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ORIGINAL ARTICLE

Climate-resilient practices and welfare impacts on rice-cultivating households in Vietnam: Does joint adoption of multiple practices matter?

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Abstract
Farmers have a long history of adjusting their production practices in response to changing production conditions. Using a multinomial endogenous treatment effects model that accounts for observable and unobservable heterogeneity, this study investigates the adoption and welfare impacts of climate-resilient practices on Vietnamese rice-cultivating households. We found evidence of clear and positive welfare impacts from the adoption of canal irrigation (CI) and the joint adoption of agricultural conservation practices (CP) and CI as the main adaptation strategies to increase water stress. More importantly, although farmers with access to CI systems obtained the highest returns, the joint adoption of multiple practices still had substantially high adoption rates and significantly positive effects on rice yield, rice revenue and household income. Our findings indicate that farms' and farmers' characteristics, market information and climatic conditions are generally the main factors driving rice farmers' decisions to adopt climate-resilient technologies, both individually and jointly. Follow-up policy interventions should focus on improving CI systems and promoting the joint adoption of climate-resilient technologies to improve rice farmers' well-being and enhance their resilience capacity to cope with incoming climatic uncertainty.

KEYWORDS
adoption, climate-resilient practices, rice production, Vietnam, welfare impact

JEL CLASSIFICATION
O33, Q12, Q15

1 | INTRODUCTION

Despite Vietnam's rapid economic development, agriculture continues to play a vital role in the country's economy, accounting for 22% of the gross domestic product and 54% of the labour force (GSO, 2021). The *Renovation Policy* ('*Doi Moi*') introduced in 1986 has achieved remarkable results: total farm output more than tripled from 1990 to 2013, lifting rural incomes, reducing poverty and increasing agricultural exports (OECD, 2015). Vietnam's agricultural sector has also outperformed that of other Asian countries during the last few decades (OECD, 2015). The *Renovation Policy* has also resulted in substantial changes in land use practices and land ownership in Vietnam. Specifically, smallholder farmers have gained more flexibility in managing their agricultural land, including the ability to choose and apply the most appropriate advancements in agricultural development, such as new seed varieties, improved irrigation systems, and soil and water protection methods (Hoang, 2020; Marsh et al., 2006).

However, ongoing changes in climatic conditions are likely to be especially challenging for rice production, a key agricultural activity in Vietnam and many other developing countries, given its direct exposure to weather. Adaptation through the use of various climate-resilient practices is the predominant strategy for mitigating the detrimental effects of climate change (Fentie & Beyene, 2019; Ha et al., 2022; Hoang, 2020; Martey et al., 2021; Phuong et al., 2018). Consequently, the pathways associated with agricultural technology adoption in coping with climate change are of ongoing interest in the agricultural economics literature, especially in developing countries such as Vietnam. This is because improved practices promise to bring about a substantial increase in agricultural yield and improvements in rural incomes towards poverty reduction in the context of changing production conditions (Feder et al., 1985; Ogundari & Bolarinwa, 2018; Wossen et al., 2019; Zheng et al., 2021). The specific focus of this paper is on the 'climate-resilient practices', such as the adoption of canal irrigation (CI) systems and soil and water conservation methods. These practices have long been recommended by agricultural extension services in Vietnam and the Food and Agriculture Organization (FAO; see Appendix S1).

Most previous empirical studies have focussed on the welfare impact of a single climate-resilient technology of interest, such as drought-tolerant maize varieties (Martey, Etwire, & Abdoulaye, 2020; Martey, Etwire, & Kuwornu, 2020), improved wheat varieties (Bezu et al., 2014) and climate-smart agricultural practices (Alemayehu & Bewket, 2017; Fentie & Beyene, 2019; Hoang, 2020; Nguyen et al., 2021). Studies considering the joint adoption of multiple agricultural technologies and their impact at the farm level are relatively sparse in the literature (Issahaku & Abdulai, 2020; Kassie et al., 2015; Khonje et al., 2018; Oyetunde-Usman et al., 2021). The joint adoption of multiple climate-resilient practices can result in substantial co-benefits; however, empirical evidence for rice farming in Vietnam remains limited. To provide further empirical evidence, we apply the approach described by Kassie et al. (2015) and Khonje et al. (2018) and examine the joint adoption of multiple agricultural practices and their impact on rice-cultivating households across regions of Vietnam.

In addition, several previous studies have used cross-sectional datasets to investigate farmers' behavioural changes under changing climatic conditions (Cazzuffi et al., 2020; Doss, 2006; Ho et al., 2021; Tivet & Boulakia, 2017). This means that cross-sectional data are used to address an issue that is inherently dynamic over time and requires panel data analysis to measure aggregate change over time at the household level (Doss, 2006). This leaves gaps in the literature that the current study addresses.

This study adds value to the existing literature in several ways. It complements and expands the existing empirical work by investigating the adoption of multiple climate-resilient practices and their effects, with a special focus on comparing nonadopters, adopters and joint adopters. In doing so, we apply a multinomial endogenous switching regression (MESR), which is used to specify more flexible functional forms representing different farmers' choices and to control for both selection bias and unobservable factors (Danso-Abbeam & Baiyegunhi, 2018; Kassie et al., 2015; Liang et al., 2021; Martey, Etwire, & Abdoulaye, 2020; Martey, Etwire, & Kuwornu, 2020; Midingoyi et al., 2019). This approach overcomes the limitation of focussing on a single specific practice, as has been done in many other empirical studies. We conduct further robustness checks by visually comparing the estimates of the means and quantiles of the welfare variables corresponding to each level of the treatment variable to reveal the heterogeneity in the impact of technology adoption. We base our analysis on a rich panel dataset, thereby overcoming the issues that emerge from using only cross-sectional data for the investigation of farmers' decisions around adaptation to climate change.

The remainder of this paper is organised as follows. The next section provides an overview of the agricultural sector, climate change and agricultural technology changes in Vietnam. The conceptual framework, empirical model and estimation strategy are presented in Section 3. Section 4 describes the study sites and data used in this study. Section 5 presents the empirical results and discussion. Finally, Section 6 provides the concluding remarks.

2 | BACKGROUND

The agricultural sector is a significant part of the Vietnamese economy (GSO, 2021). The structural transition since the introduction of the *Renovation Policy* in 1986 has provided farmers with opportunities to alter their production in response to technological changes and market signals and to cope with the risks associated with variations in the production environment. As a result, agricultural output in Vietnam has overperformed other Asian countries, leading to improved farmers' income and reduced poverty (Figure 1).

Crop production in Vietnam continues to be dominated by rice as the major cash crop, accounting for approximately 40% of the total agricultural land (GSO, 2021). Rice farmers are typically smallholders, and their livelihoods depend heavily on agriculture as the predominant source of income. Rice production in Vietnam follows irrigation and rain-fed cultivation and is spread across several agro-ecological regions. Large cultivated areas in the Mekong and Red River deltas are mainly irrigated; however, irrigation is not always reliable (Nguyen, Ancev, & Randall, 2019; Nguyen, Renaud, & Sebesvari, 2019; Tong et al., 2022). Therefore, rice production remains significantly exposed and sensitive to weather factors.

According to IPCC (2007), nations such as Vietnam, which depend heavily on agriculture, are particularly vulnerable to weather shocks and long-term effects brought about by climate change (IPCC, 2007). Climatic variability and change are likely to be especially challenging for rice growth and could impose large detrimental effects on rice production. At a national scale, Nguyen et al. (2013) note an increasing trend in average temperatures throughout Vietnam over the last several decades. In addition, the variability in annual rainfall has increased dramatically across the climatic zones of Vietnam (Nguyen, Ancev, & Randall, 2019; Nguyen, Renaud, & Sebesvari, 2019). Strong evidence of climatic change across regions of Vietnam highlights the need to foster adaptation practices to mitigate adverse effects on farming and farmers' livelihoods.

In Vietnam, rice cultivation is inherently vulnerable to climate change because, as a typical broadacre crop, it is directly exposed to shifts in temperature and precipitation. In response, Vietnamese farmers have applied a broad range of strategies, such as the adoption of CI and conservation practices (CP) (e.g. rock bunds, soil bunds, terraces and grass lines;

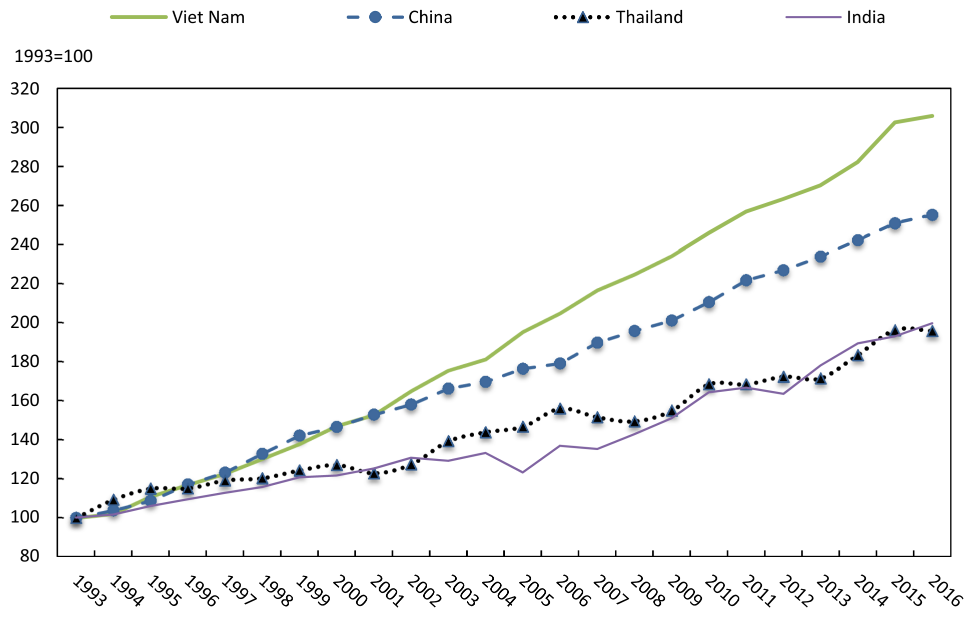

FIGURE 1 Growth in gross agricultural output in Vietnam and select Asian countries. Gross Agricultural Output (GAO); Taking indices for 1993 as 100. Source: Adapted from FAOSTAT (2021) [Colour figure can be viewed at wileyonlinelibrary.com]

Nguyen, Ancev, & Randall, 2019; Sen et al., 2021).[1] The descriptions of these methods are detailed in Appendix S1. Improved soil and water CP could be considered as a key adaptation strategy to minimise the adverse impact of growing water shortages and worsening soil conditions.

3 | CONCEPTUAL FRAMEWORK, EMPIRICAL MODEL AND ESTIMATION STRATEGY

In the context of developing countries, the decision-making of production units, such as agricultural households, is often modelled based on the concept of expected utility (Green et al., 1996). In particular, discrete choice models are based on a random utility framework (McFadden, 1981). This framework has been frequently used in studies on the adoption of agricultural practices in response to the impacts of climate-related changes (Deressa et al., 2009). To evaluate the impact of agricultural technology adoption, we followed Kassie et al. (2015) and Khonje et al. (2018) to quantify the level of impact on farming households. Indicators of farm performance were modelled using MESR with a two-stage process.

3.1 | Empirical model and estimation strategy

This study considered the adoption of climate-resilient practices and their effects on farm performance (rice yield, rice revenue and net household income) in a two-stage decision-making process. The first stage (adoption decision) and the second stage (impact on indicators of farm

[1]These soil and water conservation techniques were also introduced by FAO in published technical manuals. These manuals briefly present the theoretical background and benefits of these techniques and also discuss their application at the farm level.

performance) were modelled simultaneously using MESR, which has been widely applied in many previous empirical studies (Danso-Abbeam & Baiyegunhi, 2018; Kassie et al., 2015; Khonje et al., 2018; Martey, Etwire, & Abdoulaye, 2020; Martey, Etwire, & Kuwornu, 2020; Midingoyi et al., 2019). In Stage 1, a multinomial logit selection (MNLS) model was used to capture the multiple-choice outcomes of the data. Stage 2 evaluated the magnitude of the relationship between each adoption choice and its impact on farm performance indicators using ordinary least squares (OLS), with inverse Mills ratios (IMRs) as additional covariates to account for selection bias. We used the Stata command *mlogit* for Stage 1 and the user-written command *selmlog* for Stage 2 (Bourguignon et al., 2002).

Stage 1: Factors associated with the decision to adopt climate-resilient practices using the multinomial logit model

In the first stage, the decision to adopt multiple agricultural practices was modelled using the MNLS. The model is based on the notion that the i^{th} farmer faces m combinations of decisions: $j = 1$ nonadoption of soil and water CP and CI, jointly designated as CI_0CP_0; $j = 2$ adoption of CP practices only (CI_0CP_1); $j = 3$ adoption of CI only (CI_1CP_0); and $j = 4$ joint adoption of CP and CI (CI_1CP_1).

Assuming that a farmer decides to adopt a combination of agricultural technologies to maximise his/hers expected utility (I_{ji}^*), and following Kassie et al. (2015) and Khonje et al. (2018), we consider the latent response formulation of the observed decision of the farmer: $I_{ji}^* = Z'\beta + \varepsilon$, where the vector Z includes a set of explanatory variables (X) and instrumental variables (IV); and ε denotes the difference between the random errors (i.e. unobserved factors). This latent function states that if farmer i chooses a combination of practices j over any other combination m, then it can be assumed that the farmer perceives that choice as having a higher utility than the others.

Let (I) be an index denoting farmers' choices of the agricultural technologies under study. The utility associated with farmers' choices is unobservable, but adoption decisions (i.e. I) are revealed. Thus, the i^{th} farmer's decision to choose not to adopt any combination of agricultural practices ($I = 1$), or to adopt some combinations j, can be described by:

$$I = \begin{cases} 1 \ if\ I_{1i}^* > \max\limits_{m \neq 1}\left(I_{mi}^*\right) \\ j \ if\ I_{ji}^* > \max\limits_{m \neq J}\left(I_{mi}^*\right) \end{cases} \quad \vdots \text{ for all } m \neq j \tag{1}$$

The probability that farmer i chooses combination j in the MNLS is estimated using the Stata command *mlogit*. The IMRs for each agricultural practice are defined as $\widehat{IMR} = \phi\left(F\left(Z'\beta\right)\right)/\Phi\left(F\left(Z'\beta\right)\right)$, where ϕ is the probability density function, Φ is the cumulative distribution function, and β is a vector of the parameters. In applying this approach, the two-stage estimation is linked by incorporating the IMRs obtained from Stage 1 to Stage 2, enabling us to account for any correlation between the residuals of the two stages and, consequently, avoid biased estimation.

Stage 2: Impact of climate-resilient practice adoption on indicators of farm performance using the multinomial endogenous switching treatment regression (MESR) framework

In the second stage of the MESR, the relationship between the outcome variables indicating farm performance (rice yield, rice revenue and net household income) and a set of explanatory variables (X) was estimated for each technology choice set. We used nonadoption ($j = 1$) as the base category, and the other three choice sets included irrigation canals ($j = 2$), CP ($j = 3$) and joint adoption of CI and CP ($j = 4$). The outcome equation for each regime (j) is as follows:

$$\begin{cases} \text{Regime 1: } W_{1i} = X'_{1i}\beta_1 + \widehat{IMR}_{1i}\lambda_1 + \varepsilon_{1i} \text{ if } I = 1 \\ \text{Regime j: } W_{ji} = X'_{ji}\beta_j + \widehat{IMR}_{ji}\lambda_j + \varepsilon_{ji} \text{ if } I = j \end{cases} \; : j = 2, 3, 4 \tag{2}$$

where W_{ji} are the farm performance indicators of the i^{th} farmer in regime (j).

The same procedure was applied to estimate the adoption impacts of the three farm performance outcomes: rice yield, rice revenue and net household income. The full information maximum likelihood (FIML) estimation approach was used to estimate the selection and outcome equations simultaneously. The coefficients from the MESR model can be used to derive the average treatment effect on the treated (ATT) by comparing the expected values of the outcomes of participation and nonparticipation in actual and counterfactual scenarios. Using nonrandomised experimental data for impact assessment may lead to biased estimates because of unobserved heterogeneity and selection bias in the sample. In Section 3.3, we address these issues using the Mundlak (1978) approach and instrumental variables, which have been widely applied in other empirical studies (Kassie et al., 2015; Martey, Etwire, & Abdoulaye, 2020; Martey, Etwire, & Kuwornu, 2020; Midingoyi et al., 2019).

3.2 | Estimation of treatment effects

The MESR framework was used to estimate the ATT. To avoid biased treatment effects in observational studies, the ATT is frequently used to compare the expected farm performance indicators of adopters and nonadopters with the counterfactual hypothetical case in which adopters do not adopt and vice versa. The ATT for the actual and counterfactual hypothetical cases is defined as the difference between Equations (3) and (4):

Adopters with adoption (actually observed in the sample)

$$E\left(W_{ji} \middle| I = j, X, \widehat{IMR}\right) = X_{ji}\beta_j + \widehat{IMR}_{ji}\lambda_j \tag{3}$$

Adopters had they decided not to adopt (counterfactual expected outcomes of adopters)

$$E\left(W_{1i} \middle| I = j, X, \widehat{IMR}\right) = X_{ji}\beta_1 + \widehat{IMR}_{ji}\lambda_1 \tag{4}$$

After estimating the MESR (Equation 2), we predicted the expected values of the three farm performance outcomes for the actual (Equation 3) and counterfactual (Equation 4) scenarios. The ATT was calculated by subtracting these conditional expectations for adopters and nonadopters in actual and counterfactual scenarios, as specified by Kassie et al. (2015) and Khonje et al. (2018).

$$ATT = E\left(W_{ji} \middle| I = j, X, \widehat{IMR}\right) - E\left(W_{1i} \middle| I = j, X, \widehat{IMR}\right) = X_{ji}\left(\beta_j - \beta_1\right) + \widehat{IMR}_{ji}\left(\lambda_j - \lambda_1\right) \tag{5}$$

3.3 | Controlling for unobserved heterogeneity and sample selection bias

Assuming that unobserved heterogeneity ε_i (Equations 1 and 2) is independent of the explanatory variables could be problematic since some correlation may exist between the observable and unobservable characteristics of a farming household. Mundlak (1978) proposed an approach to relax this assumption by allowing for a correlation between ε_i and the vector of explanatory variables across all periods, called correlated random effect (CRE) estimation. In practice, the CRE procedure is performed by adding an extra set of explanatory variables to the model, containing the means for household *i* for all time-varying variables (Mundlak, 1978; Wooldridge, 2010). We applied Mundlak's CRE estimator by adding time-varying explanatory variables ($\overline{X}_{ji}$) to both stages to handle the problem of unobserved heterogeneity.

In the MNLS model in Stage 1, sample selection bias may arise because rice farmers may endogenously self-select into adoption or nonadoption groups. Di Falco et al. (2011) and Kassie et al. (2015) suggest including a set of instrumental variables in the MNLS model to control for selection bias. It is critical to select those variables in such a way that they affect adoption decisions but do not directly influence outcome variables such as rice yield, rice revenue and net household income. Considering this, we used the number of visits by extension agents and the distance to the main road as instrumental variables and added them to Stage 1. These two variables are commonly used in empirical studies of agricultural technology adoption (Kassie et al., 2015; Liang et al., 2021). Following Di Falco et al. (2011) and Kassie et al. (2015), we tested the validity of the instruments using a simple falsification test. If a variable is a valid selection instrument, it will influence the adoption decision but not the outcome variables of interest among nonadopting farm households. The test results for the joint significance of the instrumental variables in Table 3 (Wald test) and Table 4 (*F*-test) show that the selected instrumental variables may be considered as valid selection instruments.

3.4 | Nonparametric regression analysis

We first applied nonparametric local polynomial regression to generalise the overall relationship between the outcome variables and adoption decisions. In the context of this study, this method was used to examine whether the adoption of a particular combination of climate-resilient practices is associated with better outcomes (i.e. the three farm performance indicators) for farmers. One way to interpret the results of nonparametric local polynomial regression is to compare the areas under the cumulative probability curves for the adopted combination and the alternative (Kassie et al., 2015; Khonje et al., 2018). Graphically, the adopted combination is dominant in the analysis if the area under its cumulative probability curve is smaller at every outcome level than the area under the curve of the alternative. The nonparametric analysis is often used as a way to obtain a ‘first look’ at any potential impact without any assumptions about the population distribution (Krzywinski & Altman, 2014). This can provide a preliminary understanding of the impact of adopting climate-resilient practices on farm performance, which will be further explored using more advanced statistical techniques such as the MESR framework.

4 | STUDY SITES AND DATA

This study exploited a rich longitudinal dataset from a nationally representative sample of households from 12 provinces across various agro-ecological regions of Vietnam (Figure 2). A panel dataset was created by combining data from two rounds of the Vietnam Access to Resources Household Survey (VARHS 2014, 2016). The sample attrition rate was fairly low, at approximately 1.5%. The balanced panel includes 2666 households, but due to missing values of climate-resilient variables of interest, the final sample with 1879 observations was used for further analysis. The sample of VARHS households largely resembles the Vietnam Household Living Standards Survey; therefore, it can be seen as a nationally representative dataset. The sample was selected based on a three-stage sampling strategy to represent the various

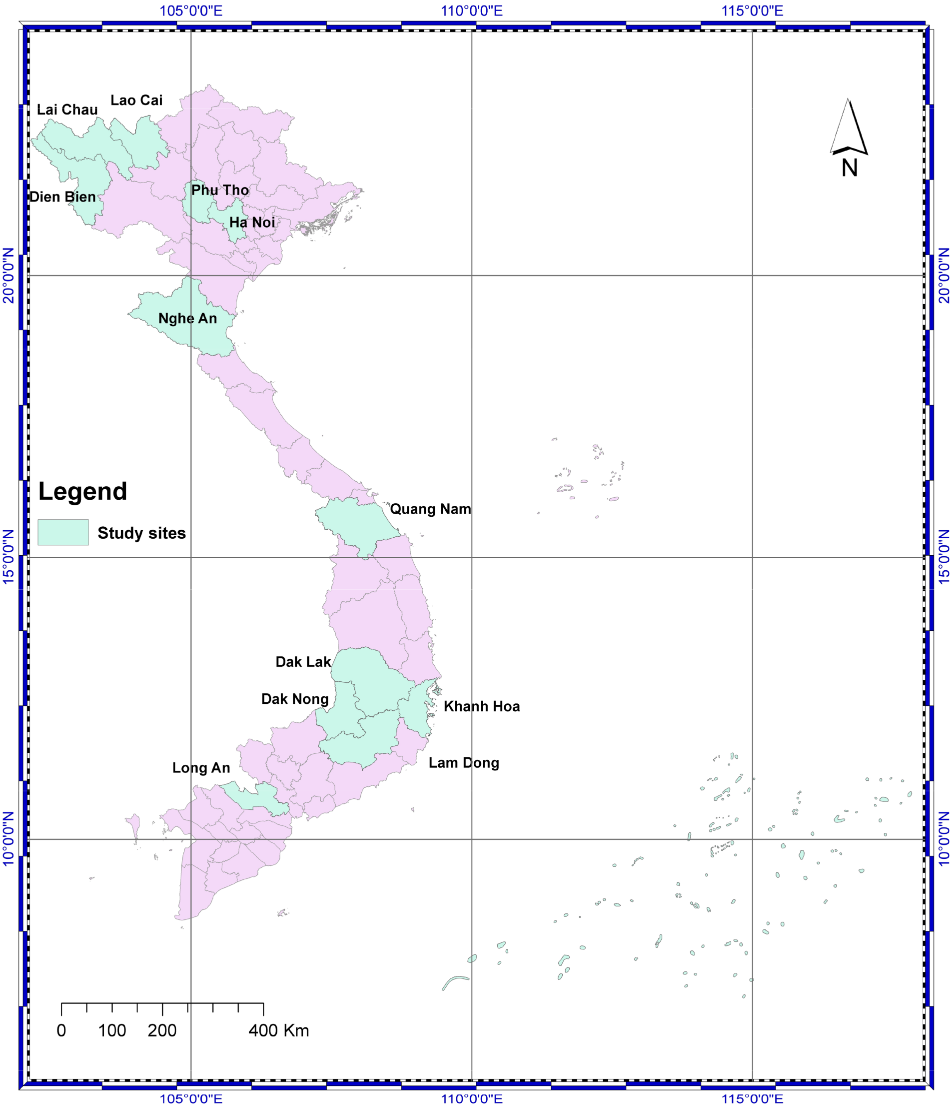

FIGURE 2 Study area indicating the data collection sites in Vietnam [Colour figure can be viewed at wileyonlinelibrary.com]

geographic regions of Vietnam. All surveys collected information on household and farm-level characteristics, agricultural production, coping strategies with risks, nonfarm employment, expenditure, assets, savings and credit. Outcome variables included rice yield (tonne/ha), rice revenue (Million VND/ha) and net household income (Million VND/capita). Net household income is the sum of the net income of each household member from different sources (e.g. farming, livestock, wages, salaries, investment returns and remittances) after taxes and mandatory contributions. To calculate the real values, data on rice revenue, net household income and input and output prices were collected in parallel with household surveys and deflated using the Consumer Price Index published by the Vietnam General Statistics Office.

Climatic conditions across regions of Vietnam have changed considerably in terms of climate patterns and the frequency and intensity of extreme events such as floods, typhoons and droughts (Nguyen, Ancev, & Randall, 2019; Nguyen, Renaud, & Sebesvari, 2019). Consequently, by observing and reacting to these changes, farmers might adopt certain types of agricultural practices to mitigate the adverse impacts of climate risks. We used farmers' perceptions of the observed climate change as an explanatory variable in this study. Their subjective evaluation of climate conditions (on a scale of 1–3 from better to worse) and experience of extreme weather events (yes = 1) are key variables representing a farmer's view and could lead to behavioural changes in their technology adoption (Issahaku & Abdulai, 2020). This is consistent with the way in which the relevant questions were specified in the survey questionnaires: '*During the last three years, how has the weather for agriculture been in general*? ' and '*Since [date], did the household suffer from an unexpected loss from any of the following shocks?*'. This question was followed by a long list of weather-related events such as floods, droughts, typhoons and other natural disasters as presented in Section 9B of the questionnaire.

Among the other factors that influence the uptake of agricultural practices, farm labour availability is a key factor. Doss (2006) points out that households must rely on their labour force for agricultural activities where the labour market does not function effectively, particularly in developing countries. Hence, we included household labour size as an explanatory variable for climate-resilient adoption decisions on farm. Other variables representing the features of households (household head farming experience, gender, and educational level) that are commonly used in adoption studies were also used in this study (Cazzuffi et al., 2020; Tivet & Boulakia, 2017).

In addition to household characteristics, previous studies on technology use have considered the biophysical features of farms. Generally, the overall impact of farm size on technological change is inconclusive (Piya et al., 2013). Maddison (2007) and Van-Phan and O'Brien (2022) point out that landholding size positively influences technology adoption decisions, whereas Piya et al. (2013) find a negative relationship between agricultural technology adoption and farm size. Additionally, land ownership has been considered in several empirical studies. However, Feder et al. (1985) state that there are conflicting empirical results regarding the relationship between tenure and the decision to apply improved agricultural technologies. Here, we use farm size and tenure as the explanatory variables. We also used the number of plots, soil quality and soil slope to better express the nature of the farm in which the climate-resilient practices took place. Furthermore, Vietnamese farmers use livestock manure as the primary source of nutrients in their fields, particularly for conservation purposes. Thus, we expect that farms with livestock production may have a greater tendency to adopt climate-resilient practices.

Market characteristics such as price and market access may influence changes in agricultural technology. Just and Zilberman (1984) show that uncertainty around input and output prices is likely to affect adoption decisions. Therefore, we used the average farm-gate rice price as an explanatory variable to model price expectations.

Table 1 presents descriptive statistics of the variables used in this study. The adoption of the two most popular climate-resilient practices, CI and soil and water conservation, led to four possible combinations of practices that farmers could choose (Table 2).

Of the balanced panel of 1879 rice-cultivating households, 15.3% did not use climate-resilient practices (CI_0CP_0). Approximately 60.5% of households adopted both practices (CI_1CP_1) simultaneously. The rates of adoption of a single practice remain relatively low, at 11.2% and 12.8% for CI and conservation agriculture, respectively. This provides further evidence for the importance of emphasising the significance of the joint adoption of multiple adaptation practices.

5 | EMPIRICAL RESULTS AND DISCUSSION

5.1 | Determinants of adoption of climate-resilient practices: First-stage MESR model

The probability of a farmer choosing single or multiple agricultural practices was estimated using a multinomial logit model with nonadoption as the base category. The results are presented in Table 3. The coefficients and marginal effects were estimated, but we report only

TABLE 1 Summary statistics

	2014		2016		Full sample	
Variables	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Outcome variables						
Rice yield (tonne/ha)	5.71	2.73	4.64	2.85	5.13	2.85
Rice revenue (Mill.VND/ha)	37.8	17.9	30.5	18.0	33.8	18.4
Net household income (Mill.VND/capita)	19.3	23.2	23.6	20.8	21.6	22.0
Treatment variables						
Adopted canal irrigation (yes = 1)	0.70	0.45	0.72	0.44	0.71	0.45
Adopted conservation agriculture practices (yes = 1)	0.78	0.40	0.68	0.46	0.73	0.44
Explanatory variables						
Household and farm characteristics						
Household labour size (persons)	4.58	1.72	4.42	1.73	4.49	1.73
Experience of household head (years)	16.4	6.85	19.0	5.58	17.8	6.32
Education of household head (years)	8.72	3.01	8.81	2.83	8.77	2.92
Gender of household head (1 = Male)	0.85	0.35	0.84	0.36	0.84	0.35
Farm size (ha)	0.48	0.68	0.75	1.25	0.63	1.04
Number of plots (plots)	3.34	2.14	3.07	2.01	3.19	2.08
Number of plots with tenure (plots)	5.55	2.57	5.04	2.42	5.27	2.50
Soil quality (from worst to best 1–4)	1.96	0.33	1.97	0.32	1.96	0.33
Soil slope (from lowest to highest 1–4)	1.41	0.67	1.35	0.63	1.38	0.65
Have livestock (yes = 1)	0.19	0.39	0.25	0.43	0.22	0.41
Input and output information						
Gate price of rice (1000VND/kg)	6.57	0.68	6.46	0.71	6.51	0.70
Extreme events, climate variability and change						
Climate conditions (from better to worse 1–3)	2.06	0.28	2.07	0.29	2.07	0.29
Extreme weather events (yes = 1)	0.46	0.50	0.11	0.31	0.17	0.38
Instrumental variables						
Distance to main road (km)	1.66	3.20	1.34	2.56	1.49	2.87
Number of extension officer visits (times/year)	0.31	1.03	0.30	0.80	0.31	0.91

Abbreviations: SD, Standard deviation; VND, Vietnamese Dong (approximately 21,015 VND/$U.S. averaged over 2014 to 2016).

the average marginal effects here because it is more straightforward to interpret the results. In general, we observe significant differences in the average marginal effects across technology choices.

There is statistically significant evidence of the effect of household characteristics on climate-resilient agricultural practices used by rice farmers. Unsurprisingly, farmers with a

TABLE 2 Combinations of adoption of climate-resilient practices

Technology choice	Combinations	Frequency (%)		
		2014 ($n = 854$)	2016 ($n = 1025$)	Full sample ($n = 1879$)
1	CI_0CP_0	16.1	14.6	15.3
2	CI_1CP_0	5.04	16.3	11.2
3	CI_0CP_1	13.1	12.6	12.8
4	CI_1CP_1	65.6	56.2	60.5

Note: CI_0CP_0, nonadopters; CI_1CP_0, adopted canal irrigation only; CI_0CP_1, adopted conservation agriculture only; CI_1CP_1, jointly adopted canal irrigation and conservation agriculture.

higher level of education showed a higher probability of adoption, especially conservation practices (CI_0CP_1) and joint adoption (CI_1CP_1). We confirmed the role of education in the adoption of practices, whereby farmers with a higher level of education tend to better understand the costs and benefits associated with a particular practice. Especially for joint adoption, an additional year of education of the household head increases the probability of jointly adopting both practices by 12.6%. Similar findings have been reported by Issahaku and Abdulai (2020). However, the role of household labour size in the agricultural practices adopted by farmers was insignificant for all combinations. We usually hypothesise that larger households that can commit plenty of manual labour to agricultural activities are associated with a significantly higher probability of applying agricultural practices, but our estimated results do not support this.

Farmers with smaller farm sizes, more defragmented farmlands and more secure land ownership are generally more likely to jointly adopt these practices. The results also showed that the adoption of canal irrigation (CI_1CP_0) and conservation agriculture only (CI_0CP_1) was positively related to larger farm size. This is in line with findings reported in the literature (Kassie et al., 2015; Martey, Etwire, & Abdoulaye, 2020; Martey, Etwire, & Kuwornu, 2020), and it is due to these adaptation practices often requiring substantial inputs, such as materials and labour, and can therefore be quite costly for farmers. Besides the initial investment, farmers also need to decide whether to continue using the practices by investing in annual maintenance costs. Investments with long-run expected returns often require long-term commitments based on favourable farming conditions, such as suitable agricultural land for farming activities. This point is further confirmed by the variables representing soil conditions: better soil quality and flat slopes are more likely to be associated with farmers' joint adoption decisions regarding climate-resilient practices. A farm with better land quality and a flat slope increases the probability of jointly adopting the two practices by 15.4% and 16.1%, respectively.

Output price expectations are strongly associated with the adoption and diffusion of agricultural technologies. Statistically significant evidence of a positive relationship between the higher farm-gate price of rice and the decision to adopt agricultural practices was found for canal irrigation (CI_1CP_0) and conservation agriculture (CI_0CP_1). Our findings confirm the positive relationship between farm-gate prices and the level of agricultural technologies used by farmers in many previous studies (Bezu et al., 2014). We also found evidence of the effect of climate-related variables, such as extreme weather events and farmers' perception of changing climatic conditions, on the adoption of climate-resilient technologies. There was a statistically significant correlation between joint adoption (CI_1CP_1) and the probability of farmers reporting that they experienced extreme events in previous years. Moreover, a farmer's perception of worsening climatic conditions is significantly positively correlated with the decision to adopt resilient technologies, such as conservation agriculture (CI_0CP_1),

TABLE 3 Marginal effects of factors associated with the adoption of climate-resilient practices

Variables	CI_1CP_0	CI_0CP_1	CI_1CP_1
Household labour size	0.001	−0.073	0.047
	(0.034)	(0.056)	(0.071)
Experience of household head	0.001	−0.038	0.018
	(0.034)	(0.037)	(0.035)
Education of household head	−0.055	0.063**	0.126*
	(0.048)	(0.024)	(0.057)
Gender of household head	0.031	0.004	−0.009
	(0.026)	(0.026)	(0.043)
Farm size	0.012	0.046***	−0.070***
	(0.016)	(0.017)	(0.021)
Number of plots	0.020	−0.091***	0.128***
	(0.029)	(0.030)	(0.026)
Number of plots with tenure	0.046	0.206***	0.373***
	(0.064)	(0.073)	(0.066)
Soil quality	−0.037**	−0.061**	0.154***
	(0.016)	(0.027)	(0.027)
Soil slope	−0.015	0.065***	−0.161***
	(0.016)	(0.009)	(0.023)
Have livestock	−0.030	0.041	0.010
	(0.024)	(0.039)	(0.033)
Gate price of rice	0.035*	0.044*	0.033
	(0.020)	(0.026)	(0.044)
Climate conditions	−0.009	0.030***	−0.016
	(0.032)	(0.012)	(0.038)
Extreme weather events	−0.027	0.014	0.107***
	(0.019)	(0.049)	(0.043)
Number of extension officer visits (times/year)	−0.027	−0.017	0.043**
	(0.019)	(0.016)	(0.020)
Distance to main road (km)	0.015	−0.005	−0.039***
	(0.010)	(0.008)	(0.012)
Joint significance of instrumental variables: $\chi2$ (6)		52.77***	
Year dummy	Yes		
Location dummy	Yes		
Within-household means	Yes		

Note: CI_0CP_0, nonadopters (base); CI_1CP_0, adopted canal irrigation only; CI_0CP_1, adopted conservation agriculture only; CI_1CP_1, jointly adopted canal irrigation and conservation agriculture. Coefficients and *p*-values obtained by *margins* command in Stata; clustered standard errors in parentheses; *, **, *** significant at the 10%, 5% and 1% levels, respectively; estimated results of year dummy, location dummy and within-household mean variables in Appendix S2.

because they may be able to understand the benefits of maintaining soil moisture and controlling soil erosion (Arslan et al., 2014). As Vietnam has experienced an increasingly changing climate, fostering the adoption of climate-resilient practices is the primary way to cope better with emerging challenges.

TABLE 4 Determinants of log rice yield, rice revenue and net household income by climate-resilient practices: second-stage MESR estimation

	Rice yield			Rice revenue			Net household income		
Variables	CI_1CP_0	CI_0CP_1	CI_1CP_1	CI_1CP_0	CI_0CP_1	CI_1CP_1	CI_1CP_0	CI_0CP_1	CI_1CP_1
Household labour size	0.143	0.393	0.058	0.133	0.390	0.058	−0.429	0.286	0.211
	(0.265)	(0.311)	(0.130)	(0.272)	(0.321)	(0.126)	(0.367)	(0.345)	(0.164)
Experience of household head	−0.218	0.031	−0.062	−0.217	0.033	−0.061	0.087	−0.018	0.121*
	(0.207)	(0.206)	(0.062)	(0.202)	(0.203)	(0.064)	(0.210)	(0.217)	(0.091)
Education of household head	0.018	−0.005	0.289*	0.017	−0.006	0.281*	0.309	0.073	0.192
	(0.261)	(0.172)	(0.166)	(0.242)	(0.167)	(0.165)	(0.289)	(0.151)	(0.178)
Gender of household head	−0.219*	−0.097	0.030	−0.217*	−0.099	0.031	−0.181	−0.343*	−0.051
	(0.129)	(0.195)	(0.056)	(0.125)	(0.193)	(0.058)	(0.208)	(0.196)	(0.080)
Farm size	0.342***	0.449***	0.393***	0.658***	0.551***	0.607***	0.137	0.069	0.039
	(0.132)	(0.132)	(0.057)	(0.125)	(0.138)	(0.060)	(0.162)	(0.150)	(0.065)
Number of plots	0.232	0.263	0.353***	0.230	0.261	0.323***	−0.823**	−0.514**	0.009
	(0.280)	(0.222)	(0.121)	(0.290)	(0.228)	(0.115)	(0.384)	(0.224)	(0.141)
Number of plots with tenure	−0.365	−0.305	−0.078	−0.385	−0.345	−0.088	0.658	1.129*	−0.066
	(0.438)	(0.582)	(0.193)	(0.441)	(0.584)	(0.189)	(0.611)	(0.636)	(0.226)
Soil quality	0.092	0.348**	0.121*	0.072	0.361**	0.122*	0.379*	0.098	0.057
	(0.205)	(0.163)	(0.075)	(0.201)	(0.161)	(0.075)	(0.233)	(0.170)	(0.097)
Soil slope	0.344*	0.012	0.073	0.345*	0.014	0.093	0.018	−0.082	−0.010
	(0.215)	(0.137)	(0.103)	(0.220)	(0.137)	(0.102)	(0.255)	(0.157)	(0.115)
Have livestock	−0.224*	0.195	−0.012	−0.225*	0.185	−0.012	−0.082	−0.324*	−0.157**
	(0.121)	(0.177)	(0.052)	(0.117)	(0.192)	(0.055)	(0.171)	(0.203)	(0.072)
Gate price of rice	−0.150	−0.267**	−0.097	0.850***	0.733***	0.903***	0.098	−0.145	0.075
	(0.141)	(0.116)	(0.076)	(0.139)	(0.123)	(0.072)	(0.172)	(0.131)	(0.083)

(Continues)

TABLE 4 (Continued)

Variables	Rice yield			Rice revenue			Net household income		
	CI_1CP_0	CI_0CP_1	CI_1CP_1	CI_1CP_0	CI_0CP_1	CI_1CP_1	CI_1CP_0	CI_0CP_1	CI_1CP_1
Climate conditions	0.109	0.156	0.003	0.107	0.159	0.003	−0.159	−0.077	−0.201**
	(0.175)	(0.133)	(0.065)	(0.183)	(0.132)	(0.067)	(0.244)	(0.188)	(0.095)
Extreme weather events	−0.321*	−0.323***	−0.179***	−0.320*	−0.328***	−0.176***	−0.221	0.057	0.052
	(0.143)	(0.393)	(0.058)_	(0.168)	(0.120)	(0.060)	(0.273)	(0.140)	(0.078)
Joint significance of instruments	$F(2, 146) = 1.11$	$F(2, 173) = 0.88$	$F(2, 775) = 1.67$	$F(2, 146) = 1.01$	$F(2, 173) = 1.88$	$F(2, 775) = 1.60$	$F(2, 146) = 0.90$	$F(2, 174) = 0.94$	$F(2, 774) = 0.31$
λ_1	1.276 (0.62)*	0.152 (0.55)	0.167 (0.52)	1.276 (0.65)	0.152 (0.54)	0.167 (0.51)	1.148 (0.59)	0.726 (0.45)	0.228 (0.49)
λ_2		0.422 (0.71)	−0.814 (0.34)		0.422 (0.72)	−0.814 (0.34)**		−0.562 (0.62)	−0.901 (0.30)***
λ_3	−0.795 (0.76)		0.693 (0.66)	−0.795 (0.73)		0.693 (0.65)	−0.716 (0.69)		0.687 (0.60)
λ_4	−0.203 (0.57)	−0.548 (0.53)		−0.203 (0.55)	−0.548 (0.52)		−0.183 (0.55)	−0.122 (0.51)	

Note: CI_0CP_0 is the reference category; bootstrapped standard errors in parentheses; *, **, *** significant at the 10%, 5% and 1% levels.

5.2 | Determinants of farm performance indicators: Second-stage MESR model

Table 4 presents estimated results of the second-stage MESR model, accounting for sample selectivity effects.

The results show that farm characteristics, prices and weather events are the main factors influencing indicators of farm performance. Farm size had a significant effect on rice yield and revenue, but not on net household income. However, it is important to note that the surveyed households in the VARHS have diverse sources of income, including crop cultivation, livestock, other nonfarm activities, regular wages and salaries, casual wages, nonfarm businesses and remittances, which may affect the role of rice production in overall household income.

As expected, the estimated coefficients of soil quality had a positive and significant effect on all the three outcome variables. Extreme weather events, such as floods and droughts, have a negative and significant impact on rice yield and revenue but not on net household income. Thus, promoting the adoption of climate-resilient practices can help mitigate the negative effects of extreme weather events and improve the resilience of agricultural systems to climate change.

5.3 | Impact of adopting climate-resilient practices on farm performance indicators

5.3.1 | Nonparametric analysis using kernel density estimation

We provide visual comparisons of the likely impacts of different climate-resilient adoption decisions using kernel density estimation. This is a nonparametric method for estimating the probability density function of a variable of interest, such as the outcome variables in this study. The results are shown in Figures 3, 4 and 5.

Comparing the indicators of farm performance (rice yield, rice revenue and net household income) between adopters and nonadopters, we find that their unconditional distributions are concentrated on the far-right side. These results indicate the presence of positive impacts on farm performance of adoption compared with nonadoption (Figures 3, 4 and 5). While this offers initial evidence of the impact of technology adoption, more rigorous analyses are needed to further confirm this evidence. In order to accurately assess the impact of adopting climate-resilient practices on farm performance, we estimated the treatment effects using the MESR framework in the following section.

5.3.2 | Estimating treatment effects using multinomial endogenous switching regression

Table 5 presents the results of the treatment effects of adopting multiple agricultural practices on the outcome variables using MESR, accounting for the selection bias originating from observed and unobserved factors. We compared three outcomes (rice yield, rice revenue and net household income) between adopters and nonadopters in various settings. Here, we report the unconditional ATT of adoption on outcome variables derived from actual and counterfactual distributions. The results for other settings are presented in Appendix S3.

5.3.3 | Yield effects of adopting climate-resilient practices

Table 5 shows that the adoption of all combinations of climate-resilient practices has a positive impact on rice yield (log), indicating that farmers who adopted those practices would

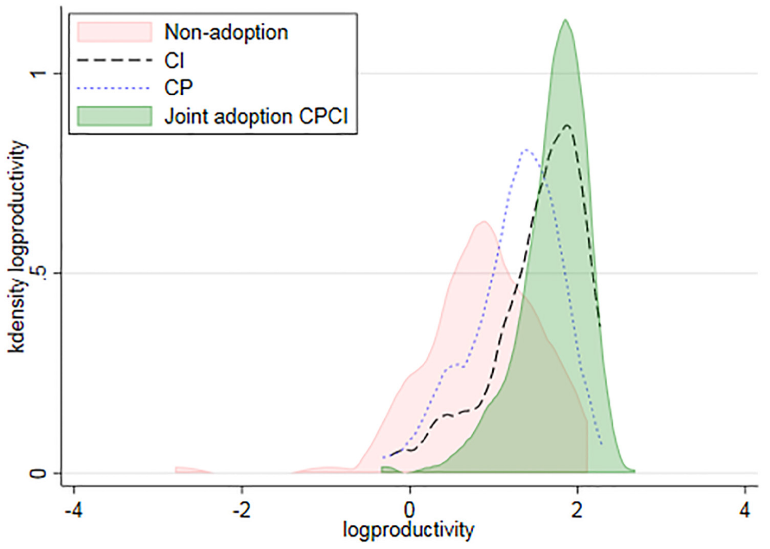

FIGURE 3 Unconditional log(rice yield) kernel density distributions [Colour figure can be viewed at wileyonlinelibrary.com]

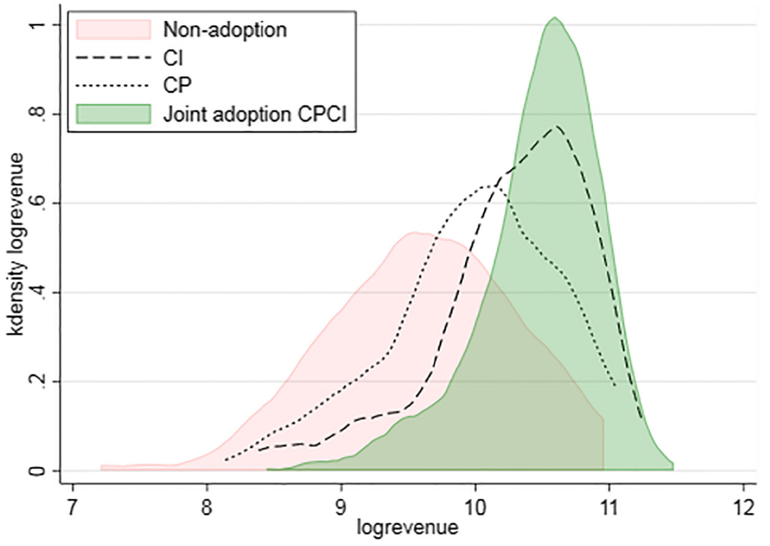

FIGURE 4 Unconditional log(rice revenue) kernel density distributions [Colour figure can be viewed at wileyonlinelibrary.com]

have obtained higher yields than nonadopters. Specifically, farmers adopting canal irrigation only (CI_1CP_0) and jointly adopting canal irrigation and conservation agriculture (CI_1CP_1) have realised large yield gains, 16.67% and 11.36%, respectively, and the impacts are statistically significant. This emphasises the important role of irrigation in rice (Tivet & Boulakia, 2017). Besides improving crop yield, joint adoption shows complementary benefits of simultaneously maintaining soil moisture, controlling soil erosion and reducing nutrient losses. This estimated treatment effects on rice yield using MESR have confirmed the initial finding of kernel density estimation in Figure 3. Hence, for the case of smallholder farming households in Vietnam, this

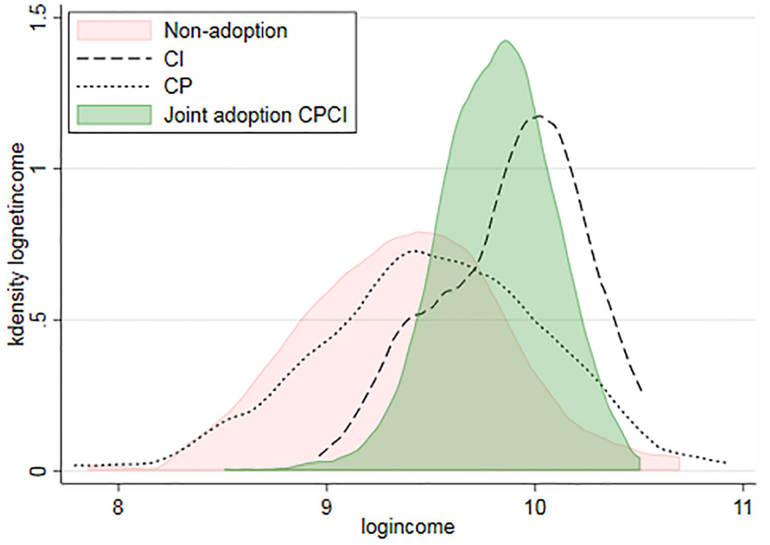

FIGURE 5 Unconditional log(net household income per capita) kernel density distributions [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 5 Estimated results of MESR-based unconditional average treatment effects of the adoption of climate-resilient practices on household welfare

Outcome variables	Combinations	Adoption status: Adopting (j = 2,3,4) (a)	Nonadopting (j = 1) (b)	ATT (c) = (a)-(b)	Change in outcome (%)
Rice yield (tonne/ha)	CI_1CP_0	1.40	1.20	0.201***	16.67
	CI_0CP_1	1.00	0.91	0.086***	9.41
	CI_1CP_1	1.47	1.32	0.150***	11.3
Rice revenue (Mill. VND/ha)	CI_1CP_0	2.49	2.29	0.201***	8.73
	CI_0CP_1	2.64	2.55	0.092***	3.53
	CI_1CP_1	2.35	2.24	0.110**	4.91
Net household income (Mill.VND/capita)	CI_1CP_0	2.93	2.80	0.128**	4.64
	CI_0CP_1	2.52	2.65	−0.130	−4.91
	CI_1CP_1	2.89	2.85	0.004*	1.40

Note: Estimated by user-written command selmlog (Bourguignon et al., 2007); t-test to compare means between groups; *, **, *** significant at the 10%, 5% and 1% levels. The other settings for the treatment effects are given in Appendix S3.

Abbreviations: CP, conservation agriculture; CI, canal irrigation; VND, Vietnamese Dong (approximately 21,015 VND/$U.S. averaged from 2014 to 2016) outcome variables in log form.

finding provides empirical evidence of the benefits of adopting climate-resilient practices on rice yield. This is important for policies aiming at promoting agricultural technologies to better cope with climatic uncertainty.

5.3.4 | Revenue effects of adopting climate-resilient practices

Rice farming remains the predominant source of income for many rural households in Vietnam. The estimated treatment effects of adopting climate-resilient practices on households' revenue from rice cultivation show that adoption was associated with increased revenue, notably higher for the adoption of CI only and for joint adoption. Similar to the yield effect, the adoption of canal irrigation CI_1CP_0 had the greatest impact (8.73% increase in rice revenue (log)), followed by joint adoption CI_1CP_1 (4.91%), and conservation agriculture only CI_0CP_1 (3.53%). Thus, increasing rice yields seems to be the main driver of rice revenue gain. Findings from MESR on rice revenue agree with the results of the nonparametric analysis in Figure 4, where the kernel density of rice revenue distributions for adoption combinations lies on the right compared with nonadoption, especially for CI_1CP_0 and CI_1CP_1.

5.3.5 | Income effects of adopting climate-resilient practices

The positive effects of adoption on rice yield and revenue are expected to improve the net household income (Figure 5). The estimated results using MESR for income effects in Table 5 imply that the adoption of CI_1CP_0 and joint adoption have a statistically significant impact on net household income. The combination of CI_1CP_0 and joint adoption is associated with 4.64% and 1.4% increases in per capita net household income (log), respectively. This further confirms the initial evidence of a positive relationship between technology adoption and household income from the nonparametric analysis using the kernel density estimation (Figure 5). Hence, the returns obtained from the adoption of climate-resilient technologies should encourage farmers to invest more in adaptation practices, which can help improve the resilience of their farming operations to the impacts of climate change. This is consistent with the findings of other studies such as Kassie et al. (2015), Khonje et al. (2018) and Nguyen, Renaud, & Sebesvari (2019), who examined the impact of climate-resilient practices on farm performance.

In general, it is evident that the adoption of multiple climate-resilient practices yields positive benefits for the performance indicators of rice-cultivating households in the study area. This confirms the critical role of agricultural advancements, not only in agricultural production but also in income generation towards poverty reduction in developing countries. In the context of smallholder farming households with budget constraints, such as those found in developing countries like Vietnam, follow-up policy interventions should continue to target agricultural innovation to improve overall well-being. It is important to note that although CI systems play a critical role in irrigated rice production, the joint adoption of multiple practices still shows significant effects. The profound benefits of irrigation in rice production have been widely acknowledged in the literature, particularly in Vietnam. However, the findings of this study also show that the joint adoption of multiple practices is a key farming strategy with statistically significant and positive impacts on the tested outcomes. Thus, promoting the joint adoption of multiple climate-resilient practices is going to be an important step towards improving rice-cultivating household welfare for poverty alleviation in the era of profoundly changing climatic conditions in Vietnam.

Furthermore, joint adoption is even more important in areas that experience severe soil degradation and insufficient water for irrigation. The joint adoption of technology combinations, such as improved irrigation systems and conservation agriculture, can lead to a range of co-benefits beyond technical, financial and economic profitability (Page et al., 2020). For the joint adoption of technology combinations in this study, improved irrigation systems can help maintain sufficient soil moisture during the production period, whereas conservation agriculture can contribute to increasing soil water storage and improving soil quality. This can help buffer farming activities against environmental challenges, such as extreme weather events, and improve the resilience of agricultural systems to the impacts of climate change (Corsi & Muminjanov, 2019).

5.4 | Robustness checks

To assess the robustness of the estimated models, we followed two strategies: re-estimating all models for three quantiles according to the distribution of plot numbers and estimating the multivalued treatment effects (MVTE) model. Appendix S4 presents the estimated results of the robustness checks. The first approach aimed at investigating the potential effects of land fragmentation on farming activities. There are concerns in the literature regarding the impact of a single farm operating in numerous spatially separated plots on crop yield and agricultural technology adoption (Orea et al., 2015; Zeng et al., 2017). Our findings support the observation that high levels of land fragmentation are associated with a significant loss of benefits (see Appendices S7 and S8). The second approach of using MVTE is commonly applied in the economics literature. This could be considered as a standard tool for estimating the treatment effects of the control and treated groups in studies in which any potential bias may exist.

We estimated and visually compared the means and quantiles of the potential distributions of outcome variables corresponding to each level of the treatment variable. In general, we observed very similar patterns in the impact of adopting multiple climate-resilient practices on outcomes compared with MESR, except for net household income (Appendix S5). These practices had positive effects on rice yield, rice revenue and net household income, especially in the case of CI only and joint adoption. For MVTE at different quantiles, Figure D2 in Appendix S4 shows the marginal differences in the parameters of each outcome variable distribution across treatment levels. The means, medians and three quantiles increased slightly and linearly over the treatment levels, except for treatment level 2, which indicated the adoption of CP only. In particular, the impact of the adoption of CP on household net income was quite limited, as confirmed by the estimated results from MESR (Table 5) and MVTE (Appendix S5). Although the estimated results of MVTE were generally consistent with those of MESR, the impact of the adoption of climate-resilient practices on net household income was not statistically significant. According to Issahaku and Abdulai (2020), one possible reason is that while MESR estimates the ATT, MVTE only estimates the average treatment effect of the population (ATE).

Overall, our robustness checks provide strong evidence for the positive impact of adopting climate-resilient practices on farming households. These findings are going to inform future policies to promote agricultural advancements in the light of climate change in developing countries such as Vietnam.

6 | CONCLUSION AND POLICY IMPLICATIONS

This study identified factors that are likely to be associated with the adoption of climate-resilient practices in rice-cultivating households across Vietnam. Using a rich longitudinal dataset, the decisions to adopt and their impacts on three variables that indicate farm performance (rice yield, rice revenue and net household income) were analysed in a MESR framework, controlling for both observable and unobservable factors that may affect the decision-making process.

There were clear and persistent patterns in the impact of adoption practices on farming households. In general, adoption substantially increases rice yield, rice revenue and net household income compared with nonadoption. Farmers with access to CI systems obtained the highest returns, followed by joint adoption of CP and CI and adoption of conservation agriculture. The profound benefit of irrigation in rice production has been widely acknowledged in the literature; however, the findings of this study also show that the joint adoption of multiple technologies is a key farming strategy for coping with climate change. In an era of significant environmental challenges, such as climate change, the multiple benefits associated with jointly adopting multiple climate-resilient practices could be of great help to farmers.

In recent decades, Vietnamese farmers have operated under a continuously transforming policy environment. Such policy transitions have significantly shaped the agricultural sector, increased yields and enhanced rural producer income. The findings of this study provide strong empirical evidence for the positive impact of adopting climate-resilient practices on farming households. Follow-up policies should promote the joint adoption of climate-resilient technologies to improve rice farmers' well-being and enhance their capacity to cope with the ongoing climate uncertainty.

There are important avenues for further research on the co-benefits of adopting multiple climate-resilient practices jointly. The joint adoption of multiple climate-resilient practices, such as irrigation and CP, produces substantial co-benefits (e.g. simultaneously increasing soil water storage, increasing crop yield and income, reducing water use, enhancing resilience and reducing greenhouse gas emissions) that encourage farmers to adopt. However, owing to data limitations (e.g. incomplete data on co-benefits), quantifying some of these benefits is beyond the scope of this study. Additionally, we used a relatively short-duration dataset with few study sites to address an inherently dynamic issue that requires longer panel data analysis at the household or plot levels. As more data become available in future, further analyses will be performed based on the approach presented here to better understand the dynamic nature of behavioural change in adopting agricultural practices conducive to adaptation to climate change. Filling these gaps could significantly improve our understanding of the factors that drive farmers' decisions to adopt climate-resilient practices individually or as a package and how this contributes to improving their overall well-being.

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DATA AVAILABILITY STATEMENT

The data and code for this study are available on request.

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REFERENCES

Alemayehu, A. & Bewket, W. (2017) Smallholder farmers' coping and adaptation strategies to climate change and variability in the central highlands of Ethiopia. *Local Environment*, 22, 825–839.

Arslan, A., McCarthy, N., Lipper, L., Asfaw, S. & Cattaneo, A. (2014) Adoption and intensity of adoption of conservation farming practices in Zambia. *Agriculture, Ecosystems & Environment*, 187, 72–86.

Bezu, S., Kassie, G.T., Shiferaw, B. & Ricker-Gilbert, J. (2014) Impact of improved maize adoption on welfare of farm households in Malawi: a panel data analysis. *World Development*, 59, 120–131.

Bourguignon, F., Fournier, M. & Gurgand, M. (2002) SELMLOG: Stata module to perform selection bias correction based on the multinomial logit model.

Bourguignon, F., Fournier, M. & Gurgand, M. (2007) Selection bias corrections based on the multinomial logit model: Monte-Carlo comparisons. *Journal of Economic Surveys*, 21, 174–205.

Cazzuffi, C., McKay, A. & Perge, E. (2020) The impact of agricultural commercialisation on household welfare in rural Vietnam. *Food Policy*, 94, 101811.

Corsi, S. & Muminjanov, H. (2019) *Conservation agriculture: training guide for extension agents and farmers in Eastern Europe and Central Asia*. Rome: FAO.

Danso-Abbeam, G. & Baiyegunhi, L.J.S. (2018) Welfare impact of pesticides management practices among smallholder cocoa farmers in Ghana. *Technology in Society*, 54, 10–19.

Deressa, T.T., Hassan, R.M., Ringler, C., Alemu, T. & Yesuf, M. (2009) Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. *Global Environmental Change*, 19, 248–255.

Di Falco, S., Veronesi, M. & Yesuf, M. (2011) Does adaptation to climate change provide food security? A microperspective from Ethiopia. *American Journal of Agricultural Economics*, 93(3), 829–846.

Doss, C.R. (2006) Analyzing technology adoption using microstudies: limitations, challenges, and opportunities for improvement. *Agricultural Economics*, 34, 207–219.

FAOSTAT. (2021) Food and Agriculture Organization of the United. Available from: http://www.fao.org/faostat [Accessed 12th January 2021].

Feder, G., Just, R. & Zilberman, E.D. (1985) Adoption of agricultural innovations in developing countries: a survey. *Economic Development and Cultural Change*, 33, 255–298.

Fentie, A. & Beyene, A.D. (2019) Climate-smart agricultural practices and welfare of rural smallholders in Ethiopia: does planting method matter? *Land Use Policy*, 85, 387–396.

Green, G., Sunding, D., Zilberman, D. & Parker, D. (1996) Explaining irrigation technology choices: a microparameter approach. *American Journal of Agricultural Economics*, 78, 1064–1072.

GSO. (2021) *Vietnam statiscal yearbook 2021. General Statistics Office*. Hanoi: Statistical Publishing House.

Ha, V.H., Mizunoya, T., Kien, N.D., Dung, T.Q., An, L.T., Phan, N.T. et al. (2022) Post-flood recovery in the central coastal plain of Vietnam: determinants and policy implications. *Asia-Pacific Journal of Regional Science*, 6, 899–929.

Ho, T.D.N., Kuwornu, J.K.M., Tsusaka, T.W., Nguyen, L.T. & Datta, A. (2021) An assessment of the smallholder rice farming households' vulnerability to climate change and variability in the Mekong delta region of Vietnam. *Local Environment*, 26, 948–966.

Hoang, H.G. (2020) Exploring Vietnamese cereal smallholders' perceptions and adaptations to temperature and precipitation variability: implications for adaptation strategies. *Local Environment*, 25, 597–611.

IPCC. (2007) *Climate change 2007: impacts, adaptation and vulnerability. Intergovernmental Panel on Climate Change*. New York, NY: Cambridge University Press.

Issahaku, G. & Abdulai, A. (2020) Adoption of climate-smart practices and its impact on farm performance and risk exposure among smallholder farmers in Ghana. *Australian Journal of Agricultural and Resource Economics*, 64, 396–420.

Just, R.E., & Zilberman, D. (1984) Equility implication of agricultural policies. Working paper - Giannini Foundation of Agricultural Economics, California Agricultural Experiment Station (USA).

Kassie, M., Teklewold, H., Marenya, P., Jaleta, M. & Erenstein, O. (2015) Production risks and food security under alternative technology choices in Malawi: application of a multinomial endogenous switching regression. *Journal of Agricultural Economics*, 66(3), 640–659.

Khonje, M.G., Manda, J., Mkandawire, P., Tufa, A.H. & Alene, A.D. (2018) Adoption and welfare impacts of multiple agricultural technologies: evidence from eastern Zambia. *Agricultural Economics*, 49, 599–609.

Krzywinski, M. & Altman, N. (2014) Non-parametric tests. *Nature Methods*, 11, 467–468.

Liang, Z., Zhang, L., Li, W., Zhang, J. & Frewer, L.J. (2021) Adoption of combinations of adaptive and mitigatory climate-smart agricultural practices and its impacts on rice yield and income: empirical evidence from Hubei, China. *Climate Risk Management*, 32, 100314.

Maddison, D. (2007) The perception of adaptation to climate change in Africa. World Bank Policy Research Working Paper No. 4308. Available from: http://ssrn.com/abstract=1005547

Marsh, S.P., MacAulay, T.G. & Hung, P. (2006) *Agricultural development and land policy in Vietnam*. Canberra, Australia: Australian Centre for International Agricultural Research.

Martey, E., Etwire, P.M. & Abdoulaye, T. (2020) Welfare impacts of climate-smart agriculture in Ghana: does row planting and drought-tolerant maize varieties matter? *Land Use Policy*, 95(February), 104622.

Martey, E., Etwire, P.M. & Kuwornu, J.K.M. (2020) Economic impacts of smallholder farmers' adoption of drought-tolerant maize varieties. *Land Use Policy*, 94, 104524.

Martey, E., Etwire, P.M. & Mockshell, J. (2021) Climate-smart cowpea adoption and welfare effects of comprehensive agricultural training programs. *Technology in Society*, 64, 101468.

McFadden, D. (1981) Econometric models of probabilistic choice. Structural analysis of discrete data with econometric applications, 198272.

Midingoyi, S.G., Kassie, M., Muriithi, B., Diiro, G. & Ekesi, S. (2019) Do farmers and the environment benefit from adopting integrated Pest management practices? Evidence from Kenya. *Journal of Agricultural Economics*, 70(2), 452–470.

Mundlak, Y. (1978) On the pooling of time series and cross section data. *Econometrica: Journal of the Econometric Society*, 46, 69–85.

Nguyen, D.K., Ancev, T. & Randall, A. (2019) Evidence of climatic change in Vietnam: some implications for agricultural production. *Journal of Environmental Management*, 231, 524–545.

Nguyen, D.K., Ancev, T. & Randall, A. (2021) Farmers' choices of climate-resilient strategies: evidence from Vietnam. *Journal of Cleaner Production*, 317, 128399.

Nguyen, M.T., Renaud, F.G. & Sebesvari, Z. (2019) Drivers of change and adaptation pathways of agricultural systems facing increased salinity intrusion in coastal areas of the Mekong and Red River deltas in Vietnam. *Environmental Science & Policy*, 92, 331–348.

Nguyen, D.Q., Renwichk, J. & McGregor, J. (2013). Variations of surface temperature and rainfall in Vietnam from 1971 to 2010, *International Journal of Climatology*, 34, 249–264.

OECD (2015) Agricultural policies in Viet Nam. In: OECD (Ed.) *OECD food and agricultural reviews*. Paris: OECD publishing.

Ogundari, K. & Bolarinwa, O.D. (2018) Impact of agricultural innovation adoption: a meta-analysis. *Australian Journal of Agricultural and Resource Economics*, 62, 217–236.

Orea, L., Perez, J.A. & Roibas, D. (2015) Evaluating the double effect of land fragmentation on technology choice and dairy farm productivity: a latent class model approach. *Land Use Policy*, 45, 189–198.

Oyetunde-Usman, Z., Olagunju, K.O. & Ogunpaimo, O.R. (2021) Determinants of adoption of multiple sustainable agricultural practices among smallholder farmers in Nigeria. *International Soil and Water Conservation Research*, 9, 241–248.

Page, K.L., Dang, Y.P. & Dalal, R.C. (2020) The ability of conservation agriculture to conserve soil organic carbon and the subsequent impact on soil physical. *Chemical, and Biological Properties and Yield, Frontiers in Sustainable Food Systems*, 4, 31. Available from: https://10.3389/fsufs.2020.00031

Phuong, L.T.H., Biesbroek, G.R., Sen, L.T.H. & Wals, A.E.J. (2018) Understanding smallholder farmers' capacity to respond to climate change in a coastal community in Central Vietnam. *Climate and Development*, 10, 701–716.

Piya, L., Maharjan, K.L. & Joshi, N.P. (2013) Determinants of adaptation practices to climate change by Chepang households in the rural Mid-Hills of Nepal. *Regional Environmental Change*, 13, 437–447.

Sen, L.T.H., Bond, J., Phuong, L.T.H., Winkel, A., Tran, U.C. & Le, N.V. (2021) The importance of climate change awareness for the adaptive capacity of ethnic minority farmers in the mountainous areas of Thua Thien hue province. *Local Environment*, 26, 239–251.

Tivet, F. & Boulakia, S. (2017) *Climate smart rice cropping systems in Vietnam, State of knowledge and prospects*. Montpellier, France: CIRAD.

Tong, L.A., Ulubaşoğlu, M.A. & Guven, C. (2022) Growing more Rice with less water: the system of Rice intensification and water productivity in Vietnam. *Australian Journal of Agricultural and Resource Economics*, 66, 581–611.

Van-Phan, P. & O'Brien, M. (2022) Is small beautiful? An empirical analysis of land characteristics and rural household income in Vietnam. *Australian Journal of Agricultural and Resource Economics*, 66, 561–580.

Wooldridge, J.M. (2010) *Econometric analysis of cross section and panel data*. London, UK: MIT Press.

Wossen, T., Alene, A., Abdoulaye, T., Feleke, S. & Manyong, V. (2019) Agricultural technology adoption and household welfare: measurement and evidence. *Food Policy*, 87, 101742.

Zeng, D., Alwang, J., Norton, G.W., Shiferaw, B., Jaleta, M. & Yirga, C. (2017) Agricultural technology adoption and child nutrition enhancement: improved maize varieties in rural Ethiopia. *Agricultural Economics*, 48, 573–586.

Zheng, H., Ma, W. & Li, G. (2021) Adoption of organic soil amendments and its impact on farm performance: evidence from wheat farmers in China. *Australian Journal of Agricultural and Resource Economics*, 65, 367–390.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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