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Impacts of Farmers' Adaptation to Extreme Weather Events on Rice Productivity

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ABSTRACT

Floods and drought are the extreme weather events that pose major concerns on rice farmers in Thailand, particularly those in the Chao Phraya River Basin (CPRB). To mitigate the impacts of extreme weather events on the rice production and their livelihoods, some of these farm households have undertaken some adaptation strategies, such as shifting crop calendar, changing rice varieties, etc. Using data from the survey of farm household in the CPRB, this study highlights the adaptation strategies adopted by farm households and analyzes the impacts of adaptation to extreme weather events on rice productivity using the endogenous switching model. Our results show that adaptation to floods that took place in CPRB increases the wet-season rice productivity. The unconditional impacts of adaptation on wet-season rice productivity are around 120 kilograms per rai (approximately 0.16 hectares). The treatment effect, which captures the counterfactual case whereby farm households who adapted instead chose not to adapt at the decision stage, shows that the impacts of adaptation on wet-season rice productivity is around 31 kilograms per rai, i.e. farm households who adapted to extreme weather events would have produced 31 kilograms less per rai if they did not adapt.

Key words*:* adaptation, extreme weather events, Chao Phraya River Basin of Thailand, endogenous switching, rice productivity

JEL classification: Q12, Q18, Q54

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1. Introduction

Agriculture has been an important driver of Thailand's economy in the past, especially between 1960s and the early 1980s. Even though the agricultural sector's share of GDP has declined over time and this sector contributes only about 10% of GDP, close to 30% of the Thai labor force still participate in the agricultural sector. Within the agricultural sector, rice has played a fundamental role in income generation and ensuring food security. Rice exports account for about 16 percent of Thailand's total export revenue derived from agricultural-related products (Ministry of Commerce, 2023). Thus, the agricultural sector, especially the rice production, remains a crucial sector that requires attention.

The agricultural sector, particularly the rice production, in Thailand is challenged by many factors, of which the major ones are the climate-related disasters and extreme weather events, such as droughts and floods, (Attavanich, 2012). Climate change has contributed to the acceleration in terms of both frequency and intensity of extreme weather events, especially droughts and floods. According to the World Bank and Asian Development Bank (2021), weather-related challenges pose serious obstacles to rice cultivation and to Thai farmers' livelihoods. The lack of water caused by drought causes rice grains to develop cracks in their kernels (Krishnan et al., 2011; Shi et al., 2018). Cracked grains typically cannot withstand the milling pressure and are thus more likely to break, reducing both the price the farmers receive for the crop and the net head rice yield (Lyman et al., 2013). The environmental stresses caused by droughts and floods, especially during the flowering periods, have a harmful impact on rice pollination, causing poor seed setting and reduction in grain size (e.g. skinny grains) (Kumar et al., 2006; Davatgar et al., 2009; Zhou et al., 2020).

According to Attavanich (2017), the cumulative impacts of climate change on Thai agriculture during 2011-2045 are in the range of 0.61 to 2.85 trillion Thai Bahts (17,806 to 83,195 million US dollars). Given these discouraging prospects, the identification of adaptation strategies is vital to support agricultural productivity. These adaptation strategies can help the farm households buffering against climate change and extreme weather events and play a crucial role in enhancing security and livelihood of farm households. Di Falco et al. (2011) found that adaptation increases agricultural productivity. Other studies on the impacts of adaptation on agricultural productivity in the context of Vietnam, Europe and South Africa are Yu et al. (2010), Aaheim et al. (2012) and Calzadilla et al. (2014), respectively. In Thailand's context, there are some studies that identified the adaptation actions in the agricultural sector. Some of these studies look at adaptation from the macro perspective (Supnithadnaporn et al., 2011), while others look at the adaptation implemented at the community level (Chinvanno and Kerdsuk, 2013). These papers, however, do not evaluate the impacts of adaptation on agricultural productivity. The study by Yokying and Promkhambut (2024) highlight the impacts of climate change on rice productivity and stresses that off-farm and on-farm livelihood diversification becomes an inevitable survival strategy for many rice-farming households to manage weather related challenges, stabilize their income, and smooth consumption. Their findings point out the need to bolster on-farm adaption capacities of rice farmers. Nevertheless, their study relies on the qualitative data obtained from the interviews with rice farmers in Uthaithani, Chainat, and Ayutthaya provinces. Thus, there exists a gap in the literature in Thailand's context on estimation of impacts of adaptation to extreme weather events on the agricultural productivity. This paper aims to fill this existing gap in the literature.

We narrow the scope of our study to only rice. Thailand has two main rice-planting seasons: a wet season and a dry season. The wet season is from May to mid-October, while the dry season is usually from November to April (c. Most productive paddy fields are in the plains of Central Thailand, thanks to the fertile alluvial soils from the Chao Phraya River delta. The area of focus for this study is, therefore, in the CPRB. CPRB is one of the most important river basins in Thailand. This basis is divided into 8 sub-basins based on the natural distribution of the river system. In the past, floods and droughts are natural phenomena in the CPRB. Although farmers have adapted their livelihoods and agricultural production during the recent years and the Thai Government put in place reservoirs and flood control infrastructure in the CPRB, the frequent occurrences of extreme floods and droughts in the region cast doubts on the adequacy of these past efforts.

The key objectives of this paper are twofold. First, this paper aims to highlight the adaptation strategies adopted by rice farmers in the CPRB in response to the extreme weather events. Second, this paper aims to analyze the impacts of adaptation on the productivity of wet-season and dry-season rice in the CPRB by using the endogenous switching model.

The rest of the paper is organized as follows. The next contains the description of the study sites and the survey instruments. Section 3 presents the adaptation strategies adopted by rice farmers that took part in the survey to mitigate the risks of extreme weather events. Section 4 presents the methods used to estimate the impacts of adaptation to extreme weather events on rice productivity. Section 5 contains the results, while section 6 concludes.

2. Description of study sites and survey instruments

The data used in this study came from our farm household survey in six Central provinces in the CPRB, namely Phitsanulok, Nakorn Sawan, Utaithani, Lopburi, Suphanburi and Ayutthaya. In overall, 815 households from 80 sub-districts took part in the survey. Purposive random sampling was used in the selection of households into the survey, i.e., the sample districts were purposely selected according to the drought and flood severity indices constructed by the Department of Disaster Prevention and Mitigation (DDPM). Then, in each of the selected district, two sub-districts were randomly selected. To ensure that there is greater degree of variety in the survey data, we impose a condition that two sub-districts to be selected must not be adjacent to each other. Once the sub-districts were selected, households were randomly selected. Blue diamonds in Figure 1 show the survey villages in this study. Table 1 contains details about the number of farm households, and sub-districts in each of the 6 provinces in the CPRB.

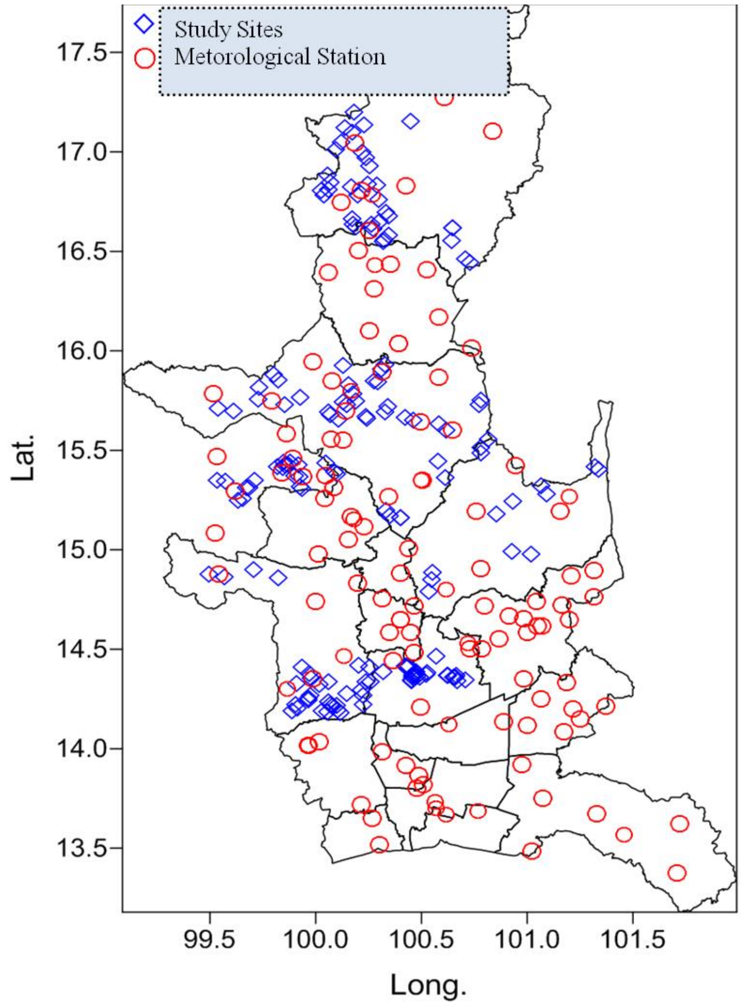

Figure 1: Locations of the villages in the farm household survey

Table 1: Sample sizes in the six provinces

Provinces	Number of Sub-districts	Number of Villages	Number of Farm Households
Phitsanulok	18	37	196
Nakhon Sawan	19	37	212
Utaithani	11	21	112
Lopburi	7	14	89
Suphanburi	14	32	124

Provinces	Number of Sub-districts	Number of Villages	Number of Farm Households
Ayutthaya	11	27	82
Total	80	168	815

The farm household survey used the structured questionnaire, which is comprising of seven main parts, namely demography and household characteristics, agricultural land utilization and land tenure, agriculture and livestock production, perceptions of climate change, incidence of severe flood, incidence of severe drought and perception of Government's flood management projects.

3. Adaptation strategies for extreme weather events adopted by farm households

According to future climate predictions and modelling, results indicate that temperatures in both the upper and lower areas of the Chao Phraya River are likely to rise even further and the frequency of extreme weather events area on the increasing trend in terms of both severity and intensity. How should the rice farmers respond to these unfavorable climate prospects? Resigning themselves to fate and trying to cope with the same problem year in and year out spells defeat. They need to confront the problem of climate change and undertake adaptation strategies. But droughts and floods are also not a novel phenomenon for Thai farmers. They have coped with droughts and floods over the past three decades, and learning how they have done so can provide useful insights into how to deal with whatever hazards the future brings.

According to the results of the farm household survey conducted in the six provinces of the CPRB, farm households adopted different adaptation strategies in mitigating the risks of different extreme weather events. This study focuses on two types of extreme weather events, namely flood and drought.

Among the farm households that adapted to flood, the strategies adopted by farm households include changing rice varieties to flood-tolerant rice varieties, land elevation and dike construction, changing crop calendar, and others. Examples of other adaptation strategies include changing crop type, changing cropping pattern, and pumping water out of farmland. These flood adaptation strategies are not mutually exclusive. In fact, farm households might need a combination of adaptation strategies to reduce long-term flood risk. For instance, to change crop calendar to avoid the wet-season rice from being affected by flood, farm households also need short-duration rice varieties. Besides, no universally optimal adaptation strategy exists. Though one adaptation strategy works well with one location, it might not necessarily work for other location. Diversity of adaptation strategies also resulted from individual farmers' specific characteristics, such as farmers' knowledge about technical issues and whether markets exist.

In the case of drought, the most adopted adaptation strategies among the households in our sample include finding alternative water sources, changing crop calendar and changing crop types. It is interesting to note that, in the case of adaptation to drought, some farm households decided to quit farming, especially those households who cannot find alternative water supplies for growing dry-season rice and domestic consumption during the dry season.

What factors influence the farmers' adaptation decision? There is, indeed, a large growing literature that investigate the farmers' adaptation decision to climate change. By using econometric analysis of cross-sectional data, Di Falco et al. (2011) found that factors that influence Ethiopian farmers' adaptation to climate change include information on farming practices and on climate change and adaptation increases crop productivity. Deressa et al. (2008) used the multinomial logit model to study the determinants of farmers' choice of adaptation methods. Their results show that wealth attributes of households, availability of information, agroecological features, social capital and temperature influence adaptation to climate change in the Nile Basin of Ethiopia. Piya et al. (2012) used the multivariate probit model to analyze the factors that influence the adoption of various adaptation practices of highly marginalized indigenous community in Nepal. The results from their analysis show that perception of rainfall change, size of landholding, status of land tenure, distance to motor road, access to productive credit, information, extension services and skill development training all influence households to adopt adaptation practices to climate change. In the case of Thailand, the study by Sheikh et al. (2024) used the multivariate probit model to analyze the factors that impact selection of adaptation strategies among Thai farmers in Rangsit, Prathumthani province, Thailand.

In this paper, we used the data from the farm household survey in 6 provinces in the CPRB to analyze the determinants of farmers' adaptation to extreme weather events. Given that the rice farmers might respond differently in terms of adaptation to flood and to drought, we conducted the regression analysis separately to find the determinants of adaptation to flood and drought events.

Table 2 shows the estimation results for the factors that determine farmers' decision to adapt to flood. The results from the probit regression analysis shown in Table 2 show that farm households with access to agricultural credits are more likely to adapt to flood. Access to affordable credits increases the financial resources available to farm households to meet the adaptation costs, such as purchase of new rice or crop varieties, new technology or important inputs that would be more suitable for the changing climatic conditions (Nhemachena and Hassan, 2007). Land ownership also matters. Farm households who do not own farmland are less likely to invest in adaptation strategies compared to those with land ownership. Land ownership provides an incentive to farmers to invest in their farms, especially making investment in physical infrastructure, such as land elevation, construction of on-farm water storage, etc. Climatic factors also matter for adaptation decisions. Our results show that increasing average wet season rainfall increases the probability of adaptation. Having previous experience with flood-related crop damages raises the likelihood of implementing adaptation measures. Table 2 shows that some of the socio-economic characteristics also matter. Farm households with well-educated household head are more likely to adapt. This is along the line with the findings by Norris and Batie (1987), Deressa et al. (2008), Igoden et al. (1990), Lin (1991) and Maddison (2006).

Table 2: Results from probit regression for determinants of farmers' adaptation to flood

Adaptation 1/0	(1)	(2)
Socio-economic characteristics		
constant	-0.9813**	-1.1858**
	(0.3981)	(0.5487)
household size	-0.0520**	-0.0646*
	(0.0242)	(0.0373)
d_male	-0.0460	0.1239
	(0.2219)	(0.2320)
age	0.0213	0.0194
	(0.0169)	(0.0205)
age-squared	-0.0002*	-0.0003*
	(0.0001)	(0.0002)
d_single	0.4542*	0.9805**
	(0.2615)	(0.5011)
d_secondary_education	0.1911***	0.2746*
	(0.0618)	(0.1472)
d_access_credit	0.1869*	0.1203
	(0.1064)	(0.1009)
d_publicland		-0.5541***
		(0.0914)
d_nonfarm_income		-0.0383
		(0.2799)
Climatic factors		

Adaptation 1/0	(1)	(2)
d_past_crop_damage		0.4766^{*}
		(0.2714)
average_wet_season_rainfall		0.0005^{*}
		(0.0002)
perception_rainfall_increase		0.1214
		(0.1265)
N	454	283
Log Pseudolikelihood	-258.2076	-160.8436
Pseudo R^2	0.0190	0.0607

***, **, * statistically significant at 1%, 5% and 10%, respectively

Clustered by province and robust standard errors are shown in parentheses

Table 3 shows the estimation results for the factors that determine farmers' decision to adapt to drought. Asset ownership affects the probability of farm households adapting to drought. According to Table 3, farm households that own vehicles are likely to adapt to drought as vehicle ownership reflects households' financial status. Farm households with female head are more likely to adapt to drought. Unlike flood, lack of access to credit and lack of land ownership does not seem to deter households from adapting to drought. Households with more members engaging in farming are more likely to adapt to drought. Increase in average rainfall and perception that average rainfall will increase in the future lead to lower probability of adaptation to drought though these two variables are not statistically significant.

Table 3: Results from probit regression for determinants of farmers' adaptation to drought

Adaptation 1/0	(1)	(2)
Socio-economic characteristics		
constant	-2.8924	10.9641
	(1.8008)	(7.6622)
on-farm members	0.3629^{***}	0.4251^{**}
	(0.1230)	(0.1971)
d_male	-0.4558^{***}	-0.5383^{***}

Adaptation 1/0	(1)	(2)
	(0.1677)	(0.1595)
age	0.1097*	0.1002
	(0.0631)	(0.0722)
age-squared	-0.0011*	-0.0010
	(0.0006)	(0.0006)
d_single	-0.1168	-0.1448
	(0.1882)	(0.1745)
d_secondary_education	0.2593	0.2409
	(0.2558)	(0.2765)
d_access_credit	-0.3167*	-0.4346**
	(0.1838)	(0.1733)
d_publicland		0.6085***
		(0.1716)
possession vehicle	0.4364***	0.3605**
	(0.1602)	(0.1605)
Climatic factors		
average_rainfall		-0.0015
		(0.0011)
average_temperature		-0.3826*
		(0.1982)
perception_rainfall_increase	-0.0252	
	(0.2386)	
N	127	128
Log Pseudolikelihood	-73.3219	-73.2420
Pseudo R^2	0.0431	0.0592

***, **, * statistically significant at 1%, 5% and 10%, respectively

Clustered by province and robust standard errors are shown in parentheses

The next section is devoted to discussing about the method used to analyze the impacts of adaptation to extreme weather events on rice productivity.

4. Methods

To model adaptation decision and its impact on crop productivity[1], we applied a two-stage framework Di Falco et al., 2011). In the first stage, a selection model for adaptation was applied: a farm household chooses to adapt if the adaptation strategy generates net benefits. Let I^*be the latent variable that captures the expected benefits from adaptation with respect to not adapting. This variable is specified as follows:

$$I_i^* = Z_i\gamma + \eta_i \ \ with \ \ I_i = \begin{cases} 1 \ if I_i^* > 0 \\ 0 \ \ otherwise \end{cases} \tag{1}$$

The model considered here describes the behavior of a farm household with two regression equations. The criterion function, I_i in equation (1) determines which regime the farm household will face. The farm household $\boldsymbol{i}$ will choose to adapt if $I^* > 0$ and will choose not to adapt otherwise. The vector, $\boldsymbol{Z}$, comprises of variables that affect the expected benefits of adaptation.

The second stage models the impact of adaptation on crop productivity via a representation of the production technology. The functional form considered here is a linear specification. Given that the OLS estimation of impact of adaptation on productivity yields biased estimates because of the assumption that adaptation is exogenously determined, in this paper, we address this endogeneity of the adaptation decision by estimating model of adaptation and crop productivity with endogenous switching regression model by using maximum likelihood method (Lokshin and Sajaia, 2004). The farm households face 2 regimes (Regime 1) to adapt and (Regime 2) not to adapt:

$$\text{Regime 1:} \quad y_{1i} = \boldsymbol{M_{1i}\alpha_1} + \varepsilon_{1i} \ \text{ if } \ I_i = 1 \tag{2a}$$

$$\text{Regime 2:} \quad y_{2i} = \boldsymbol{M_{2i}\alpha_2} + \varepsilon_{2i} \ \text{ if } \ I_i = 0 \tag{2b}$$

where y_i denotes the quantity of rice produced per rai in regimes 1 and 2; $\boldsymbol{M_i}$ is a vector of inputs and of the farmer head's and the farm household's characteristics, assets and the climatic factors. Assume that the error terms in equation (1), (1a) and (1b) have a trivariate normal distribution with mean vector zero and covariance matrix:

$$\Omega = \begin{bmatrix} \sigma_\eta^2 & \sigma_{1\eta} & \sigma_{2\eta} \\ \sigma_{1\eta} & \sigma_1^2 & \cdot \\ \sigma_{2\eta} & \cdot & \sigma_2^2 \end{bmatrix},$$

where σ_η^2 is the variance of the error term in the selection equation (1); σ_1^2 and σ_2^2 are variances of the error terms in the productivity functions (2a; 2b); $\sigma_{1\eta}$ is the covariance of η_i and ε_{1i} ; and $\sigma_{2\eta}$ is the covariance of η_i and ε_{2i}. Given that y_{1i} and y_{2i} are never observed simultaneously, the covariance between ε_{1i} and ε_{2i} is not defined. Since γ is estimable only up to a scalar factor, we can assume that $\sigma_\eta^2 =$

[1] In this paper, two types of rice are considered, namely the wet-season and dry-season rice, which are widely grown in the CPRB.

1 (Maddala, 1983; Lokshin and Sajaia, 2004). Given the assumptions regarding distribution of the disturbance terms, the logarithmic likelihood function for the system of (2a and 2b) is:

$$lnL_i = \sum_{i=1}^{N} I_i \left[ln\phi\left(\frac{\varepsilon_{1i}}{\sigma_1}\right) - ln\sigma_1 + ln\Phi(\lambda_{1i})\right] + (1 - I_i)\left[ln\phi\left(\frac{\varepsilon_{2i}}{\sigma_2}\right) - ln\sigma_2 + ln\big(1 - \Phi(\lambda_{2i})\big)\right],$$

where $\phi(\cdot)$ is the standard normal probability density function; $\Phi(\cdot)$ is the standard normal cumulative density function and $\lambda_{ji} = \frac{(\boldsymbol{Z}_i\gamma + \rho_j\varepsilon_{ji}/\sigma_j)}{\sqrt{1-\rho_j^2}}$ with ρ_j denoting the correlation coefficient between the error term η_i and the error term ε_{ji} of equations (2a) and (2b), respectively.

After estimating the parameters of the model, one can calculate the unconditional and conditional expectations of crop productivity of the farm households that adapted with respect to the farm households that did not adapt. The unconditional expectations are given by:

$$E(y_{1i}|\boldsymbol{X_{1i}}) = \boldsymbol{X_{1i}\alpha_1} \quad (3a)$$

$$E(y_{2i}|\boldsymbol{X_{2i}}) = \boldsymbol{X_{2i}\alpha_2} \quad (3b)$$

and the conditional expectations for crop productivity are given by:

$$E(y_{1i}|I_i = 1) = \boldsymbol{X_{1i}\alpha_1} + \sigma_{1\eta}\varphi_{1i} \quad (4a)$$

$$E(y_{2i}|I_i = 0) = \boldsymbol{X_{2i}\alpha_2} + \sigma_{2\eta}\varphi_{2i} \quad (4b)$$

$$E(y_{2i}|I_i = 1) = \boldsymbol{X_{1i}\alpha_2} + \sigma_{2\eta}\varphi_{1i} \quad (4c)$$

$$E(y_{1i}|I_i = 0) = \boldsymbol{X_{2i}\alpha_1} + \sigma_{1\eta}\varphi_{2i} \quad (4d)$$

where $\varphi_{1i} = \frac{\phi(\boldsymbol{Z}_i\gamma)}{\Phi(\boldsymbol{Z}_i\gamma)}$ and $\varphi_{2i} = -\frac{\phi(\boldsymbol{Z}_i\gamma)}{1-\Phi(\boldsymbol{Z}_i\gamma)}$. Table 4 summarizes different cases of conditional expectations for crop productivity, both the actual expectations and the counterfactual expected outcomes.

Table 4: Conditional Expectations, Treatment Effects and Heterogeneity Effects

Subsamples	Decision Stage		Treatment Effects
	To Adapt	Not to Adapt	
Farm households that adapted	(4a) $E(y_{1i}\|I_i = 1)$	(4c) $E(y_{2i}\|I_i = 1)$	TT
Farm households that did not adapt	(4d) $E(y_{1i}\|I_i = 0)$	(4b) $E(y_{2i}\|I_i = 0)$	TU
Heterogeneity effects	BH_1	BH_2	TH

From Table 4, the following treatment effects are calculated: first, the effect of treatment on the treated (TT) and, second the effect of the treatment on the untreated (TU):

$$TT = E(y_{1i}|I_i = 1) - E(y_{2i}|I_i = 1)$$

and

$$TU = E(y_{1i}|I_i = 0) - E(y_{2i}|I_i = 0).$$

Note that TT represents the effect of adaptation on crop productivity of the farm households that actually adapted to climate change, and TU represents the effect of adaptation on crop productivity of the farm households that did not adapt. Besides the treatment effects, the heterogeneity effects will also be calculated. As shown in Table 4, the effect of base heterogeneity for the group of farm households that decided to adapt, BH_1, and the effect of base heterogeneity for the farm households that decided not to adapt, BH_2, can be calculated as follows:

$$BH_1 = E(y_{1i}|I_i = 1) - E(y_{1i}|I_i = 0)$$

and

$$BH_2 = E(y_{2i}|I_i = 1) - E(y_{2i}|I_i = 0).$$

Finally, the transitional heterogeneity (TH=TT-TU), which captures whether the effect of adapting on crop productivity is larger or smaller for farm households that actually adapted relative to farm households that actually did not adapt.

5. Results

5.1 Impacts of Adaptation on Wet-season Rice Productivity

We begin with the estimation of benefits of adaptation, i.e. the impact of adaptation on wet-season rice productivity. Table 5 shows the estimation results. Column 1 shows the OLS estimation of wet-season rice productivity function with no switching but with the dummy variable for adaptation. Columns 2, 3 and 4 show the estimation results of the selection equation (1) and of the wet-season rice productivity functions (2a) and (2b) for farm households that adapted and did not adapt to floods.

The unconditional expectation of quantity of wet-season rice produced per rai[2] (approximately 0.16 hectares) for farm households that adapted is 683.87 kilograms per rai and the unconditional expectation of quantity of wet-season rice produced per rai for farm households that did not adapt is 617.75 kilograms per rai. The difference in the amount of quantity produced per rai between the two groups of farm households is 66.12 kilograms per rai. Nevertheless, it is important that we calculate the conditional expectation of quantity of wet-season rice produced per rai

[2] It is important to note that "rai" is the unit of area commonly used in Thailand and 6.25 rai is equivalent to 1 hectare. Thus, the unconditional expectation of quantity of wet-season rice produced for farm household that adapted is 4,274.19 kilogram per hectare and the unconditional expectation of quantity of wet-season rice produced for farm household that did not adapt is 3,860.94 kilograms per hectare. The difference in the amount of wet-season rice quantity produced is 413.25 kilograms per hectare.

under actual and counterfactual conditions in order to estimate the impacts of adaptation on wet-season rice productivity. Table 6 shows these results.

In Table 6, cells (a) and (b) represent the expected quantity of wet-season rice produced per rai observed in the sample. The expected quantity of wet-season rice produced per rai among the adapted farm households is about 696 kilograms, while the expected quantity of wet-season rice produced per rai by the non-adapted farm households is about 576 kilograms. Thus, considering only the unconditional expectations, on average, the farm households that adapted produced 120 kilograms more than the farm households that did not adapt.

Next, the treatment effect is calculated. The last column of Table 6 shows the treatment effects of adaptation on wet-season rice productivity. Cell (c) shows one of the counterfactual cases, i.e. what if the farm households who adapted choose not to adapt at the decision stage. As shown in the table, farm households who actually adapted would have produced about 31 kilograms less if they did not adapt. Thus, the treatment effect for the farm households that adapted (TT) is 31 kilograms of wet-season rice per rai. Given the average wet-season rice productivity among adapted households of 697 kilograms, if the adapters instead choose not to adapt, their average yield would be reduced by around 4 percent.

In the second counterfactual case (d), results presented in Table 6 show that farm households that actually did not adapt would have produced about 94 kilograms more if they instead chose to adapt. Thus, the treatment on the untreated (TU) or treatment effects for non-adapters are 94 kilograms of wet-season rice. This implies that, if the non-adapters instead choose to adapt, their average wet-season rice productivity would be increased by approximately 14 percent. However, given that the transitional heterogeneity (TH) is negative, the effect of adaptation on wet-season rice productivity is smaller for the farm households that adapted relative to the farm households that did not adapt.

Table 5: Estimation Results of Impacts of Adaptation on Wet-Season Rice Productivity

	[1]	[2]	[3]	[4]
		Endogenous Switching Regression		
Model	**OLS**		**Regime 1 Adaptation =1 (Farm HH that adapted)**	**Regime 2 Adaptation =0 (Farm HH that not adapted)**
Dependent Variable	**Quantity of Wet-Season Rice per Rai**	**Adaptation 1/0**	**Quantity of Wet-Season Rice per Rai**	**Quantity of Wet-Season Rice per Rai**
Adaptation 1/0	-4.2598 (33.0957)			
Climatic factor:				
Rainfall during rainy season	0.5113** (0.2367)	0.0026 (0.0017)	0.3852 (0.2879)	1.3967*** (0.3993)
Inputs:				
Seed quantity per rai	-0.073 (1.8829)		-9.6174*** (3.3708)	4.4544** (2.1344)
Manure quantity per rai	1.7446*** (0.6543)		1.5765* (0.8170)	0.8209 (0.8245)
Plot Size	-2.0842* (1.2192)		-0.5870 (1.9418)	-2.9380* (1.6026)
Farm HH characteristics:				
Number of members on farm	25.3956 (18.8248)	0.1953 (0.1323)	15.9732 (25.7653)	-48.6293* (26.9470)
Married HH Head	-61.4768 (81.3436)	0.8257 (0.6695)	-91.8556 (174.3721)	-22.6188 (87.9050)
Debt: agricultural credit	1.6220 (50.1590)	-0.6004* (0.3470)	-61.8170 (59.9071)	465.5958*** (95.9533)
Perception:				
Perception about rainfall		0.4376* (0.2539)		
Constant	427.72** (186.77)	-2.3719* (1.4253)	850.3315*** (297.7367)	-467.9752* (249.8715)
σ_i			164.7331*** (13.1062)	160.3512*** (23.8089)
ρ_i			-0.0031 (0.4562)	-0.3057 (0.6523)

Remark: Estimation by maximum likelihood at the plot level (153 plots)
* Significant at 10% level; ** significant at 5% level, *** significant at 1% level

Next, we examine the potential heterogeneity in the sample by considering the bottom row of Table 6. Since both BH_1 and BH_2 are positive, these results imply that there are some sources of heterogeneity (i.e. unobservable characteristics such as skills) that makes the adapters better producers than the non-adapters irrespective of the issue of climate change.[3]

[3] See Di Falco et al. (2011) for similar findings.

Table 6: Treatment and Heterogeneity Effects for Wet-season Rice

Subsamples	Decision Stage		Treatment Effects
	To Adapt	Not to Adapt	
Farm households that adapted	(a) 695.81 (13.3797)	(c) 664.46 (14.8840)	TT = 31.35*** (2.2934)
Farm households that did not adapt	(d) 669.79 (13.8864)	(b) 575.69 (22.6851)	TU = 94.10*** (3.0151)
Heterogeneity effects	BH_1 = 26.02*** (2.2072)	BH_2 = 88.77*** (3.0788)	TH = -62.75

Note: Standard errors are shown in parentheses

In this paper, we also investigated the costs of wet-season rice production among the adapters and non-adapters. Our results show that the farm households that adapted face higher costs of wet-season rice production than the farm households that did not adapt. The average cost of wet-season rice production among the farm households that adapted is 4,500 baht per rai, while the average cost of production for the non-adapters is 4,057 baht per rai. The difference in costs between the adapters and non-adapters is 443 baht per rai.

5.2 Impacts of Adaptation on Dry-season Rice Productivity

In what follows, we examine the impact of adaptation on the dry-season rice productivity. The first column of Table 7 shows the OLS estimation of dry-season rice productivity function with no switching but with the dummy variable for adaptation[4], while columns 2, 3 and 4 show the estimation results of the selection equation (1) and of the dry-season rice productivity functions (2a) and (2b) for farm households that adapted and did not adapt.

The unconditional expectation of quantity of dry-season rice produced per rai for farm households that adapted is 905 kilograms per rai, and the unconditional expectation of quantity of dry-season rice produced per rai for farm households that did not adapt is 727.11 kilograms per rai. The difference in the amount of quantity produced per rai between the adapters and non-adapters is 177.90 kilograms per rai.

Next, we calculate the conditional expectation of quantity of dry-season rice produced per rai under actual and counterfactual conditions. Table 8 presents the results.

[4] This dummy variable for adaptation equals to 1 if the farm household adapt to drought and equals to 0 otherwise.

Table 7: Estimation Results of Impacts of Adaptation on Dry-Season Rice Productivity

	[1]	[2]	[3]	[4]
		Endogenous Switching Regression		
Model	**OLS**		**Regime 1 Adaptation =1 (Farm HH that adapted)**	**Regime 2 Adaptation =0 (Farm HH that not adapted)**
Dependent Variable	**Quantity of Dry-Season Rice per Rai**	**Adaptation 1/0**	**Quantity of Dry-Season Rice per Rai**	**Quantity of Dry-Season Rice per Rai**
Adaptation 1/0	-66.7382 (47.5827)			
Climatic factor:				
Annual rainfall	0.2724* (0.1643)	0.0005 (0.0014)	-0.2209 (1.1532)	0.2687* (0.1655)
Night temperature	69.3754* (41.2718)	0.5257 (0.3473)	-2857.033 (1825.323)	69.1188* (42.7908)
Inputs:				
Manure quantity per rai	1.2088** (0.5423)		0.8485 (1.1838)	1.1484* (0.6888)
Assets:				
Agricultural tools index	107.3349 (92.0770)	1.9580** (0.7984)	730.5529* (424.2428)	78.02655 (110.7071)
Farm HH characteristics:				
Number of members on farm	-39.1231* (21.1359)	-0.3880** (0.1773)	-147.8869* (87.87016)	-31.2640 (24.0845)
At least secondary education	27.04636 (42.94704)	-0.7611** (0.4063)	126.8271 (168.5219)	29.6167 (48.2940)
Debt: agricultural credit	-67.8387 (45.8886)	-0.4014 (0.3434)	234.2928 (150.3982)	-78.4917 (53.2702)
Perception:				
Perception about rainfall		-0.3958 (0.3337)		
Constant	-1368.025 (1122.066)	-14.9777 (9.4992)	73864.01 (47317.43)	-1353.987 (1149.06)
σ_i			182.7427*** (27.5855)	207.1728*** (12.4635)
ρ_i			-0.0856 (0.8970)	-0.0855 (0.4512)

Remark: Estimation by maximum likelihood at the plot level (170 plots)

* Significant at 10% level; ** significant at 5% level, *** significant at 1% level

Table 8: Treatment and Heterogeneity Effects for Dry-season Rice

Subsamples	**Decision Stage**		**Treatment Effects**
	To Adapt	**Not to Adapt**	
Farm households that adapted	(a) 700.63 (22.5415)	(c) 725.83 (6.5547)	TT = -25.21*** (4.4544)
Farm households that did not adapt	(d) 941.90 (108.6289)	(b) 734.16 (13.0725)	TU = 207.74*** (9.4084)
Heterogeneity effects	BH_1 = -241.27*** (10.0742)	BH_2 = -8.33*** (2.6213)	TH = -232.95

Note: Standard errors in parentheses

Table 8 shows the average expected dry-season rice productivity per rai under actual and counterfactual cases. Cells (a) and (b) represent the expected quantity of dry-season rice produced per rai observed in the sample. The table shows that the expected quantity of dry-season rice produced per rai among the farm households that adapted is about 701 kilograms, while the expected quantity of dry-season rice produced per rai by the non-adapters is about 734 kilograms. Next, the treatment effects are calculated. The last column of Table 8 shows the treatment effects of adaptation on dry-season rice productivity. In this case, the impact of adaptation on dry-season rice productivity is unclear. Cell (c) shows that the adapters would have produced about 25 kilograms more if they instead chose not to adapt. This implies that, by instead choosing not to adapt, the adapters' average dry-season rice productivity would have increased around 4 percent. In the second counterfactual case (d), the non-adapters would have produced about 208 kilograms more if they instead chose to adapt. Thus, if the non-adapted households instead choose to adapt, their average yield per rai would have increased by 28 percent. With these conflicting results, one cannot conclude at this point that adaptation would unambiguously increase productivity of dry-season rice. Moreover, with the negative transitional heterogeneity (TH), the effect of adaptation on dry-season rice productivity is smaller for the farm households that adapted relative to the farm households that did not adapt.

Next, we compare the cost of production for dry-season rice between the adapters and non-adapters. Our results show that the households that did not adapt face higher costs of dry-season rice production than the households that adapted. The average cost of production among the farm households that adapted is 3,892 baht per rai, while the average cost of production for the non-adapters is 4,631 baht per rai. The difference in costs between the adapters and non-adapters is 739 baht per rai. Therefore, in case of dry-season rice, the benefit of adaptation is not entirely clear, but the cost is lower among the farm households that adapted.

5.3 Barriers to Adaptation and Policy Implications

Even though extreme weather events that occurred in the CPRB have imposed adverse impacts on livelihood, agricultural production and properties of the farm households, not all farm households decided to adapt to be more resilient to the extreme weather events. What are the factors that hinder adaptation of households in the CPRB? Figure 2 shows the factors that are barriers for adaptation to flood and Figure 3 shows the barriers for adaptation to drought[5].

[5] Some of these barriers to adaptation are consistent with the findings of Deressa et al. (2008).

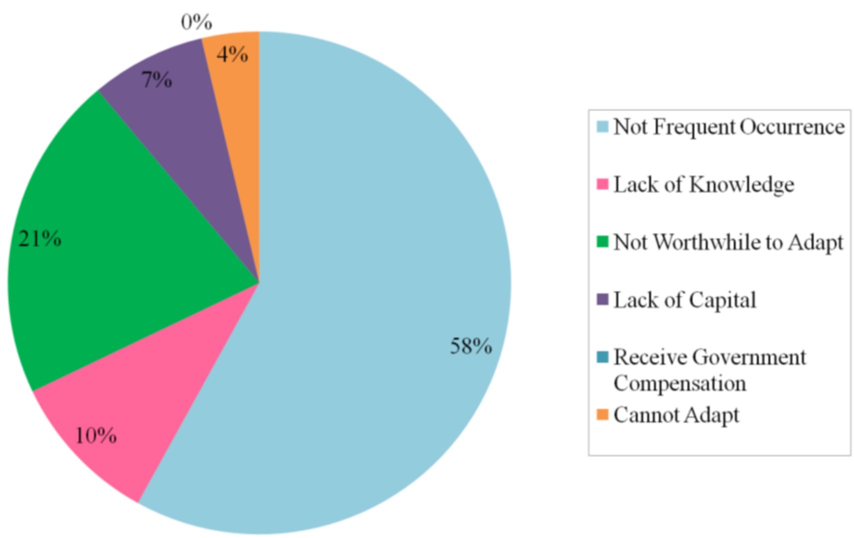

Figure 2: Barriers for Adaptation to Flood

As shown in Figure 2, the three mostly mentioned reasons for not adapting to flood include the perception that floods that took place were rare events; the perception that adaptation is not worthwhile thing to do; and ack of knowledge, information and knowhow on how to adapt to flood.

For drought, according to Figure 3, the mostly mentioned barriers for adaptation are perception that droughts that took place are rare events, perception that adaptation to drought is not worthwhile, lack of knowledge on how to adapt to drought and lack of capital to invest in adaptation technology. If farmers perceive that droughts do not occur frequently, they do not pursue long-term adaptation measures. Instead, they rely on the short-term strategies or reactive measures to cope with droughts such as finding temporary jobs. To promote wider adoption of adaptation strategies among farm households in the CPRB, it is vital that the responsible government agencies step in to help the farm households overcome these barriers to adaptation.

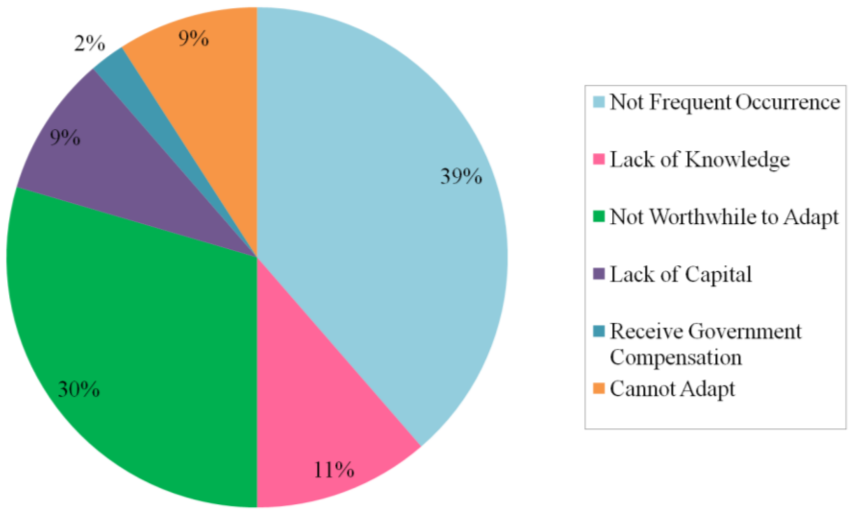

Figure 3: Barriers for Adaptation to Drought

As highlighted above, the foremost important barrier that hinders the farm households' incentive to adapt to extreme weather events – both flood and drought – is the lack of awareness about the urgency and frequency of extreme weather events. Even though in the past extreme events in some areas occurred on infrequent basis, with climate change, the frequency of occurrence of extreme weather events might increase. Therefore, prudent adaptation decision and adaptation programs in response to the future climate change must take these changing probabilities into account when making risk assessments and devising adaptation measures. In this respect, educating the farm households on the concept of climate risk assessment in the most non-technical manner is essential.

Next, concerning the lack of knowledge, technical knowhow and information on appropriate adaptation options, the relevant government agencies, such as the Department of Agricultural Extension (DOAE) and District Agricultural Extension Offices, can work in partnership with experts in the private sector and in universities to disseminate information, share knowledge on new climate tolerant rice or other crop varieties, suitable crop calendar, cropping pattern or climate smart technologies. In addition, given that market access is a factor that influences adoption of agricultural technologies since markets provide an important platform for farmers to gather and share information according to previous studies (Maddison, 2006), some steps should be taken by the Thai Government agencies to improve farmers' access to market. Examples are the initiatives by the DOAE and the "A Farm Mart" by the Bank for Agriculture and Agricultural Cooperatives (BAAC), which link farmers to the market. Additionally, online platforms like Shopee and Lazada, along with other agritech platforms such as FARMTO, are expanding the market for agricultural products for Thai farmers.

To address the high costs of adapting to extreme weather events, the Bank for Agriculture and Agricultural Cooperatives (BAAC) can play a very important role. The BAAC can provide different types of credit product and services to Thai farmers, such as the loan for investment in water infrastructure to cope with the risk of drought, investment in new agricultural technology or farming technique to increase resilience to extreme events, such as flood or drought.

Finally, given that there are some farm households that did not adapt because of the unconditional subsidies or financial supports received from the Government, it is thus essential that the Government redesign the subsidies from unconditional subsidies to subsidies conditional on farmers adapting to climate change.

6. Conclusion

Given that extreme weather events, particularly flood and drought, are known to affect rice productivity, identification and implementation of "climate-proofing" adaptation strategies are vital to ensure that rice productivity is not impacted by extreme weather events. This study analyzes the determinants of adaptation to extreme weather events. Results from our study show that asset possession, past experience with crop failure or damages from unfavorable climatic conditions, education of the head of household, access to credits as well as climatic variables are playing crucial roles in influencing the farmers' adaptation decisions.

We also analyze the impacts of adaptation on rice productivity by using the endogenous switching regression model. Our results show that adaptation increases the wet-season rice productivity. The impacts of adaptation on wet-season rice productivity is smaller for the adapters than the non-adapters. Farn households that adapted have higher cost of production than farm households that did not adapt.

In the case of dry-season rice, though the unconditional expectation of quantity of dry-season rice produced per rai for farm households that adapted is higher than the unconditional expectation of quantity of dry-season rice produced per rai for farm households that did not adapt, the treatment effects are not clear. On one hand, farm households who adapted would have produced more of the dry-season rice if they did not adapt. On the other hand, farm households that actually did not adapt would have produced more if they had adapted. Thus, one cannot conclude that adaptation to drought would unambiguously increase productivity of dry-season rice. The farm households that adapted have lower cost of production for dry-season rice than the households that did not adapt.

There are some barriers that prevent some farm households from adapting to climate change. The mostly mentioned barriers are the lack of awareness about the frequency and urgency of the extreme weather events, lack of knowledge on the appropriate adaptation strategies, lack of capital and the receipt of unconditional financial supports from the Government. To promote adaptation to extreme weather events among the farmers, some policy interventions are necessary. First is educating the farm households on the concept of climate risk assessment and how their agricultural production and livelihood are impacted by climate change. Second, both the government agencies and the private sector need to share knowledge to the farm households on the suitable adaptation strategies. Third is enhancing the farmers' access to credit to ensure that they have sufficient capital to adapt to extreme weather events, such as purchase of climate-tolerant crop varieties, climate change adaptation technologies, etc. Last but not least, the Government should redesign the subsidies from unconditional subsidies to subsidies conditional on farmers adapting to climate change.

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