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Determinants of adoption of climate-smart agriculture technologies in rice production in Vietnam

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Abstract

Purpose – In recent years, climate-smart agriculture (CSA) was introduced to Vietnam to enhance farmers' resilience and adaptation to climate change. Among the climate-smart agricultural technologies (CSATs) introduced were water-saving techniques and improved stress tolerant varieties. This study aims to examine the determinants of farmers' adoption of these technologies and the effects of their adoption on net rice income (NRI) in three provinces as follows: Thai Binh (North), Ha Tinh (Central) and Bac Lieu (South).

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Design/methodology/approach – Determinants of adoption of CSATs and the adoption effects on NRI are analyzed by using a multinomial endogenous switching regression framework.

Findings – The results showed that gender, age, number of family workers, climate-related factors, farm characteristics, distance to markets, access to climate information, confidence on the know-how of extension workers, membership in social/agricultural groups and attitude toward risk were the major factors affecting the decision to adopt CSATs. However, the effects of these factors on the adoption of CSATs varied across three provinces. These technologies when adopted tend to increase NRI but the increase is much greater when these are combined.

Practical implications – It is important to consider first the appropriateness of the CSA packages to the specific conditions of the target areas before they are promoted. It is also necessary to enhance the technical capacity of local extension workers and provide farmers more training on CSATs.

Originality/value – This study is the first attempt to identify key determinants of adoption of CSATs either singly or in combination and the adoption effects on NRI in Vietnam.

Keywords Climate change, Climate-smart agriculture, Adoption, Rice, Farmers, Vietnam

Paper type Research paper

1. Introduction

The recent years have seen a tremendous increase in the volume of literature on climate change and its impacts on agricultural productivity and farmers' livelihood in Southeast Asia. In particular, Vietnam is considered as one of these countries that are most seriously affected by climate change because of its long coastline, geographic location, diverse topography, climate, high concentration of population and economic activity in coastal area (Vien, 2011; World Bank, 2011). The climatic changes that have caused the sea level rise, floods and drought have affected especially Vietnam's rice production sector and its efforts on poverty reduction, food security, employment and export (Trung, 2013).

In Southeast Asia, a key response to these climatic changes was the introduction of climate-smart agriculture (CSA)[1]. The goals for introducing these technologies were to:

- enable these Southeast Asian countries to sustainably increase their incomes and agricultural productivity;
- build both the resilience and the capacity of its agricultural and food systems to adapt to climate change; and
- seek opportunities to reduce and remove greenhouse gas (GHG) to meet their national food security and development goals (Asfaw and Maggio, 2016).

The application of climate-smart agricultural technologies (CSATs) to cope with climate change was viewed as a key strategy for restructuring the agriculture sector program of Vietnam although the current legal framework for integrating CSATs into development policies has been faced with several drawbacks and limitations. The CSA concept is relatively new and not well understood and appreciated by policymakers, scientists and farmers (Nghia *et al.*, 2015).

Farmers have a vast array of alternative technologies that they can use either singly or in combination to deal with various environmental conditions (Dorfman, 1996; Teklewold *et al.*, 2017). Due, however, to differences in cultures, awareness, resource endowments, objectives, preferences and socio-economic backgrounds, farmers differ in their willingness to adopt new technologies (Maguza-Tembo *et al.*, 2017). Farmers may modify or combine different CSATs with other practices and technologies to address their specific conditions and strategy. Therefore, scientists and policymakers should pay more attention to identifying factors that affect farmer's adoption of separate and combined CSATs. The CSATs considered in this study include water-saving techniques (WS) and improved stress tolerant varieties (IS).

Fortunately, the costs and benefits of potential and priority CSATs have been determined in various studies conducted in Vietnam (Nghia *et al.*, 2015). Farmers often build sustainable agricultural production systems that are resilient to different climate-related conditions and other shocks by using a combination of various CSATs (Maguza-Tembo *et al.*, 2017). Unfortunately, of the few studies that have attempted to identify the determinants of farmer adoption of more than one CSAT (Di Falco and Veronesi, 2013; Parvathi and Waibel, 2015; Teklewold *et al.*, 2013, 2017), none of them have been conducted in Vietnam. Thus, it is important to conduct such a study to identify the factors that determine the successful adoption of CSATs in the country. Moreover, there is also a need to test a methodology for identifying key determinants of CSA adoption whether singly or in combination. The findings of this study can guide policymakers in developing plans and programs for disseminating appropriate CSATs and mitigate the detrimental impacts of climate change on the agricultural sector.

2. Selection of study area and sampling selection method

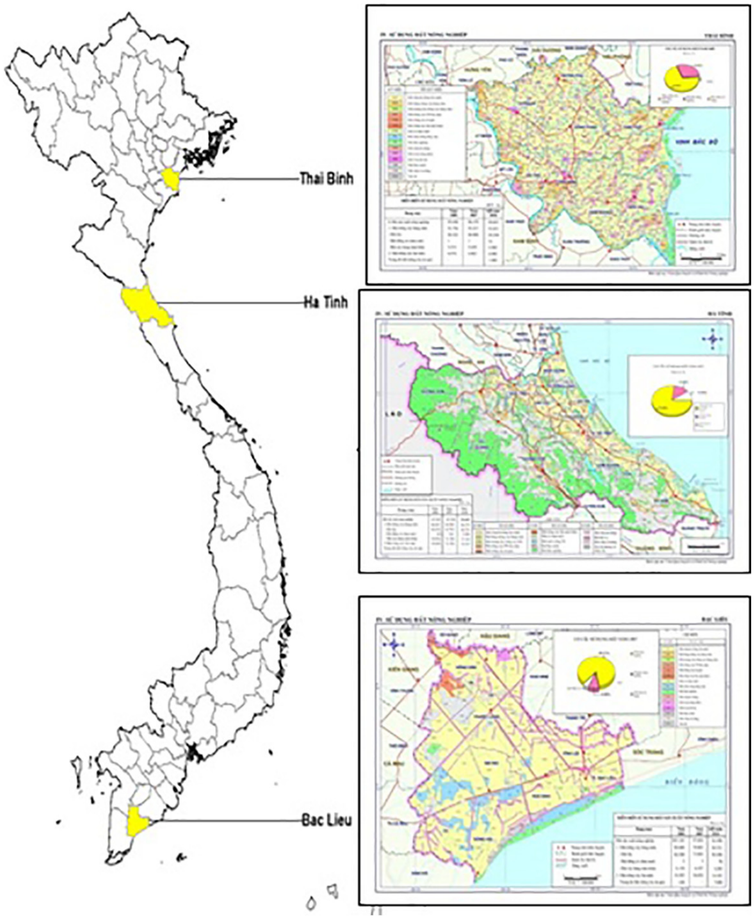
2.1 Selection of study area

The study was conducted in Bac Lieu, Ha Tinh and Thai Binh provinces that are representative of different agro-ecological regions of Mekong River Delta, North Central Coast and Red River Delta, respectively (Figure 1). These provinces have also successfully implemented some of the CSATs such as improved tolerant rice variety, alternate wetting and drying (AWD), a system of rice intensification and others (Dung and Phu, 2016; Sen *et al.*, 2015; Simelton *et al.*, 2017).

Mekong River Delta is one of the major rice-growing regions of the world that is faced with increasing frequency and magnitude of flooding, sea water intrusion with high tide, contaminated soil, sea level rise and seasonal tropical storms (Ninh *et al.*, 2007). In Bac Lieu, a province that is located on the southeast of the Mekong River Delta, the poverty rate is low at 6.4 per cent. It is a relative rather flat area with three ecological zones, namely, brackish water, fresh water and salt-water (General Statistical Office, 2017). The sea level rise, drought and salt-water intrusion in the province adversely affect agriculture and aquaculture production (Phong *et al.*, 2015; Vien, 2011). Three rice crops are grown in the province with both rainfed and irrigated rice production systems (Paris *et al.*, 2010).

The Red River Delta in the North is the second most important agricultural production zones in Vietnam that is critically vulnerable to the impacts of climate change. Thai Binh province, a Coastal Eastern province in the Red River Delta has a fairly flat topographic feature (Dao *et al.*, 2006). Despite the increase in the number of industries because of the market-based economic policy of Vietnam, the agriculture, forestry and aquaculture sectors have still contributing 25-35 per cent of the total provincial value of production over the past 30 years (Thai Binh DONRE (Department of Natural Resources and Environement), 2011). The source of livelihood of about 26 per cent of farmers living along coastal areas is from aquaculture, with most of them also in other traditional livelihood activities. The farmers can grow two crops of rice in the irrigated areas (Paris *et al.*, 2010). The poverty incidence in Thai Binh province at 8.4 per cent in 2017 is one of the lowest in the country (General Statistical Office, 2017).

In the central coast region, including Ha Tinh province, is one of the most vulnerable to typhoons, storm surges, flash floods, drought and saline water intrusion (Chaudhry and Ruysschaert, 2008). About 80 per cent of the province is covered by mountains and a small delta, which is separated by mountains and rivers. Ha Tinh is one of the poorest provinces in the country (General Statistical Office, 2017) and experiencing more variable weather and associated disasters than in the past. Farmers in the province can grow two crops of rice a year in irrigated areas. Then, because of the long coastal line with four estuaries, fishing and aquaculture are also very important to the economy of the province (Thao, 2012).



Source: Invest in Vietnam 2017

Figure 1. Map of Thai Binh, Ha Tinh and Bac Lieu provinces

2.2 Sampling selection method

The primary data were collected in 2016/2017 crop seasons from 579 rice-farming households with 1,747 farming-plots in the three provinces through face-to-face interviews using a household questionnaire (Figure 1). A stratified random sampling procedure was used to select 12 villages of 3 districts in each province. Moreover, villages that do not produce rice were not included. In each province, 200 respondents who were the household heads were randomly selected and evenly distributed into four groups of CSATs combination (Table I).

3. Analytical framework

This study uses a multinomial endogenous switching regression framework to identify the key factors affecting the adoption of CSATs and estimate the effect of adoption on NRI. It can be used for evaluating individual and combined CSA packages (Mansur *et al.*, 2008;

Province	Choice	Package of CSA	WS		IS		Frequency (%)
			WS_0	WS_1	IS_0	IS_1	
Bac Lieu	1	WS_0IS_0	✓		✓		33.2
	2	WS_1IS_0		✓	✓		18.9
	3	WS_0IS_1	✓			✓	24.7
	4	WS_1IS_1		✓		✓	23.2
Ha Tinh	1	WS_0IS_0	✓		✓		25.0
	2	WS_1IS_0		✓	✓		25.5
	3	WS_0IS_1	✓			✓	23.5
	4	WS_1IS_1		✓		✓	26.0
Thai Binh	1	WS_0IS_0	✓		✓		26.9
	2	WS_1IS_0		✓	✓		25.4
	3	WS_0IS_1	✓			✓	29.0
	4	WS_1IS_1		✓		✓	18.7

Note: Subscript is 1 if adopted and 0 otherwise

Table I.
CSA packages used on farming plots

Wu and Babcock, 1998). This framework is composed of two steps. In Step 1, a multinomial adoption selection model is used to identify the key determinants of adoption of CSATs singly and in combination. In Step 2, a counterfactual analysis is used to estimate the average adoption effect of alternative CSA packages on NRI (Teklewold *et al.*, 2017).

3.1 Multinomial adoption selection model

Farmers' adoption choices among WS and IS lead to four possible combinations from which farmers could choose (Table I). Adoption of these combinations may not be random but farmers may endogenously self-select into using or not-using decisions. Thus, decisions are likely to be affected by unobserved characteristics (e.g. expectation of yield gain from adoption, managerial skills, motivation, etc.) that may correlate with the outcome of interest (net farm income, crop yield and cost of material input) (Teklewold *et al.*, 2013, 2017). Farmers will adopt CSATs if the expected utility obtained from the technology is higher than the current technology. Thus, the theory of expected utility maximization is appropriate to use in investigating the farmer's adoption of individual and combined CSATs, as the maximizing solution can be one or multiple (Maguza-Tembo *et al.*, 2017). When the selection is over a large number of exclusive choices, a polychotomous choice framework such as the multinomial logit specification is preferred because of its simplicity. However, the additional hypotheses must be used to embed the multinomial logit into a selection bias correction model (Bourguignon *et al.*, 2007; Parvathi and Waibel, 2015). We assumed that farmers choose to adopt the combination of CSATs to maximize their expected utility (Y^*_{ij}). The latent model (Y^*_{ij}), which describes the behavior of farmer "i" in adopting CSA combination "j" rather than adopting any other alternative combinations can be expressed as following equation (1):

$$Y^*_{ij} = \beta_i X_i + \varepsilon_{ij}\; j = 1 \ldots J \tag{1}$$

Where X_i is a vector of observed exogenous variables that determine the decision to use (household-specific characteristics, economic factors, climate-related shocks, market and institutional factors, farm characteristics and attitudes); and ε_i is a random error term.

The utility to the farmer from choosing a CSA combination is not observed, but the farmer's adoption decision is observable. Let (Y) be an index that denotes the farmer's choice of CSA package. Thus, the farmer will choose a combination of CSATs "j" preferences for adopting any other CSA combinations m if:

$$Y = \begin{cases} 1 \text{ iff } \ \delta_{i1} < 0 \text{ or } Y^*_{i1} > \max\limits_{m \neq 1}\left(Y^*_{im}\right) \\ . \\ . \\ . \\ j \text{ iff } \ \delta_{ij} < 0 \text{ or } Y^*_{ij} > \max\limits_{m \neq j}\left(Y^*_{im}\right) \end{cases} \quad \text{for all} \quad m \neq j \tag{2}$$

$$\text{Since } \delta_{ij = \max\limits_{m \neq j}\left(Y^*_{im} - Y^*_{ij}\right)^{m \neq j} < 0}$$

Equation (2) indicates that a combination of CSA "j" will be chosen by farmer "i" to maximize his expected profit and obtain greater expected profit than any other combination $m \neq j$ (Bourguignon *et al.*, 2007; Teklewold *et al.*, 2013).

The (δ_j)s are assumed to be independent and identically Gumbel distributed (the so-called independence of irrelevant alternatives hypothesis) (Bourguignon *et al.*, 2007). The probability that farmer "i" with characteristics X_i choosing a combination of CSATs "j" over other combination of CSATs can be specified by a multinomial logit selection model (McFadden, 1973) as follows:

$$P\left(\delta_{ij} < 0/X_I\right) = \frac{\exp\left(X_i \beta_j\right)}{\sum_{m=1}^{J} \exp\left(X_i \beta_m\right)} \tag{3}$$

This expression shows that consistent maximum likelihood estimates of the (δ_j) can be easily obtained given their cumulative and density functions $G(\delta) = \exp(-e^{-\delta})$ and $g(\delta) = \exp(-\delta - e^{-\delta})$, respectively.

3.2 Counterfactual analysis

The average adoption effect of CSA packages on the NRI is estimated in the second stage using a counterfactual analysis. The estimate corrects for the selection bias from the first stage. The relationship between the NRI, (Q_{ij}), and a set of exogenous variables Z (household-specific characteristics, economic factors, climate-related shocks, farm characteristics, market and institutional factors and attitudes) is estimated for each chosen combination of CSATs (Bourguignon *et al.*, 2007). The base category, non-adoption of any CSATs is denoted as j = 1. In the remaining combination (j = 2, 3 and 4) at least one CSAT is adopted. The conditional Ricardian specification for each regime (CSA combination) "j" is given as:

$$\begin{cases} \text{Regime 1}: Q_{i1} = \alpha_1 Z_{i1} + u_{i1} \quad \text{if } Y = 1 \\ . \\ . \\ . \\ \text{Regime 4}: Q_{ij} = \alpha_j Z_{ij} + u_{iJ} \quad \text{if } Y = j \end{cases} \quad j = 2, 3, 4 \tag{4}$$

Where Q_{ij} is the NRI of the i-th farmer in regime j; Z is as defined above; and u denotes error terms that capture the uncertainty faced by farmers with $E(u_{ij}/X, Z) = 0$ and $Var\,(uij/X, Z) = \sigma_j^2$. If the ε' and u's are not independent, a consistent estimation requires the inclusion of the selection correction terms of the alternative choices in equation (4). Estimates of α in the outcome equation (4) can be obtained by estimating the following selection bias-corrected models (Bourguignon *et al.*, 2007):

$$\begin{cases} \text{Regime 1}: Q_{i1} = \alpha_1 Z_{i1} + \sigma_{1\widehat{\lambda}_{i1}} + e_{i1} \quad \text{if } Y = 1 \\ \quad . \\ \quad . \qquad\qquad\qquad\qquad\qquad\qquad j = 2, 3, 4 \\ \quad . \\ \text{Regime 4}: Q_{i4} = \alpha_4 Z_{i4} + \sigma_{4\widehat{\lambda}_{i1}} + e_{i4} \quad \text{if } Y = 4 \end{cases} \tag{5}$$

Here, e is the error term with an expected value of 0, σ is the covariance between ϵ's and u's, λ_{ij} is the inverse Mills ratio computed from the estimated probabilities in equation (3) as follows:

$$\lambda_{ij} = \sum_{m \neq j}^{J} \rho_j \left[\frac{\widehat{P_{im}} \ln\left(\widehat{P_{im}}\right)}{1 - \widehat{P_{im}}} + \ln\left(\widehat{P_{ij}}\right) \right] \tag{6}$$

Here, ρ is the correlation coefficient of ε's and u's are error terms with an expected value of 0. In the multinomial choice setting, there are J-1 selection correction terms, one for each alternative combination of technologies. The error terms in equation (5) are likely to exhibit heteroscedasticity arising from the two-stage estimation procedure. To deal with the heteroscedastic problems, standard errors in equation (5) are bootstrapped (Kassie *et al.*, 2013; Teklewold *et al.*, 2017).

Self-selection models that are estimated in a two-stage procedure have been criticized for being sensitive to misspecification (Wu and Babcock, 1998). The lack of identification is particularly a problem when variables affecting the adoption decisions (X) are the same as those affecting the subsequent outcome equations (Z). For equation (5) to be identified, a simple falsification test with a set of selection instruments (e.g. distance to input and product markets, confidence in the know-how of extension workers, access to climate change information and attitudes) and mean of plot-variant explanatory variables (e.g. soil fertility, slope of plots and land tenure), was used to test the assumption that the instrumental variables affect the choice decision but do not influence the NRI (Di Falco and Veronesi, 2013). In this stage, the least squares regression of NRI was estimated for each combination of CSATs. Then, the unconditional average treatment effect (ATE) and the conditional average treatment effect on treated (ATT) average effects of various combinations of CSATs are derived.

The ATE is estimated to determine whether the adopters of any single CSATs or in combination obtain on average more or less than the value of NRI than non-adopters. From the equation (7), the ATE of combination of technologies (j) versus package (1) is defined as:

$$ATE = E\left(Q_{ij} - Q_{i1}/Z = z_i\right) = Z_{i(}\ \alpha_j - \ \alpha_{1)} \qquad \text{for } j = 2, 3, 4 \tag{7}$$

However, the ATE does not consider that the difference in the NRI may be caused by observable and unobservable characteristics. Thus, the ATE on the treated or average CSA adoption effect on adopters (ATT) controlling for selection bias that presents the true average adoption effects on NRI was calculated. It shows the counterfactual difference in NRI of adopters if they were non-adopters. ATT is calculated by equation (10) as the difference between equations (8) and (9). Equations (8) represent the actual expected NRI of adopters that were observed in the sample, while equation (9) are their respective counterfactual expected NRI of adopters.

- Adopters with adoption (actual):

$$E\left(Q_{ij}|I=j\right) = Z_{ij}\alpha_j + \sigma_j\lambda_{ij} \quad \text{for } j = 2, 3, 4 \tag{8}$$

- Adopters had they decided not to adopt (counterfactual):

$$E[Q_{i1}|I=j] = Z_{ij}\ \alpha_1 + \sigma_1\lambda_{ij} \quad \text{for } j = 2, 3, 4 \tag{9}$$

- The ATT:

$$ATT = \left[Q_{ij}|I=j\right] - E[Q_{i1}|I=j] = Z_i(\alpha_j - \alpha_1) + \lambda_{ij}(\sigma_j - \sigma_1) \quad \text{for } j = 2, 3, 4 \tag{10}$$

4. Results and discussion

Table I presents the proportion of rice plots cultivated under alternative combinations of WS and IS in three provinces. The combination of these two CSATs provides four mutually exclusive combinations (2^2).

In Vietnam, WS are not applied solely but are integrated with 1Must-5Reduction[2] (1M-5R), large field model[3] (LFM) or system rice intensification[4] (SRI) model. AWD[5] has been developed as a water-saving technique to increase net income and reduce GHG, especially methane, for rice cultivation (Bouman and Tuong, 2001; Lampayan *et al.*, 2015; Rejesus *et al.*, 2011; Wassmann *et al.*, 2010). AWD integrated with 1M-5R and LFM have been implemented in Bac Lieu province, while the WS has been integrated with the SRI model in Ha Tinh and Thai Binh provinces.

Currently, several rice seed companies in Vietnam are providing high quality and high yielding rice seeds that have a high tolerance to extreme weather, pests and disease. However, Vietnam is still highly dependent on imported seeds from India and China and other countries. Although some high quality seeds have been introduced to the local farmers, most farmers in the study sites keep their own seed but do not process them to ensure varietal purity or seed quality. Poor seed quality leads to low vigor and poor growth and is more prone to weed, and insect infestation and diseases. For the purpose of this study, therefore, farmers are considered as adopters if they use pure seeds of high quality that are very tolerant of extreme weather, pests and diseases.

A review of the literature shows that there are many categories for grouping the factors affecting farmer's adoption of new technologies (Kassie *et al.*, 2013; Maguza-Tembo *et al.*, 2017; Mwangi and Kariuki, 2015; Rejesus *et al.*, 2011; Teklewold *et al.*, 2013, 2017) based on the current technologies being investigated, the location and the researcher's reference or even suitability to clients' needs (Bonabana-Wabbi, 2002). In this study, the categorization is based on the CSATs being investigated and literature reviews. These factors include household-specific characteristics (gender, age, education level of respondents, number of family workers and experience in rice cultivation) (Bonabana-Wabbi, 2002; Chander and Thangavelu, 2004;

Lavison, 2013; Leavy and Smith, 2010; Mignouna *et al.*, 2011; Obisesan, 2014; Omonona *et al.*, 2006; Teklewold *et al.*, 2017); economic factors (rice income, off-farm income, tropical livestock unit and area of rice farms) (Ellis and Freeman, 2004; Gabre-Madhin and Haggblade, 2004; Harper *et al.*, 1990; Katengeza *et al.*, 2012; Lowenberg-DeBoer, 2000; Maguza-Tembo *et al.*, 2017; Mignouna *et al.*, 2011; Parvathi and Waibel, 2015; Reardon *et al.*, 2007; Uaiene *et al.*, 2009; Yaron *et al.*, 1992); market factors (distance from household to input and product markets) (Jansen *et al.*, 2006; Wollni *et al.*, 2010); institutional factors (access to agricultural extension and credit, access to climate information, confidence on the know-how of extension workers and membership in social/agricultural groups) (Maguza-Tembo *et al.*, 2017; Mignouna *et al.*, 2011; Mwangi and Kariuki, 2015; Teklewold *et al.*, 2017); climate-related shocks (rainfall satisfaction index, waterlogging, drought stress, and pest and disease stress) (Jansen *et al.*, 2006; Kassie *et al.*, 2013; Teklewold *et al.*, 2013); farm characteristics (land tenure, slope of plots and soil fertility); and attitudes (self-assessments of likelihood of willingness to try new technologies and attitude toward risk) (Arslan *et al.*, 2017; Besley, 1995; Kassie *et al.*, 2013; Teklewold *et al.*, 2013, 2017). The description and descriptive statistics of these explanatory variables are not reported to conserve space but are available upon request from the authors.

Farmers in Bac Lieu province have on average significantly higher income from their rice production (86.7 million dong/year) than in other provinces (24.3 and 11.3 million dong/year for Ha Tinh and Thai Binh province, respectively) while their off-farm income is relatively lower (23.8, 32.0 and 34.1 million dong/year for Bac Lieu, Ha Tinh and Thai Binh provinces, respectively). The reason is that rice production is the main income source of farmers in Bac lieu province (i.e. rice production occupied 78 per cent to total household income) while the households in Ha Tinh and Thai Binh provinces derive most of their income from other off-farm and non-farm income activities to compensate for the low income from rice production (i.e. rice production contributed 24 and 20 per cent to total household income in Ha Tinh and Thai Binh provinces, respectively). A comparison of farm households by the level of household income shows that the higher-income households were more likely to adopt CSATs in all provinces.

4.1 Determinants of adoption of climate-smart agricultural technologies

Table II presents results of the multinomial logit selection model that compared all factors affecting the adoption of CSATs for alternative combinations of CSATs in Bac Lieu, Ha Tinh and Thai Binh provinces. The result shows that there is good correlation between unobserved household fixed effect and observed covariates in these models. The estimated results show that the models fit data reasonably well. It also shows the relatively different results in the adoption different packages of CSATs in each province and among the three provinces.

The positive relationship of gender within a selection of CSATs in Bac Lieu province and negative in other provinces means that women in Ha Tinh and Thai Binh provinces are more likely to adopt CSATs in comparison to the men. This is because Ha Tinh and Thai Binh provinces have smaller plots of rice fields[6] compared to Bac Lieu province. Therefore, most farmers in Ha Tinh and Thai Binh provinces cultivate rice for home consumption rather than for sale. Because of the small farm sizes and limited income from rice farming, 16.8 per cent of male household heads[7] from Ha Tinh and 22.6 per cent from Thai Binh provinces have left and sought non-farm work in the cities or other countries. The absence of the male household heads who seek non-farm work may increase the tasks and farm management responsibilities of the wives or women (Paris *et al.*, 2009). As a consequence, the women left behind gain more experience and knowledge about managing their rice farms so that they are now more likely to adopt CSATs. These results corroborated the

Table II. Summary of the key determinants of adoption of CSATs

Determinants of CSA adoption	Bac Lieu WS_1IS_0	Bac Lieu WS_0IS_1	Bac Lieu WS_1IS_1	Ha Tinh WS_1IS_0	Ha Tinh WS_0IS_1	Ha Tinh WS_1IS_1	Thai Binh WS_1IS_0	Thai Binh WS_0IS_1	Thai Binh WS_1IS_1
Gender (1 = male, 0 = female)	3.30*	1.29*	0.78	−1.43	−1.57*	−1.08	−1.80**	−1.31**	−0.60
Age (yrs)	−0.14*	−0.09**	−0.04	0.09	0.19***	0.08	0.01	−0.06	−0.21***
Education (yrs)	0.18	0.04	0.10	0.08	−0.14	0.06	0.07	−0.16	0.07
Experience in rice cultivation (yrs)	0.10	0.06	0.03	−0.02	−0.06	0.04	0.001	0.009	0.17***
No. of family workers (people)	−1.91**	0.21	−0.04	−1.73**	−0.60	−2.16**	−0.89	−0.63	−0.50
Rice area (ha)	−2.70***	−2.00***	−1.65**	9.54***	11.61***	12.95***	−5.73**	−2.18	−0.54
Rice income (million dong/year)	0.05***	0.04***	0.03***	0.003	0.03	0.01	0.13***	0.06**	0.10***
Off-farm income (million dong/year)	0.01	−0.02	0.004	−0.01	0.001	−0.01	−0.009	−0.03***	−0.06***
Tropical livestock unit	0.34	−0.29	−0.09	0.54**	0.57***	0.49**	−0.60**	−0.043	−0.30
Rainfall index (1 = best, 0 = worst)	−4.81**	7.19***	2.48*	−1.27	2.44**	2.66	2.03	3.24*	6.54***
Pest and disease (1 = yes, 0 = otherwise)	0.76	−1.84*	0.96	0.87	0.54	2.12**	−1.39	−0.21	14.60***
Waterlogging (1 = yes, 0 = otherwise)	1.39	2.54***	0.37	−0.52	0.26	−1.75	2.18***	0.89	1.69**
Drought (1 = yes, 0 = otherwise)	6.06***	8.13***	5.20***	2.59***	1.27	1.98**	1.62	1.91**	0.80
Land tenure (1 = own the plot, 0 = otherwise)	3.74	−1.201	12.08***	5.28***	3.27*	2.17	1.26	−1.05	0.50
Soil fertility (3 = highly fertile, 2 = moderately fertile and 1 = poorly fertile)	−2.35***	−1.68***	−2.20***	2.91**	0.85	3.73***	3.64***	3.65***	2.35**
Slope of plots (1 = deep, 2 = medium and 3 = flat)	−0.85	6.09***	5.25***	−1.31	−2.09	−0.97	1.62***	−0.11	1.27
Distance to product market (km)	−1.51	−4.22***	−2.86**	−0.91	−1.30**	−0.29	1.58	−0.59	2.04*
Distance to input market (km)	−0.18	−0.64***	−0.22	−0.86***	−0.32*	−0.81***	1.51***	0.60	2.04***
Access to extension (1 = yes, 0 = otherwise)	0.90	0.28	0.67	0.71	−0.97	0.59	1.36	1.14	−0.88
Access to credit (1 = yes, 0 = otherwise)	0.42	2.38***	1.45*	0.36	0.34	0.03	−0.79	−0.25	−0.97
Access to CC information (1 = yes, 0 = otherwise)	−0.21	0.77	1.04	3.60***	0.90	1.17	0.17	2.83**	2.34
Confidence in know-how of extension workers (scale 1-5 where 5 signifies high confidence)	1.27	1.60**	0.49	0.57**	−0.09***	0.45	1.44**	0.99**	0.50
Membership in social/agricultural groups (groups)	−1.83**	−0.30	−0.37	0.21	0.18	−0.07	1.29***	1.54***	1.55**
Attitude toward risk (1 = farmers is risk loving, 0 = otherwise)	3.08**	0.58	0.02	2.46***	1.65**	1.82**	0.76	3.70**	0.58
Self-assessments of innovative index	−0.59	0.66	1.76***	−0.16	−0.63	−1.19	−0.38	−0.62	−0.32
Joint significance of selection instruments χ^2 (5)	9.26*	19.43***	6.39	27.54***	16.98***	20.58***	12.32**	12.18**	16.12***
Joint significance of plot varying covariates χ^2 (3)	9.77**	17.84***	10.81**	15.98***	3.63	19.00***	21.12***	12.70***	13.26***
	Number of observations = 190; Wald χ^2 (84) = 1,145.35; $p > \chi^2 = 0.0000$			Number of observations = 196; Wald χ^2 (84) = 197.32; $p > \chi^2 = 0.0000$			Number of observations = 193; Wald χ^2 (84) = 900.74; Prob > $\chi^2 = 0.0000$		

Notes: *, **; *** indicate statistical significance at the 10, 5 and 1% level, respectively. The subscript is 1 if adopted and 0 otherwise findings of Nhemachena and Hassan (2007), which revealed that female-headed households tend to adopt climate change adaption methods in farming. The situation in Bac Lieu province is a bit different given the larger farm sizes and favorable biophysical conditions for rice production. The male household heads are not forced to leave and take non-farm jobs, and thus, are the ones managing their own rice farms, which are the major source of income. Only 5.5 per cent of the male household heads leave in Bac Lieu province to work in other provinces.

The age of farmers was also found to have different influences on the adoption decision of CSATs in the three provinces. In Ha Tinh province, the older farmers are more likely to adopt CSATs. This finding is similar to those of Mignouna *et al.* (2011) and Kariyasa and Dewi (2013), who argued that older farmers have gained knowledge and experience over time from coping with climate-related shocks and are better at evaluating technology information than younger farmers. In contrast, the younger farmers in Bac Lieu and Thai Binh provinces are more likely to adopt CSATs than older farmers. This corroborated the findings of Adesina and Zinnah (1993) and Leavy and Smith (2010), who found that older farmers were more risk averse and less likely to make long-term investments in the farm than younger farmers.

It is interesting to note that the availability of family labor has a significant effect on the adoption of WS for rice production (WS_1IS_0) in Bac Lieu and Ha Tinh provinces in contrast to that of Thai Binh province where it is not considered important. The result, however, is inconsistent with the findings of Bonabana-Wabbi (2002), Mignouna *et al.* (2011) and Teklewold *et al.* (2013), whose findings show that farmers with larger households are more willing to adopt CSATs especially those new technologies, which are more labor intensive. Income from rice farming also has a positive effect on the decision of farmers to adopt CSATs in the three provinces, as it provides them the necessary capital for investment in the CSATs (Katengeza *et al.*, 2012; Maguza-Tembo *et al.*, 2017).

Most of the climate-related factors are found to have a significant impact on CSA adoption. CSA packages are more likely to be adopted in drought and waterlogged plots. Farmers in different provinces have also different strategies to cope with pest and disease infestation. In Bac Lieu province, farmers are not likely to apply the IS (WS_0S_1) on the plot areas that experienced the pest and disease infestation. However, WS in combination with IS (WS_1IS_1) is more likely to be adopted on plots previously affected by pests and disease in Ha Tinh and Thai Binh provinces. This result shows that the adoption of different packages of CSATs is very site-specific, which considers the unique characteristics that influence the appropriateness of the technology.

Land tenure and slope of plots have positive effects on the use of alternative CSA packages. Farmers are more likely to adopt CSATs (WS_1S_1) if they own the land and the topography is flat as shown in the case of Bac Lieu province. These results support the previous works of Kassie and Holden (2007) and Maguza-Tembo *et al.* (2017), who found that tenants are less likely to apply new technologies on rented plots because of the absence of security of tenure in the farm. In the same way, the quality of the soil and the weather conditions affect the farmers' adoption decisions. For instance, the biophysical conditions in the Bac Lieu province is very favorable for rice production, as the soil is still very fertile. Thus, farmers would tend to adopt technology only if the soil is poor or moderately fertile. In contrast, the soil quality in the Central and the Northern regions of Vietnam such as Ha Tinh and Thai Binh provinces that are more exposed to extreme weather conditions is quite poor. Thus, farmers in Ha Tinh and Thai Binh provinces only tend to apply CSATs on plots that are very fertile to reduce the risk of yield loss.

The distance to markets has a negative effect on the CSA decisions of farmers in both Bac Lieu and Ha Tinh provinces. Local farmers are likely to apply the new technologies if their land/plot is close to the markets for their farm produce and source of farm inputs and services. Also, institutional factors such as access to climate information, confidence in know-how of extension workers and membership in social/agricultural groups have a positive impact on the adoption of different packages of CSATs that confirm the finding in the studies of Mignouna *et al.* (2011), Mwangi and Kariuki (2015), Teklewold *et al.* (2017) and Maguza-Tembo *et al.* (2017).

An interesting finding is that more than access to extension services, confidence in the know-how of extension workers is a more important factor influencing farmers to adopt of CSATs. This result supports the finding of Teklewold *et al.* (2017), who found that it is not the extension contact *per se* that influences the adoption decision, but rather the quality of the extension workers. This is probably because the package of technologies that combine the WS and IS is relatively knowledge-intensive and requires considerable managerial skills. All these results emphasize the importance of quality of extension services, the provision of climate information to farmers and the role of social organizations in enhancing and disseminating the CSATs. Farmers' attitude toward risk is also found to have a positive influence on the uptake of CSATs. Thus, providing evidence-based critical climate change information and knowledge of CSATs to build resilience and reduce uncertainty to farmers is important.

4.2 Effects of adoption of climate-smart agricultural technologies on net rice income

The least squares regression of NRI for each combination of CSATs is estimated in the second stage while correcting the selection bias in the first stage[8]. Generally, there is a statistically significant correlation between the number of explanatory variables and NRI. There are substantial differences between the NRI equations' coefficients among different packages of CSATs. This illustrates the heterogeneity in the sample in relation to NRI. Also, most selection correction terms are not statistically significant indicating that adoption of WS and IS will have the same effect on NRI impact of non-adopters, if they choose to apply these CSATs as those farmers who have already implemented them.

Table III presents the unconditional average effects (ATE) of the adoption of different combinations of WS and IS in the three provinces. The estimates of ATE indicate that adopters of any CSA package either in isolation or in combination earn more NRI, on average than non-adopters. Except for the case of Bac Lieu province, the *t*-test result shows that there is no significant difference between adoption of WS and IS package (WS_1IS_1) and non-adoption of any CSA (WS_0IS_0).

CSA packages	Bac Lieu NRI	Bac Lieu ATE	Ha Tinh NRI	Ha Tinh ATE	Thai Binh NRI	Thai Binh ATE
WS_0IS_0	35.8 (12.84)	–	22.08 (0.80)	–	31.95 (1.02)	–
WS_1IS_0	42.7 (39.42)	6.90** (3.01)	36.10 (1.31)	14.00*** (1.53)	37.88 (1.31)	5.93*** (1.67)
WS_0IS_1	54.4 (20.67)	18.57*** (1.77)	28.84 (0.85)	6.76*** (1.17)	39.60 (0.94)	7.65*** (1.39)
WS_1IS_1	31.0 (61.05)	−4.80 (4.53)	27.31 (1.05)	5.23*** (1.32)	46.90 (1.56)	14.95*** (1.87)

Notes: Figures in parentheses are standard errors; **; *** indicate statistical significance at the 5 and 1% level, respectively. The subscript is 1 if adopted and 0 otherwise

Table III. The unconditional average effect of the adoption of CSATs on NRI (million dong/ha/year)

The conclusion, however, from this simple comparison is misleading because it does not take into account the observed and unobserved factors that may affect the NRI. The naive comparison by using ATE would lead to the conclusion that farm households in Ha Tinh province that adopted IS (WS_0IS_1) earned about 14 million dong/ha/year more than farm households that did not adopt. Thus, the conditional average effects (ATT) were estimated to show the true average adoption effects on NRI given different packages of CSA in isolation or combination.

The estimated results of ATT (Column C) is presented in Table IV by comparing the Columns A and B. In Bac Lieu province, the results show that the adoption of WS (WS_1IS_0) singly or a combination of IS (WS_1IS_1) provide higher NRI compared with non-adoption (WS_0IS_0). Also, the results show that there is no difference in NRI between the adoption of IS (WS_0IS_1) and non-adoption (WS_0IS_0). This could be explained by the fact that majority of local farmers suffered from yield losses due to rice lodging that was caused by the occurrence of unanticipated cyclones during the harvesting time. However, the largest income effect (36.75 million dong/ha/year) was obtained from applying IS joint with WS (WS_1IS_1).

In Ha Tinh and Thai Binh provinces, the ATT results show that the adoption of any CSATs, whether singly or in combination, provides higher NRI compared with non-adoption. However, the effect of IS on NRI is highly significant at the 1 per cent statistical level when combined with WS. For Ha Tinh province, the effect of WS and IS package (WS_1IS_1) is equal to 15.0 million dong/ha/year while the impact of WS (WS_1IS_0) and IS in isolation (WS_0IS_1) are 9.12 and 10.37 million dong/ha in 2017, respectively. Similarly, the higher NRI (11.36 million dong/ha/year) was obtained from the adoption of WS in combination with the IS in Thai Binh province. This is a clear indication of complementarity between the two CSATs.

5. Conclusions and recommendations

This study provides an analysis of determinants of adoption of CSATs and adoption effects on NRI in Thai Binh, Ha Tinh and Bac Lieu provinces. The findings indicate that the current choice of different packages of CSATs in three provinces are significantly affected by gender, age, number of family workers, climate-related factors, farm characteristics, distance to markets, institutional factors such as access to climate information, confidence on the know-how of extension workers, membership in social/agricultural groups and attitude toward risk although in general these factors are found to have different effects on the adoption decision of CSATs among the three provinces.

In particular, the findings of the study are as follows:

- Gender has a positive effect on the adoption of WS and IS in Bac Lieu province, but a negative effect on adoption of these CSATs in other provinces;
- The older farmers are more willing to adopt CSATs in Ha Tinh province, in contrast to Bac Lieu and Thai Binh provinces where the younger farmers are more willing to adopt these CSATs;
- The number of family workers is negatively related to the likelihood of adopting WS in Bac Lieu and Ha Tinh provinces in contrast to the Thai Binh province where it is not an important consideration;
- CSATs are more likely to be adopted in rice plots that experienced a lack of water and waterlogging than those that did not;

Table IV. The conditional average effect of the adoption of CSATs on NRI of adopter (million dong/ha/year)

	Bac Lieu			Ha Tinh			Thai Binh		
	(A)	(B)	(C)	(A)	(B)	(C)	(A)	(B)	(C)
Out-come	Actual NRI if farm HHs did adopt	Counterfactual NRI if farm HHs did not adopt	ATT	Actual NRI if farm HHs did adopt	Counterfactual NRI HHs did not adopt	ATT	Actual NRI if farm HHs did adopt	Counterfactual NRI if farm HHs did not adopt	ATT
WS_1IS_0	49.88 (3.28)	42.71 (6.48)	7.18** (9.05)	29.82 (1.69)	20.70 (1.48)	9.12*** (2.25)	38.56 (1.47)	32.97 (1.71)	5.59** (2.26)
WS_0IS_1	52.32 (2.06)	57.40 (2.88)	−5.07 (3.77)	31.17 (1.58)	20.77 (1.92)	10.40*** (2.49)	38.04 (1.41)	35.15 (2.09)	2.89** (2.52)
WS_1IS_1	48.11 (2.04)	11.35 (10.71)	36.75*** (12.81)	34.33 (1.14)	19.33 (1.66)	15.00*** (2.02)	37.57 (2.29)	26.21 (3.03)	11.36*** (3.79)

Notes: Figures in parentheses are standard errors; **; *** indicate statistical significance at the 5 and 1% level, respectively. The subscript is 1 if adopted and 0 otherwise; HHs = Households

- In Bac Lieu province, farmers are more likely to plant traditional varieties, instead of IS, if pests and disease affect their rice plots while in the other provinces, they would use IS combined with the WS;
- Security of tenure affects farmers' decision to adopt CSATs, that is, they are more likely to use them on their owned land rather than on rented or borrowed land;
- In Bac Lieu province, all packages of CSATs are more likely to be adopted by farmers in plots or farms with poor and moderate fertility while in other provinces, these are more likely to be adopted either singly or in combination where the soil is fertile;
- Distance to markets is negatively related to the adoption of CSATs, but positively related to access to climate information, confidence on the know-how of extension workers and membership in social/agricultural groups;
- Farmers who are more willing to take risks are more likely to adopt CSA; and
- The NRI is more likely to increase with the adoption of WS and IS, whether adopted singly or in combination with other technologies. However, the largest increase in income in all provinces under study is from the adoption of IS with WS.

The implications of these findings are as follows:

- It is important to take into consideration the key determinants affecting the adoption of the CSATs identified in this study in developing the plans and strategies for disseminating of these CSATs at both local and national level;
- The area-specific conditions in each province should be properly evaluated to determine the appropriateness of promoting CSA packages;
- Institute appropriate policies to provide security of tenure and facilitate the operation of the land rental markets;
- Ensure that extension workers have the necessary technical know-how to inspire the confidence of farmers on their technical capability and recommendations; and
- Finally, provide more training to farmers through field research/experiments and evidence-based critical climate change information to build resilience and increase knowledge of CSATs.

Notes

1. CSA is neither a specific technology, nor a set of practices, nor a new agricultural system that can be universally applied. It is an approach to developing the technical, policy, and investment conditions to achieve sustainable agricultural development for food security under climate change; a way to guide the needed changes of agricultural systems, given the necessity to jointly address food security and climate change. It requires site-specific assessments to identify suitable agricultural technologies and practices (World Bank, FAO and IFAD, 2015).
2. One must" recommends that farmers must use certified seeds; "five reductions" include reducing seed rate, fertilizer, pesticide, water and post-harvest loss (Chi *et al.*, 2013).
3. LFM is a type of production organization, in which enterprises or cooperatives establish a cooperative relationship with farmers to apply a uniform production system by providing production inputs and/or buying outputs from producers (Thang *et al.*, 2017).
4. Five technical principles of SRI: use healthy young seedlings, transplant single seedlings, weed early, manage water and aerate soil and apply manure and compost (World Bank, FAO and IFAD, 2015).

5. AWD irrigation is a field water management technique developed by IRRI to improve water-use efficiency in rice production. Most of the AWD field experiments that have been tested successfully in non-saline soils have significantly reduced water use and increased farm profitability. Total water inputs decreased by 15-30% without a significant impact on yield. In these studies, it was concluded that rice yield remained satisfactory if irrigation was re-supplied when the soil water tension was around −10 kPa or when the perched water table reached a threshold value of −15 cm below the soil surface (Lampayan *et al.*, 2015; Richards and Sander, 2014).
6. Based on the sample respondents, mean of rice plot area of Bac Lieu, Ha Tinh and Thai Binh provinces are 1.40, 0.33 and 0.18 ha of land, respectively.
7. Household heads are who actually make the major decisions in the household.
8. The second stage regression was estimated by using the Stata selmlog command. The results will be provided on request to conserve space.

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