate that the null hypothesis was rejected at the 99%, 95%, and 90% confidence level.

3 Results and discussion

3.1 Pre-estimation specification test

In order to construct efficiently estimated parameters in the error component model with cross-section heteroscedasticity, authors performed panel unit root test and heteroscedasticity test. To prevent the issue of spurious correlation, the test for the presence of unit root for each variable was a necessary step prior to process the FGLS estimation (Chen et al., 2004). The study employed two kinds of panel unit root tests, which fit with a balanced panel dataset; the Levin, Lin and Chu (LLC) test that assumes common unit root process and Im, Pesaran and Shin (IPS) test that assumes individual unit root process. The results showed that using different test specifications, rice production, planted area, and weather variables passed both tests and were thus stationary at level (I(0)). Therefore, there was no need to differentiate the data before the FGLS estimation. In order to confirm that the existence of the variance component of production function was reflected in the presence of heteroscedasticity in the production function, authors applied Glejser test, which regresses the absolute residuals on the original regressors as well as ARCH test that regresses the squared residuals on lagged square residuals and constant. Results of these tests provided in Table 2 firmly rejected the null hypothesis of homoscedasticity at all conventional significance levels.

3.2 Mean rice production function estimations and simulations

The final estimates of the parameters of the proposed production functions were presented in Table 3. The parameters listed in Table 3 are the estimated elasticity for rice production scenarios in northeast Thailand. The panel data model can be estimated using either a fixed effects (FE) model, which controls the omitted variables that differ between provinces but are constant over time, or a random effects (RE) model, which considers some omitted variables, may be constant over time but vary between provinces. So, to determine the appropriate model specification, this study used a redundant FE tests. The test results were given in Table 3. The FE tests χ^2-statistic and F-statistic indicates the failure to reject the null hypothesis that FE estimator is consistent and efficient. Therefore, a FE model was used in the regression of the mean rice production.

The study used three models, which differ in the estimation techniques to examine the sensitivity of the estimates of explanatory variables impact on rice production. The estimation results were summarised in Table 3 under 3 models' specifications. The first model is panel least square, the second model is cross-section FE model that assumes differences in intercepts across provinces, and the third model is cross-section FE with FGLS that model estimates a feasible GLS specification correcting for both cross-section heteroscedasticity and contemporaneous correlation. A comparison of estimated results was presented in Table 3. Based on the goodness of fit statistic, we chose models with highest adjusted R^2, cross-section FE with FGLS to explain the impact of weather on rice production.

Table 3 Estimated parameters for rice production mean function

Variables	*NE–O*	*LPD1*	*LPD2*	*LPD3*	*SPD1*	*SPD2*	*SPD3*
Panel least square							
Planted area	0.9607***	0.9629***	0.9592***	0.9627***	0.9634***	0.9662***	0.9609***
	(0.0100)	(0.0101)	(0.0103)	(0.0104)	(0.0101)	(0.0101)	(0.0100)
Average temperature	–1.9038***	–1.9772***	–1.6347***	–1.2582***	–1.9178***	–1.8863***	–1.1213***
	(0.4490)	(0.4445)	(0.4480)	(0.3911)	(0.4757)	(0.4255)	(0.3266)
Temperature variance	0.0197**	–0.0237**	–0.0355***	–0.0274	0.0158*	0.0167**	0.0011
	(0.0078)	(0.0095)	(0.0132)	(0.0186)	(0.0094)	(0.0069)	(0.0014)
Total rainfall	–0.0063	0.0200	0.1229***	0.0639**	–0.0814***	–0.0930***	–0.0748***
	(0.0352)	(0.0394)	(0.0463)	(0.0295)	(0.0279)	(0.0240)	(0.0211)
Rainfall variance	–0.0265**	–0.0429***	–0.0773***	–0.0513***	0.0013	0.0114	0.0084
	(0.0103)	(0.0149)	(0.0190)	(0.0136)	(0.0084)	(0.0072)	(0.0054)
Time trend	0.1201***	0.1143***	0.1152***	0.1187***	0.1089***	0.1086***	0.1115***
	(0.0079)	(0.0081)	(0.0078)	(0.0077)	(0.0080)	(0.0078)	(0.0078)
Constant	5.6916***	5.8623***	4.4146***	3.2365**	6.0167***	5.8599***	3.2343***
	(1.5558)	(1.5174)	(1.5180)	(1.3096)	(1.6345)	(1.4672)	(1.1383)
Adjusted R-squared	0.9597	0.9598	0.9599	0.9592	0.9588	0.9592	0.9585
Model F-statistic	1751.9270***	1756.3990***	1759.2180***	1728.9690***	1711.6800***	1729.0700***	1696.6010***

Notes: Numbers in parentheses are standard errors.
***, **, and * indicate that the null hypothesis is rejected at the 99%, 95%, and 90% confidence level.

Table 3 Estimated parameters for rice production mean function (continued)

Variables	*NE–O*	*LPD1*	*LPD2*	*LPD3*	*SPD1*	*SPD2*	*SPD3*
Cross section FE							
Planted area	1.0580***	1.0458***	1.0563***	1.0731***	1.0668***	1.0488***	1.0805***
	(0.0451)	(0.0443)	(0.0452)	(0.0449)	(0.0456)	(0.0441)	(0.0442)
Average temperature	–1.0092**	–1.4094***	–0.7457	–0.3340	–1.1524**	–1.7615***	–0.7311**
	(0.4722)	(0.4592)	(0.4822)	(0.4005)	(0.4985)	(0.4197)	(0.3045)
Temperature variance	0.0076	–0.0332***	–0.0237**	0.0065	0.0063	0.0198***	0.0008
	(0.0072)	(0.0087)	(0.0129)	(0.0183)	(0.0089)	(0.0063)	(0.0012)
Total rainfall	0.0829**	0.0855**	0.1268***	0.0290	0.0290	0.0246	–0.0089
	(0.0367)	(0.0370)	(0.0418)	(0.0268)	(0.0339)	(0.0284)	(0.0239)
Rainfall variance	–0.0141	–0.0183	–0.0333*	0.0017	0.0017	0.0106*	0.0107**
	(0.0092)	(0.0133)	(0.0178)	(0.0153)	(0.0075)	(0.0062)	(0.0048)
Time trend	0.1091***	0.1012***	0.1054***	0.1080***	0.1028***	0.1020***	0.1046***
	(0.0073)	(0.0073)	(0.0071)	(0.0070)	(0.0072)	(0.0069)	(0.0070)
Constant	0.5912	2.1393	–0.3401	–1.6643	1.2086	3.4948**	–0.2070
	(1.8795)	(1.8034)	(1.8997)	(1.5827)	(1.9568)	(1.6784)	(1.2718)
Adjusted R-squared	0.9696	0.9704	0.9698	0.9691	0.9693	0.9707	0.9695
Model F-statistic	640.8579***	658.9406***	644.6309***	629.7945***	633.0365***	664.2476***	637.8423***
FE test (χ^2-statistic)	1.0580***	1.0458***	1.0563***	1.0731***	1.0668***	1.0488***	1.0805***

Notes: Numbers in parentheses are standard errors.
***, **, and * indicate that the null hypothesis is rejected at the 99%, 95%, and 90% confidence level.

Table 3 Estimated parameters for rice production mean function (continued)

Variables	*NE–O*	*LPD1*	*LPD2*	*LPD3*	*SPD1*	*SPD2*	*SPD3*
Cross section FE with FGLS							
Planted area	1.0512***	1.0385***	1.0535***	1.0730***	1.0576***	1.0505***	1.0739***
	(0.0147)	(0.0144)	(0.0157)	(0.0155)	(0.0154)	(0.0148)	(0.0161)
Average temperature	–1.1498***	–1.5304***	–0.9288***	–0.4720**	–1.2838***	–1.7207***	–0.9766***
	(0.2734)	(0.2425)	(0.2299)	(0.2078)	(0.2548)	(0.2157)	(0.2099)
Temperature variance	0.0108**	–0.0280***	–0.0164**	0.0011	0.0088**	0.0201***	0.0009**
	(0.0044)	(0.0051)	(0.0077)	(0.0107)	(0.0044)	(0.0030)	(0.0004)
Total rainfall	0.0686***	0.0819***	0.1072***	0.0056	0.0297**	0.0241**	–0.0027
	(0.0131)	(0.0140)	(0.0158)	(0.0106)	(0.0118)	(0.0094)	(0.0091)
Rainfall variance	–0.0091***	–0.0162***	–0.0257***	0.0139**	0.0012	0.0084***	0.0088***
	(0.0031)	(0.0047)	(0.0068)	(0.0054)	(0.0024)	(0.0021)	(0.0017)
Time trend	0.1046***	0.0985***	0.1009***	0.1012***	0.0974***	0.1012***	0.0982***
	(0.0062)	(0.0062)	(0.0064)	(0.0068)	(0.0068)	(0.0055)	(0.0064)
Constant	1.2242	2.6537***	0.3588	–1.1584	1.7944	3.3573***	0.7040
	(1.0189)	(0.8980)	(0.8571)	(0.7683)	(0.9568)	(0.8046)	(0.7812)
Adjusted R-squared	0.9918	0.9907***	0.9925	0.9924	0.9914	0.9898	0.9899
Model F-statistic	2,420.9440***	2,136.9260***	2,659.3310***	2,602.0410***	2,310.9000***	1,945.1100***	1,956.6590***
FE test (F-statistic)	34.5704***	39.6937***	33.1630***	37.3208***	44.3586***	48.5578***	41.8346***

Notes: Numbers in parentheses are standard errors.
***, **, and * indicate that the null hypothesis is rejected at the 99%, 95%, and 90% confidence level.

For the results of the mean production function, Table 3 shows that the *time trend* coefficients were all positive and statistically significant for all seven scenarios. Therefore, the technological progress such as improved agronomic practices induced rice production-improvement during the study time-windows. As expected, the *planted area* elasticities were all positive. This indicated that an increase in planted area induced an increase in the rice production with statistical significance. For the effect of climate variables, the overall effect of an increase in temperature was negative on the mean rice production; whereas the effect of increased rainfall was depended on specific scenarios. The effect of change in temperature was found to be very significant. Thus, estimated elasticity for a*verage temperature* in production mean regression was consistently negative for all seven scenarios suggesting an inverse effect of an increase in average temperature on the mean rice production. For the original scenario (NE-O), the statistical results implied that 1% increase in average temperature lead to decrease in rice production accounting for 1.15%. For agro-adaptation scenarios, 1% increase in average temperature lead to decrease in rice production accounting for 1.53, 0.93, 0.47, 1.29, 1.72, and 0.98% for LPD1, LPD2, LPD3, SPD1, SPD2, and SPD3 scenario, respectively. The impact of t*emperature variance* was found to vary across scenarios. The effect of change in *total rainfall* was found to vary significantly across various rice production scenarios. NE-O, LPD1, LPD2, SPD1 and SPD2 scenarios consistently showed a positive impact of an increase in rainfall on the rice production with high statistical significance. This finding implied that 1% increase in total rainfall induced an increase in rice production between 0.02 to 0.11% for these five scenarios. The impact of *rainfall variance* was found to vary across scenarios.

3.3 Variance of rice production function estimations and simulations

The Cobb-Douglas functional form was also applied for variance of rice production. For the result of variance function, the interpretation of a positive coefficient indicated that an increase in the associated variables induced a higher production variance or risk-increased variables. For the model specification to be appropriate, this study used Hausman test. The test results were given in Table 4. The Hausman RE tests χ^2-statistic indicated that authors failed to reject the null hypothesis that RE estimator was consistent and efficient. Therefore, a RE model was used in the regression of the variance rice production. The estimation results were summarised in Table 4 under 3 models' specifications, panel least square, period RE, and cross-section SUR with FGLS. A comparison of estimated results was presented in Table 4. Based on the goodness of fit statistic, authors chose models with highest adjusted R^2, cross-section SUR with FGLS. A decrease in rice production variance with a high statistical significance is induced by *time trend* and a decrease in rice production variability was induced by the *planted area* for all scenarios as expected. A higher *average temperature* implied a consistent decrease in rice production variability for all seven scenarios, whereas the impact of *temperature variance* depended on specific scenarios. Finally, the effect of changes in rainfall on rice production variability was generally negative. Higher *total rainfall* and *rainfall variance* induced the decrease in variation of rice production.

Table 4 Estimated parameters for rice production variance function

Variables	*NE–O*	*LPD1*	*LPD2*	*LPD3*	*SPD1*	*SPD2*	*SPD3*
Panel least square							
Planted area	–0.0032	–0.0028	–0.0021	–0.0015	–0.0040	–0.0055	–0.0052
	(0.0038)	(0.0039)	(0.0039)	(0.0040)	(0.0039)	(0.0039)	(0.0040)
Average temperature	–0.3373*	–0.2882*	–0.2545	–0.1960	–0.4025**	–0.2462	–0.2021
	(0.1722)	(0.1735)	(0.1715)	(0.1491)	(0.1830)	(0.1660)	(0.1306)
Temperature variance	0.0038	–0.0008	0.0013	0.0010	0.0045	0.0006	0.0001
	(0.0030)	(0.0037)	(0.0051)	(0.0071)	(0.0036)	(0.0027)	(0.0006)
Total rainfall	–0.0149	–0.0090	0.0086	0.0076	–0.0253**	–0.0217**	–0.0186**
	(0.0135)	(0.0154)	(0.0177)	(0.0112)	(0.0107)	(0.0094)	(0.0084)
Rainfall variance	0.0001	–0.0020	–0.0084	–0.0089*	0.0014	0.0012	0.0022
	(0.0040)	(0.0058)	(0.0073)	(0.0052)	(0.0032)	(0.0028)	(0.0022)
Time trend	–0.0028	–0.0019	–0.0016	–0.0030	–0.0047	–0.0041	–0.0041
	(0.0030)	(0.0032)	(0.0030)	(0.0029)	(0.0031)	(0.0030)	(0.0031)
Constant	1.3010**	1.0999*	0.9083	0.7191	1.6009**	1.0674*	0.8802*
	(0.5966)	(0.5925)	(0.5812)	(0.4993)	(0.6288)	(0.5725)	(0.4551)
Adjusted R-squared	0.0055	0.0000	0.0061	0.0082	0.0147	0.0113	0.0067
Model F-statistic	1.4047	1.0018	1.4528	1.6069	2.0971*	1.8380*	1.4956

Notes: Numbers in parentheses are standard errors.
***, **, and * indicate that the null hypothesis is rejected at the 99%, 95%, and 90% confidence level.

Table 4 Estimated parameters for rice production variance function (continued)

Variables	*NE–O*	*LPD1*	*LPD2*	*LPD3*	*SPD1*	*SPD2*	*SPD3*
Period RE							
Planted area	–0.0032	–0.0028	–0.0021	–0.0015	–0.0040	–0.0055	–0.0052
	(0.0038)	(0.0039)	(0.0039)	(0.0040)	(0.0039)	(0.0039)	(0.0040)
Average temperature	–0.3418*	–0.2890*	–0.2545	–0.1960	–0.4052**	–0.2498	–0.2021
	(0.1747)	(0.1736)	(0.1716)	(0.1490)	(0.1838)	(0.1676)	(0.1300)
Temperature variance	0.0038	–0.0008	0.0013	0.0010	0.0045	0.0005	0.0001
	(0.0031)	(0.0037)	(0.0051)	(0.0071)	(0.0036)	(0.0027)	(0.0006)
Total rainfall	–0.0148	–0.0090	0.0086	0.0076	–0.0255**	–0.0219**	–0.0186**
	(0.0136)	(0.0154)	(0.0177)	(0.0112)	(0.0107)	(0.0094)	(0.0084)
Rainfall variance	0.0000	–0.0021	–0.0084	–0.0089*	0.0014	0.0012	0.0022
	(0.0040)	(0.0058)	(0.0073)	(0.0052)	(0.0032)	(0.0028)	(0.0022)
Time trend	–0.0028	–0.0019	–0.0016	–0.0030	–0.0047	–0.0041	–0.0041
	(0.0031)	(0.0032)	(0.0030)	(0.0029)	(0.0031)	(0.0031)	(0.0031)
Constant	1.3170**	1.1026*	0.9083	0.7191	1.6113**	1.0804*	0.8802
	(0.6048)	(0.5926)	(0.5813)	(0.4990)	(0.6314)	(0.5778)	(0.4532)
Adjusted R-squared	4.9492	0.0000	0.0061	0.0082	0.0147	0.0113	0.0067
Model F-statistic	1.3978	1.0034	1.4528	1.6069	2.0984*	1.8420*	1.4956
RE test (F-statistic)	4.9492	6.6134	6.7428	6.4513	6.7660	9.0169	9.8294

Notes: Numbers in parentheses are standard errors.
***, **, and * indicate that the null hypothesis is rejected at the 99%, 95%, and 90% confidence level.

Table 4 Estimated parameters for rice production variance function (continued)

Variables	*NE–O*	*LPD1*	*LPD2*	*LPD3*	*SPD1*	*SPD2*	*SPD3*
Cross section SUR with FGLS							
Planted area	–0.0027***	–0.0025***	–0.0019***	–0.0024***	–0.0032***	–0.0047***	–0.0044***
	(0.0003)	(0.0004)	(0.0004)	(0.0005)	(0.0004)	(0.0006)	(0.0005)
Average temperature	–0.2397***	–0.1794***	–0.1692***	–0.1008***	–0.2665***	–0.1546***	–0.1329***
	(0.0356)	(0.0361)	(0.0350)	(0.0290)	(0.0361)	(0.0347)	(0.0302)
Temperature variance	0.0027***	–0.0014*	0.0002	0.0018	0.0025***	0.0006	–0.0001
	(0.0005)	(0.0007)	(0.0012)	(0.0015)	(0.0007)	(0.0005)	(0.0001)
Total rainfall	–0.0098***	–0.0058***	0.0042	0.0058***	–0.0202***	–0.0172***	–0.0145***
	(0.0019)	(0.0020)	(0.0027)	(0.0019)	(0.0018)	(0.0016)	(0.0013)
Rainfall variance	–0.0004	–0.0025***	–0.0056***	–0.0066***	0.0013***	0.0006*	0.0015***
	(0.0005)	(0.0007)	(0.0011)	(0.0009)	(0.0004)	(0.0004)	(0.0003)
Time trend	–0.0034***	–0.0024***	–0.0023**	–0.0038***	–0.0043***	–0.0038***	–0.0040***
	(0.0009)	(0.0008)	(0.0010)	(0.0009)	(0.0009)	(0.0010)	(0.0010)
Constant	0.9378***	0.7172***	0.6293***	0.4113***	1.0959***	0.7222***	0.6149***
	(0.1242)	(0.1254)	(0.1204)	(0.0975)	(0.1271)	(0.1217)	(0.1052)
Adjusted R-squared	0.2638	0.2172	0.1881	0.2921	0.3150	0.3124	0.3298
Model F-statistic	27.3418***	21.3940***	18.0259***	31.3260***	34.7986***	34.3975***	37.1721***

Notes: Numbers in parentheses are standard errors.
***, **, and * indicate that the null hypothesis is rejected at the 99%, 95%, and 90% confidence level.

3.4 The evaluation of agro-adaptation measure

3.4.1 Simulated results of agro-adaptation measure

To explore the potential effect of changing the growing season within the year by altering planting date, the study simulated later planting dates (LPD) by shifting the planting date in one to three month increments (LPD1, LPD2, and LPD3). The findings of cross-section FE with FGLS model presented in Table 3 shows that the impacts of temperature on mean rice production decreased from 1.14 to 0.93, and 0.47% in response to the shift in the planting date later in two (LPD2) and three (LPD3) month incrementally. The positive impact of rainfall on mean rice production increased from 0.07 to 0.08 and 0.10% once the planting date later in one (LPD1) and two (LPD2) months incrementally. These findings confirmed that LPD measure could help farmers to prevent an adverse effect of poor weather on rice production. The potential effect of changing the rice crop variety was also simulated by assuming the use of shorter planting date (SPD) rice in one to three decrements (SPD1, SPD2, and SPD3). However, most of all six-simulation results provided in Table 3 show that the impact of weather condition did not induce a positive outcome in mean rice production. Accordingly, the preferable adaptation scenarios that farmers could apply to avoid the impact of temperature on rice production were LPD2, LPD3, and SPD3. The preferable adaptations to avoid the impact of rainfall were LPD1and LPD2. For the variance of rice production; the simulation result of cross-section SUR with FGLS shown in Table 4. The impact of temperature on rice production variance decreased from 0.24 to 0.18, 0.17, and 0.10% for LPD1, LPD2, and LPD3 adaptation scenarios, respectively. The impact of rainfall on rice production variance decreased from –0.009 to –0.006% when later planting date in one-month increment (LPD1) was adopted. For the SDP scenarios, the negative impact of temperature on variance of rice production would decrease substantially from 0.24 to 0.15 and 0.13% in response to SPD2 and SPD3. These simulation results revealed that agro-adaptation could be introduced to farmers to prevent their rice production risk. However, all of the three simulation results reported in Table 4 showed that the impact of rainfall condition did not induce a positive outcome in rice production variance. Therefore, the preferable adaptation scenarios that farmers can apply to avoid the impact of temperature on variance function were LPD1, LPD2, LPD3, SPD2, and SPD3. The preferable adaptation to avoid the impact of rainfall was LPD1. These findings were in accordance with previous studies of farmers' adaptation to climate change (UNEP 2010; Wang et al., 2010; Bhuvaneswari et al., 2014; Kibue et al., 2014; Deb et al., 2015a, 2015b; Shrestha et al., 2016) that farmers adapted to climate change through planting crops that were best suited for the prevailing conditions, improved varieties, and crop diversification. Besides, these preferable adaptation choices might vary in practice, which depends on farmer characteristic, conventional farm practice, and weather conditions in specific areas. The statement by Fankhauser et al. (1999) claimed that adaptation strategies may differ from situation to situation is particularly true for northeast Thailand with its pronounced ecological and farm practice management diversity.

Table 5 The RRP of preferable adaptation scenarios

Scenarios	*Original*	*Later planting date*			*Shorter planting date*		
	NE-O	*LPD1*	*LPD2*	*LPD3*	*SPD1*	*SPD2*	*SPD3*
Impact of main weather variables on production variance (%)							
Average temperature	−0.2397	−0.1794	−0.1692	−0.1008	−0.2665	−0.1546	−0.1329
Total rainfall	−0.0098	−0.0058	0.0042	0.0058	−0.0202	−0.0172	−0.0145
RRP (%)							
Average temperature		−25.1564	−29.4118	−57.9474	11.1806	−35.5027	−44.5557
Total rainfall		−40.8163	-	-	-	-	-
RRP trend							
Average temperature		Down	Down	Down	Up	Down	Down
Total rainfall		Down	-	-	-	-	-

3.4.2 Estimation of the RRP

The RRP is an important part of adaptation. Risk reducing effect can be performed under the assumption that farmer adopted the farm practice to decrease exposures to production risk/variance on rice production. Following the study of Musshoff et al. (2011), which quantifies the RRP for the average farm by a comparison of the production variance with and without having an adaptation measure. Without an adaptation, the impact of weather on variance of rice production is $VAR(R_0)$ and after adaptation impact on variance is $VAR(R_1)$.

If farmers wish to challenge production risks using altering planting date and change rice varieties, the RRP can be conducted to check whether these adaptation measures can reduce the variance in farmers' rice production as:

$$RRP = \frac{VAR(R_0) - VAR(R_1)}{VAR(R_0)} \times 100\% \tag{4}$$

where *RRP* denoted the hedging efficiency of adaptation which represents the percentage reduction of the variance in farmer's rice production after adaptation, $VAR(R_0)$ was the variance of original scenario of farmers, and $VAR(R_1)$ was the variance of the farmers' calculated rice production after adaptation. The risk reduction efficiency of adaptation scenarios were tested according to the variance function estimated in Table 4 and equation (4) was shown in Table 5.

The results of RRP reported in Table 5 confirmed that agro-adaptation in the study could reduce the impact of weather condition on farmer's rice production risk. Based on preferable adaptation scenarios, the altering planting date can reduce the impact of temperature on rice production risk by 25.16, 29.41, and 57.95% for LPD1, LPD2, and LPD3, respectively. The impact of rainfall on rice production risk was reduced by 40.82% for LPD1. The shorter planting date by using new rice varieties can reduce adverse impacts of temperature on rice production variance by 35.50 and 44.56% for SPD2 and SPD3 scenarios. The downward trend of RRP indicated that specific adaptations produce a positive impact on rice production. The research findings clearly showed that farmer could shift planting windows and change rice varieties to meet the favourable weather conditions for the growth and development of rice throughout the growing season. Such measure may encourage farmers to increase their adaptive capacity in responding to the change in climate as well as being able to come up with proactive implementation plans prior to the increase in the extremity of climate change in long-term.

4 Conclusions and recommendations

The study provided insights into the usage of an econometric model to estimate the potential impact of weather condition on rice production in northeast Thailand based on panel data for 17 provinces over the 1989–2014 periods. The simulation procedure was applied to assess the effect of agro-adaptation practice on rice production and variation. The stochastic production function and elasticities estimates are utilised to estimate the impacts of weather variables on mean and variance of rice production. The main lesson from this study is weather conditions have a major impact on rice production and appropriate agro-adaptation can be reduce the adverse impacts of weather on rice production. The study indicated that an increase in temperature during growing season suggested an inverse effect on mean production and consistently induced more variability in rice production. The impacts of the rainfall on rice production also vary across different models. Numerical simulation results for the agro-adaptation showed that the impacts of weather on rice production would decrease by later planting date and shorter planting date. The study has provided observational evidence that appropriate adaptation measures can reduce rice production risk. The results of this study suggest that it is necessary to take immediate adaptive actions to mitigate the decrease in rice production. In a particular case of rice production in northeast Thailand where rice is a predominant production region in Thailand, decrease in production under future weather condition can be mitigated significantly using proper management practices in terms of altering planting dates and applying new rice varieties. Thus, climate change policy should be prepared and educate farmers to implement adaptation capacity building activities including the provision of weather and climate change information to farmers for their participatory decision-making, provision of the source of fund for their adaptation cost, implementation of on-farm resource management systems, sharing knowledge and experience among farmers, and adaptation monitoring and evaluation. The study recommends that research findings should be disseminated to farmers in timely and appropriate manners. The central government should formulate policies to include subsidies and incentives for farmers to motivate an adoption of eco-friendly adaptation practices. However, the results of this study raises some issues which could be further investigated. The main conclusion of this study is that the two weather variables have impact on rice production, rice production may depend on a number of driven factors such as water and soil conditions, solar radiation, and farm management practices, etc. Future studies should attempt to collect more data with regard to those driven factors. Second, this study focuses only the overviews of climate change adaptation measures in the province level. Future research should try to extend the community based adaptation that found in the existing literature.

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