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RESEARCH ARTICLE

Intensive and extensive rice farm adaptations in salinity-prone areas of the Mekong Delta

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ABSTRACT
Sea-level rise and resulting salinity inundation are making many coastal areas increasingly unfavorable for rice production. This paper examines intensive and extensive adaptations to rice production in salinity-prone areas of the Mekong River Delta (MKD) of Vietnam using a two-year panel dataset of 788 rice-growing households. In terms of intensive adaptations, we estimate a fixed-effect regression model and find that salinity tolerant rice varieties (STVs) increase rice yields on fields that are not protected by salinity barriers, but overall economic benefits from STVs are limited by lower market prices compared to other varieties. In terms of extensive adaptations, farmers stop growing rice on 15% of survey fields. Probit and IV-probit model results reveal that falling rice profitability plays a significant role in these observed exits from rice production, while salinity barrier infrastructure, large rice field holdings, and community commitment to rice farming are associated with continued rice production. Development initiatives that support household adaptation to sea-level rise need to blend currently polarized policy options of investment in large rice sector infrastructure projects that lock farmers into intensive rice cultivation and of support farmer efforts to find alternative land uses in response to evolving market and environmental conditions.

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Sea-level rise; farmer adaptation; rice production; salinity-tolerant varieties; land use

Introduction

Agricultural producers can adapt to unfavorable environmental changes though intensive adaptation of current crop production systems and extensive adaptation of other crops or alternative economic activities that are potentially better suited for the new environment. Intensive adaptation to address increasingly unfavorable climatic conditions commonly entails uptake of varieties tolerant to increasing abiotic stresses (e.g. Cavatassi et al., 2010; Emerick et al., 2016) and increased use of irrigation and other mechanisms to control water availability and quality (e.g. Kurukulasuriya & Mendelsohn, 2007). Extensive adaptations focus on movements away from current crops to alternative crops (Seo & Mendelsohn, 2008), increased off-farm employment (Call et al., 2019; Reardon et al., 1988), and migration (Gray & Mueller, 2012; Kubik & Maurel, 2016) among others.

Long time scales associated with climatic change and ensuing human responses often make it difficult to identify the extent and impact of adaptions and generate supportive policy environments (Burke & Emerick, 2016; Dell et al., 2014). There are, however, cases where agricultural production-system responses to climatic change are rapid and observed. This is particularly true in unfavorable environments, where current crops do not have a strong comparative advantage and producers are forced to undertake intensive and extensive adaptations in their production systems to address high production risk and to remain competitive (Rose, 2001). Examination of rapidly changing unfavorable production environments can provide empirical evidence on the roles of intensive and extensive adaptations in response to climatic change, as well as on the factors that influence adaptation.

This paper empirically documents the current uptake of intensive and extensive adaptations in rice production in the Mekong River Delta (MKD) of Vietnam, one of the world's most climatically vulnerable and rapidly changing agricultural production environments (Dasgupta et al., 2007). Specifically, we employ a two-year panel dataset of 788 rice-growing households in salinity-prone areas of the MKD to evaluate rice profitability and intensive adaptation with salt-tolerant rice varieties and the use of salinity-control barrier infrastructures in field-level fixed effect regression models. There has been limited analysis of farm-level adoption of abiotic stress-resistant varieties in response to climate change. Fisher et al. (2015) note that prior to their analysis in eight countries, there was only one study of the adoption of drought-resistant maize varieties in sub-Saharan Africa. Similarly, Paik et al. (2020) are one of the only studies that empirically examines salt-tolerant rice adoption and performance. We know of no study that has controlled for time-invariant farmer heterogeneity in these types of climate responsive intensive adaptations with panel data.

We also examine extensive adaptation through the secession of rice cultivation and the role that rice profitability plays in observed exits with probit and IV-probit models. Few studies have been able to directly measure farm and/or

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field level transitions in vulnerable coastal delta land use in response to climate change. Previous studies have relied on household recall or remote sensing to document land use changes (Giusto et al., 2021; Nguyen et al., 2019b; Renaud et al., 2017). Evaluation of these adaptations in coastal rice production can highlight the potential benefits of policies that support further intensification of rice production relative to policies that support farmer transitions to alternative land uses. Identifying appropriate areas and levels of support for these alternative intensive adaptation and extensive adaptation strategies is relevant for the MKD, as well as in other parts of the world facing similar threats to agricultural production from sea-level rise.

Background

Rice production plays a vital role in the economy of the MKD, as well as in the economy of Vietnam as a whole. Rice accounted for 90% of the crop area planted in the MKD as of 2012 (General Statistics Office, 2013). While the region represents only 12% of the total land area of Vietnam, it accounts for around 55% of planted rice and 57% of total rice production in the country (General Statistics Office, 2015). Further, Vietnam is the world's third-largest exporter of rice, after India and Thailand, and over 90% of exported rice comes from the MKD (CGIAR, 2016).

Despite the prominent role of rice, production in many areas of the MKD is severely threatened by sea-level rise. Global predictions of sea-level rise range from an average of 25 cm to 1 m by 2100 (IPCC, 2013). Approximately 600 million people worldwide currently inhabit coastal zones that will be affected by saltwater intrusion (Wheeler, 2011). Analysis of the impact of sea-level rise has focused mainly on infrastructure and habitat damage from seawater inundation and storm surges, but saltwater intrusion will have the greatest economic impact through agriculture, aquaculture, and fresh water availability (Dasgupta et al., 2018).

The MKD is already seeing impacts from an increase in the incidence of salinity intrusion into high-productivity agricultural areas. Figure 1 shows historical growth in rice hectarage in districts of the seven provinces of the MKD that include salinity-prone areas (Kien Giang, Ca Mau, Bac Lieu, Soc Trang, Tra Vinh, Ben Tre, and Tien Giang). While the overall area under rice has increased from 2000 to 2017, the area under rice in salinity-prone districts declined over the same period. During severe saltwater intrusion in late 2015 and early 2016 salt water penetrated into rice fields up to 90 km from the Mekong River mouth (UNDP, 2016). Over 244,000 hectares of rice were heavily affected, along with 69,000 hectares of aquaculture. In the provinces of Ca Mau and Ben Tre, 41% and 31% of rice crop areas experienced significant losses, respectively (UNDP, 2016). Direct economic losses from this salinity intrusion event are estimated to be $674 million (World Bank, 2017).

The 2015/16 severe salinity intrusion event is a manifestation of the long-term increase in vulnerability to salinity intrusion in the MKD. The increased risk of salinity intrusion is associated with three factors that determine relative sea-level rise. First, most land in the MKD is only slightly (<2 m) above sea-level (Wassmann et al. 2004); and the sea-level has risen 20 cm since 1901, including 3 mm per year on average over the last 30 years (CGIAR, 2016). Second, ground-water withdrawal for agricultural irrigation and human use has generated average land subsidence of 1.1 mm a year, with some heavily irrigated areas seeing subsidence rates of up to 2.5 mm per year (Minderhoud et al., 2019). Groundwater extraction at current rates could result in land subsidence of between 0.35 m and 1.4 m by 2050 (Erban et al., 2014). Third, household livelihoods in the MKD are highly dependent on upstream river flows in the Mekong River basin, which is, in turn, impacted by upstream dams and other human settlement. Generally, reductions in upstream river-flows will lead to increased salinity inundation as salt-water infiltrates further into the coastal areas of delta rivers and less sediment is deposited by the downstream flow. However, the impacts of dams on inter-

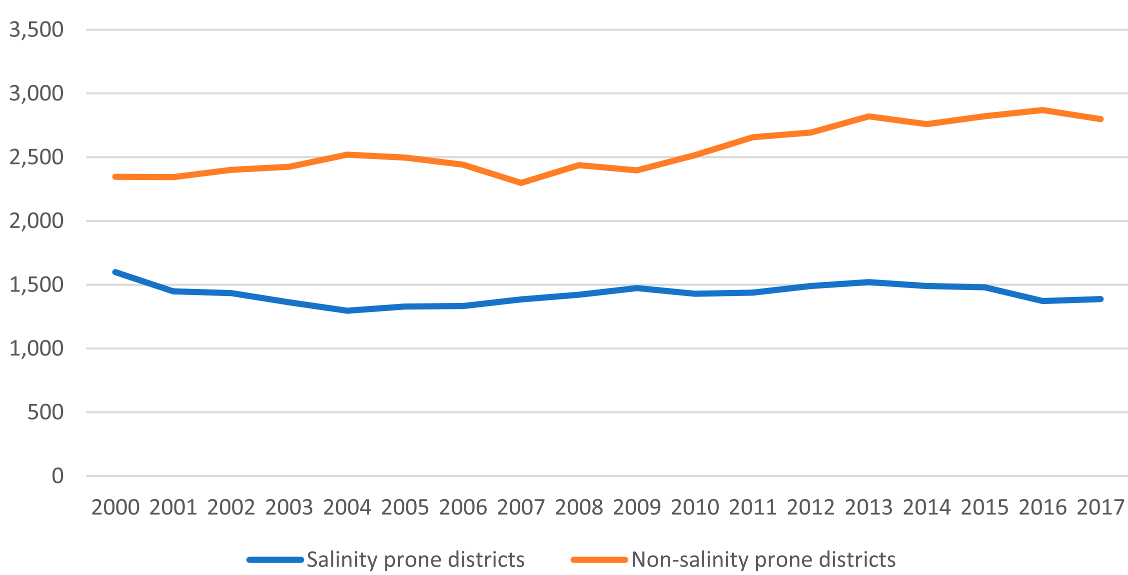

Figure 1. Rice hectarage in salinity prone and non-salinity prone areas from 2000 to 2017 ('000 hectares). Source: Mekong Delta Provinces' Statistical Yearbooks (Provincial Statistical Offices. 2009, 2013 and 2017).

annual river flow are complex. Upstream dams generally decrease wet-season flow and flood pulses. Dams, by storing water, can increase river flows in the dry season, which usually lasts from December to April in the MKD, the period when salinity inundation is highest. Recent simulations suggest that, overall, new and proposed dams in the upper Mekong River basin will increase the risk of salinity inundation (Bình et al. 2017).

In terms of impacts, Wassmann et al. (2004) estimate that under IPCC scenarios of 20 cm sea-level rise by 2030 and 70 cm by 2070, over 60% of the MKD is highly vulnerable to salinity intrusion. New high-quality 'CoastalDEM' Digital Elevation Maps suggest that even with deep cuts in carbon emissions, the high tide line will be higher than land that is home to between 26% and 31% of the Vietnamese population by 2100 (Kulp & Strauss, 2019). The majority of these impacted households reside in the MKD. Similarly, recent enhanced local 'Topo DEM' estimates of lower Mekong River Delta surface elevation suggest that much land lies closer to sea-level than previously estimated (Minderhoud et al., 2019). A 40 mm rise in relative sea level will place 25% of land below sea-level under new elevation estimates and a rise of 1 m will place over 70% of the total current population of the MKD below sea-level (Minderhoud et al., 2019). New elevation estimates also imply there is much less time for the MKD to adapt to sea-level rise than previously thought.

Conceptual framework – rice farmer adaptation to sea-level rise

Rice experiences abiotic stress when exposed over 2 parts per mille for over seven days (Wassmann et al. 2019). We use a salinity concentration measure of three parts per mille at the closest salinity monitoring station, where concentrations will be higher than on fields, to measure salinity impacts on rice production outcomes. The major adaptive responses to salinity inundation in the MKD are outlined in Figure 2. Intensive adaptation entails adoption of technologies like salinity tolerant varieties (STVs) that lower the impacts of salinity inundation. Farmers make these adaptations if technology adoption improves expected production outcomes (yields and net revenues). Extensive adaptation entails finding alternative land uses through more salinity tolerant crops or aquaculture and reallocation of household labor through off-farm employment and migration. We focus on the adaptive response of secession of rice production on fields. Farmers will cease to grow rice on land when expected profits from alternative land uses exceeds expected profits from rice production.

When salinity levels exceed three parts per mille for over two weeks, rice yields decline markedly even with salt-tolerant varieties (STVs) and viable farmer land-use options include shrimp, salinity-tolerant sugar cane and pineapple (Smajgl et al., 2015). Since farmers make extensive adaptations based on reduced field profitability from expected salinity exposure we use a historic three parts per mille measure of salinity over the previous 15 years when exploring the impacts of expected salinity on secession of rice production.

In the MKD, farmer ability to adapt land use in response to rising salinity levels is also limited by government policy, which has traditionally supported intensive rice cultivation in the MKD (Nguyen et al., 2019b). Farmer land-use constraints are further limited by the strong need to coordinate water use and the timing of agricultural activities with requirements on adjacent fields. Individual land-use decisions can also have environmental spillovers on other farmers. For instance, the leakage of saline water from shrimp ponds can damage rice crops in adjacent areas (Nguyen et al., 2019b). There is ample evidence that neighbor's actions influence farmer decisions with respect to technology adoption through social networks (e.g. Conley & Udry, 2010; Krishnan & Patnam, 2012; Paik et al., 2020). Government plans and needs for community water co-management place binding constraints on individual farmer land-use decisions. Thus, a farmer's land-use decision is very likely influenced by neighbors' land-use decisions.

In coastal communities with high levels of salinity exposure, there is significant farm-level pressure to move rice-only cultivation to rice-shrimp rotations or shrimp-only production due to high shrimp prices and profits (Nguyen et al., 2019b; Tran et al., 2019). Smajgl et al. (2015) find that annual household income is 50% higher under a shrimp – rice rotation than intensive cultivation of two rice crops a year, however, production risks associated with shrimp farming are much higher as disease outbreaks can lead to near complete losses. The relative profitability of shrimp production has created pressure to allow brackish water into freshwater areas protected by salinity barriers, and in some cases even lead to the destruction of salinity protection barriers by farmers (Tran et al., 2019).

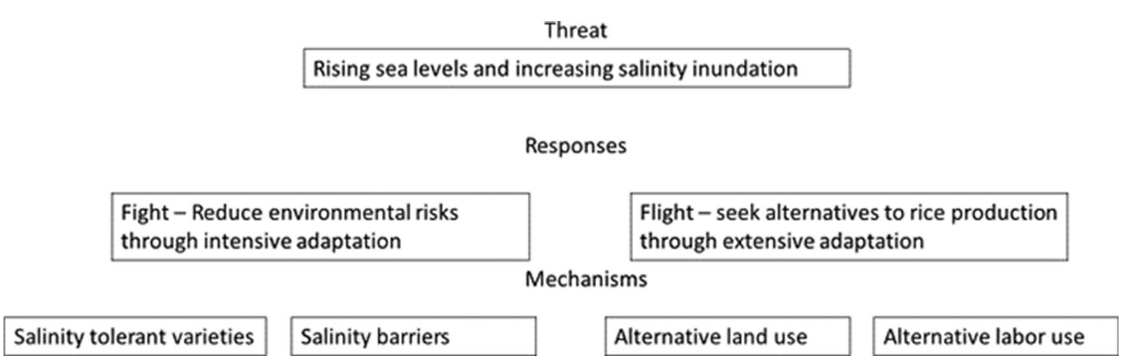

Figure 2. Adaptation Pathways.

Ceding to farmer pressure to pursue more profitable land use options, in 2000 the Government of Vietnam started to allow diversion of brackish water into some salinity-protected areas and tentatively gave farmers greater say in land-use decisions (Käkönen, 2008). In some cases, the government has permitted conversion from rice-intensive double cropping if more than 60% of farmers in the community preferred rice-shrimp cultivation. Following the major salinity event of 2015–2016, the national government allowed 400,000 ha of rice land to be converted to other crops, with the stipulation that it could later be re-converted to rice production (Nguyen et al., 2019b). Despite these cases of conversion from intensive rice cultivation to alternative land uses, national food security policies continue to require that designated areas be maintained for rice cultivation in each province and conversion from intensive two-season rice cropping in salinity-protected areas to aquaculture is generally not encouraged (Nguyen et al., 2019a).

Salinity-tolerant varieties

STVs offer potential gains to farmers in terms of reduced yield losses with mild salinity exposure (Chowdhury et al., 2012). STVs are developed through conventional breeding for salt-tolerance and, more recently, by insertion of the major gene loci that confers salt tolerance (Saltol) into locally adapted varieties (Renaud et al., 2017; Vinod et al., 2013). Multi-locational trial results in the MKD in Vietnam show that STVs suffer 10% yield losses under saline conditions, compared to 30% and 50% losses for moderately salt tolerant and sensitive varieties, respectively (Nhan et al., 2012). STVs also show little yield penalty under low salinity exposure. There has been moderate uptake of STVs in the MKD. A 2018 survey of salinity-prone districts in the Mekong River Delta identifies 42 rice varieties grown by farmers in the Dong Xuan season immediately prior to the January – April salinity surge or in the He Thu season immediately after the salinity surge (Paik et al., 2020). Of these 42 varieties, 12 are STVs that are planted on 40% of rice fields in both the Dong Xuan season and He Thu seasons. STVs do, however, come with a market-price penalty. Paik et al. (2020) find lower market prices for STVs due to less preferred taste and cooking traits. Since a primary benefit of STVs is lower losses in the face of salinity inundation, farmers may become increasingly reluctant to incur this market price penalty when faced with a series of years without salinity exposure. On the flip side, lower risk exposure associated with STV cultivation may lead farmers to intensify the use of other inputs in rice production (e.g. Emerick et al., 2016).

We examine the impact of varieties identified by the Cuu Long Delta Rice Research Institute as salt-tolerant on rice production outcomes (yield and net revenues) and on continuation of rice production.

Salinity barrier infrastructure

Salinity sluices and barrier dykes to protect against salt-water intrusion are an important infrastructure investment for intensive rice production. Most large-scale salinity barriers were built in the 1990s to protect freshwater rice cultivation from increased salinity, as well as to convert brackish water areas into freshwater areas for two-season rice cultivation under Vietnam's 'rice first' policy for self-sufficiency and export earnings (Käkönen, 2008). Major projects include Quan Lo Phung Hiep covering 450,000 hectares in Ca Mau, Bac Lieu, and Soc Trang provinces, Ba Lai in Ben Tre province covering 115,000 hectares, and Go Cong in Tien Giang Province covering 54,700 hectares.

Salinity barriers provide protection against flooding and salinity inundation, but also generate costs above and beyond construction and maintenance. Notably, salinity structures often intensify salinity intrusion and flooding outside of protected areas, leaving some groups as beneficiaries and the expense of others (Käkönen, 2008). Intensive rice cropping associated with salinity control infrastructure has increased both water consumption and the risk of saline water reaching freshwater intake points of salinity barrier systems. Salinity control infrastructures have also generated negative environmental impacts, including acidification of canals and rivers and reduced sediment and nutrient transport to fields (Nguyen et al., 2019a). Reductions in sediment and nutrient loads, combined with sea-level rise and increased storm surges, are likely to limit the long-term viability of large-scale salinity infrastructure (Smajgl et al., 2015). But plans exist for further investment in infrastructure projects, including a massive 907,000-hectare project in Kien Giang Province to protect against salinity intrusion and retain freshwater.

Since salinity barriers are long-term infrastructure investments, we cannot directly estimate barrier impacts on rice production outcomes in a panel data framework. However, we do examine if STVs show differential production outcomes on fields that are not protected by salinity barriers. We also examine the impacts of salinity barriers on continuation the of rice production through improved production outcomes and government and community pressure to maintain intensive rice production in protected areas.

Labor use

Increased salinity exposure has also changed broader livelihood strategies in the MKD. In Ca Mau province, for instance, over 40% of households reportedly changed their primary source of income from rice in the last decade (Betcherman et al., 2021). Farm household employment responses in salinity-affected areas include off-farm employment, self-employment, and wage employment on shrimp farms (Tran et al., 2019). These responses have diversified income sources, with an increased share of income from wage and nonfarm activities, and a decreased share from on-farm income (Nguyen et al., 2019a). Migration and remittances have also taken on increased importance in sustaining MKD household livelihoods (Szabo et al., 2018). About one-third of households have a member who had permanently migrated and one-third have a member with off-farm income (Nguyen et al., 2019a).

Initial household labor allocations to farm production and off-farm employment and farmer characteristics including age, education, and ethnicity may influence the opportunity costs of land and labor and the ability to transition out of rice production.

Empirical model and specification

We empirically estimate the roles that STVs and salinity barrier infrastructure play in rice profitability and other rice production outcomes, and in transitions out of rice production.

Intensive adaptation

Determinants of rice production outcomes are modeled using a field-level fixed-effect panel data model.

$$Y_{i,t} = \alpha_i + \theta_1 2018/2019_{i,t} + \beta_1 \text{STV}_{i,t} + \beta_2 \text{Salinity}_{i,t} + u_{i,t} \quad (1)$$

The dependent variable, $Y_{i,t}$, is a field-level outcome of rice production (yield, gross revenue per hectare, profits per hectare). The panel data model employs fixed effects, α_i, to control for all field-level time-invariant heterogeneity. Time-varying dependent variables for field i at time t in the model are an indicator for the second panel period ($2018/2019_{i,t}$), an indicator for use of salt-tolerant varieties ($\text{STV}_{i,t}$) and level of salinity exposure ($\text{Salinity}_{i,t}$). Potential clustering of errors at the village-sample level is controlled for in the error covariance matrix of in the error terms, $u_{i,t}$. Since the presence of salinity barrier infrastructure is time-invariant, potential impacts of salinity barriers are explored by also estimating the model separately for fields with and without salinity barriers. The fixed effect model is preferred to a random-effects specification for two reasons. First, a decomposition of variance reveals significant within field variation over the panel period in STV usages and salinity levels. Second, a Hausman-test supports the fixed-effects model specification over a random-effects specification.

Extensive adaptation

Analysis of extensive adaptation focuses on the choice to stop growing rice between the 2017/18 Dong Xuan season to 2018/19 Dong Xuan season at the field level (No Rice). Dependent variables in the analysis, x, include field level and household characteristics in the first panel year. In the base model, the rate of neighbor's (other households in the same village) rice abandonment is also employed as an independent variable to capture important constraints on land use imposed by both the government and other households in the community.

$$P(\text{No Rice}_i | \boldsymbol{x}_i) = f(B' x_i + \varepsilon_i) \quad (2)$$

Since the choice to stop growing rice is a discrete outcome, we employ a Probit model in the base specification. Potential clustering of errors at the village-sample level is again controlled for in the covariance matrix for the error term, ε_i.

As noted in the conceptual framework, ample evidence exists that there is a strong correlation between the land use and crop management decisions of farmers within a village. For example, another study that uses the first year of our panel dataset finds that farmers tend to use the predominant varieties in their communities (Paik et al., 2020). As a result, there are both strong and weak endogeneity concerns associated with the use of the share of neighbors who cease to cultivate rice as a variable in the base regression (2). Strong endogeneity concerns that the farmers choice directly influences her neighbors' choices, and weak endogeneity concerns that other unobserved variables like government land use policy influence both the farmer and neighbors' decisions. We address endogeneity concerns in a second specification for the field level choice to stop growing rice with an instrumental variable Probit model (IV-Probit hereafter) where neighbor's (other households sampled in the same village) characteristics are employed as instruments for the rate of neighbor's rice field abandonment variable. These neighbor characteristics are likely to be correlated with neighbors' decisions to abandon rice production, but influence the observed individual's decision to abandon rice production only through neighbors' abandonment decisions. A Cragg-Donald F-statistic to test instrument strength and Wald test of exogeneity of the neighbor abandonment decision support the choice of instruments (Wooldridge, 2002).

In a third specification we address the fact that land use decisions in the MKD are strongly determined by government and community decisions and may be better estimated as a village-level model of transitions out of rice production, where village-rates of secession of rice production depend on village characteristics. Specifically, we regress the share of village fields that are abandoned between the 2017–2018 Dong Xuan season and the 2018–2019 Dong Xuan season, y_i, on village averages for the variables employed in the base Probit regression (except neighbors' share of rice field abandonment).

$$y_v = B' x_v + \varepsilon_v \quad (3)$$

The village-level regression is estimated by OLS, with robust standard errors.

Data and descriptive statistics

Description of panel survey dataset

Household survey data was collected in two survey waves in June–July 2018 and May–June 2019 with approval from the Virginia Tech Institutional Review Board IRB # 18-488. In the first wave, 800 rice farming households were randomly selected following a multistage random sampling procedure. First, we identified 57 salinity-prone districts in seven Provinces of the MKD (Kien Giang, Ca Mau, Bac Lieu, Soc Trang, Tra Vinh, Ben Tre, and Tien Giang) from a 2016 salinity intrusion map from the Water Resources Research Institute of Southern Vietnam, coupled with expert opinion from the Cuu Long Delta Rice Research Institute and verification with province-level officials from the Vietnamese Sub-Department of Water Resources. Second, we selected a population-weighted random sample of 100 villages from the 57 districts. The random sample of villages spans 38 salinity-prone districts (Figure 3). Finally, we selected and interviewed 8 households in each of the 100 villages in the first survey wave in 2018 for a total initial sample size of 800 households. In the second

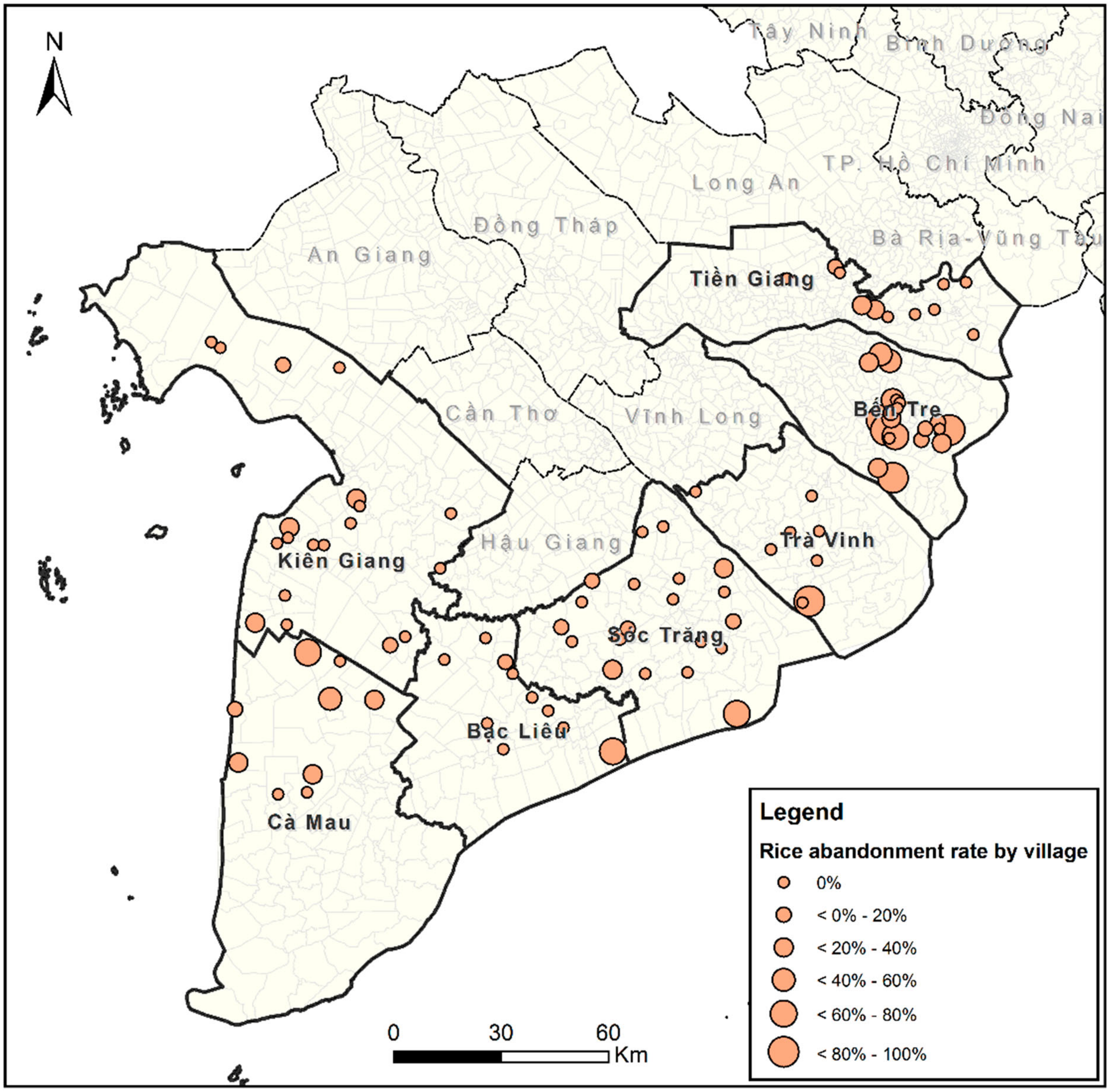

Figure 3. Village-level rice abandonment rates in 2018–2019 Dong Xuan Season.

survey wave in 2019, we interviewed the same households, to the extent possible, with a similar questionnaire in order to track changes in rice production over time. We faced low attrition and were able to retain 788 households in both waves of the survey for the analysis.

Data were collected at both the household level and the rice field plot level. The first wave household questionnaire covers household rice production activities in the 2017/18 Dong Xuan season and early stage planting activities of the 2018 He Thu season that was ongoing at the time. The second wave follows up on the remaining activities in the 2018 He Thu season, and collects information on rice production activities in the 2018/19 Dong Xuan season and initial planting activities for the 2019 He Thu season. The analysis of intensive adaptation focuses on adoption of salinity tolerant varieties (STVs) between the 2017/18 and the 2018/19 Dong Xuan seasons and associated changes in production outcomes based on a balanced sample of 765 fields (658 households) which cultivated rice in both Dong Xuan seasons. The extensive adaptation focuses on farmer decisions cease to grow rice on fields in the 2018/19 Dong Xuan season, contingent upon growing rice on the same field in the 2017/18 season. The sample for the extensive adaptation analysis includes 899 fields (771 households) that initially grew rice in the 2017/18 Dong Xuan season. The village-level analysis of abandonment of rice production focuses on the 99 villages (out of 100 villages in the sample) that initially grew rice during the 2017/18 Dong Xuan season.[1]

Variable description

Brief descriptions and descriptive statistics on the variables included in the empirical models are provided in Table 1.

Table 1. Variable description and descriptive statistics.

Variable	Description	Mean	Std. Dev.
Panel A – Intensive adaptations			
Dependent variables			
Yield	Rice harvest in kilograms per hectare	6500.104	2152.749
Gross revenue	=(Selling price of rice in VND per kg) * (kg per hectares). ('000 VND per hectare)	35,693.620	13,176.840
Net revenue1	=Gross revenues – Cost1. ('000 VND per hectare)	24,479.750	13,204.090
Net revenue2	=Gross revenues – Cost2. ('000 VND per hectare)	19,228.240	13,620.670
Net revenue3	=Gross revenues – cost3. ('000 VND per hectare)	16,453.370	14,259.050
Cost1	Including: inputs, water, and land rent costs. ('000 VND per hectare)	11,213.870	6708.090
Cost2	Including: input, water, land rent, machine, and hired labor costs. ('000 VND per hectare)	16,465.370	7255.821
Cost3	Including: input, water, land rent, machine, hired labor, and family labor costs. ('000 VND per hectare)	19,240.250	7775.530
Price	Rice selling price. ('000 VND per kilogram)	5.451	1.131
Independent variables			
STV	=1 if salinity tolerant variety was used in Dong Xuan season; =0 otherwise	0.469	0.410
Salinity	Share of days in January with salinity level greater than 3 per mille threshold	0.335	0.396
Gate	Field protected by salinity barrier infrastructure	0.731	0.444
Additional controls variables			
Farm labor	Number of adults in the household engaged in farming	0.648	0.774
Off rate	Share of adults in the household who work as a wage laborer or in non-farm self-employment	0.179	0.202
TLU	Tropical Livestock Units	1.385	3.925
WealthQ	Wealth Index Quantile based on non-farm assets & housing conditions	2.913	1.383
Panel B – Extensive adaptations			
Dependent variables			
Rice abandon	=1 if plot continue growing rice in the second wave; =0 if otherwise	0.150	0.360
Independent variables			
Plot characteristics			
STV	=1 if salinity tolerant variety was used in the first wave (2017/18 Dong Xuan season); =0 otherwise	0.396	0.489
Gate	=1 if field was protected by salinity barrier infrastructure; =0 otherwise	0.690	0.460
Historical salinity	Number of years in last 15 when the average salinity level in April exceeded 3% salinity threshold	11.170	5.410
Size	Field size in hectares	1.620	2.300
Distance	Distance from homestead to the plot in time of movement (minute)	9.770	9.660
Diverse	Number of crops grown in the past 12 months	1.960	1.200
Net revenue2	Gross revenues – Costs of rice production (input, water, land rent, machine, and hired labor costs) (000' VND per hectare)	20,810.690	12,773.710
Household characteristics			
Age	Age of a primary farmer	52.320	11.150
Eth	=1 if ethnicity of primary farmer is Khmer; =0 otherwise	0.160	0.360
Edu	=1 if primary farmer has completed high school education; =0 otherwise	0.120	0.320
Farm labor	Number of adults in the household engaged in farming	2.840	1.140
Off farm	Share of adults in the household who work as a wage laborer or in non-farm self-employment	0.176	0.210
Neighbor variables (Instruments)	Average value of a characteristic for other households in the same village (excluding observation household)		
Village level variables	Average value of households in the village		
V_Rice abandonment		0.161	0.268
V_STV		0.387	0.348
V_Historical salinity		11.051	5.534
V_Gate		0.706	0.355
V_Net revenue2		20,431	9402
V_Size		1.521	1.178
V_Distance		9.280	5.067
V_Diverse		1.995	0.814
V_Age		52.577	5.104
V_Eth		0.135	0.307
V_Edu		0.114	0.149
V_Farm labor		2.810	0.440
V_Off farm		0.175	0.096

Intensive adaptation

Dependent variables in the intensive adaptation model are field yield, gross revenue and three measures of net revenue based on three measures of costs, all on a per-hectare basis. Three different measures of costs, and associated measures of net revenues, are used due to likely errors associated with the recall of hired labor costs and with respondent valuation of family labor costs. Net revenue1 is total revenue minus input, water, and land rent costs, while net revenue2 also includes machine and hired labor costs and net revenue3 further adds imputed family labor costs. The independent variables employed in the specification are the use of salinity-tolerant varieties (STVs) and salinity level, measured by the share of days in January with a maximum salinity level greater than a threshold of three parts per mille at the nearest relevant salinity monitoring station for the rice field. Rice fields harvested from January to April account for 84% of Dong Xuan rice fields. The other 16% of fields are harvested prior to January and are effectively not exposed to the salinity surge; so their salinity exposure level is recorded as zero. It bears noting that salinity is measured at salinity monitoring station at the nearest major salinity barrier gate, and may not be representative of salinity levels on the field. An indicator for the second panel period is also included in the model to account for area-wide average trends in rice production outcomes. As noted, estimation using fixed-effect panel model already controls for the time-invariant variables such as household and plot characteristics. However, we also estimate the production outcome models separately for fields that are protected by salinity barrier infrastructure and fields that are not protected by barrier infrastructure.

Extensive adaptation

In the base model specification, analysis of extensive adaptation is also undertaken at the field-level, with the dependent variable being 1 if the field does not continue to grow rice in the Dong Xuan season in the second year of the panel and 0 otherwise. All of the explanatory variables in this analysis are from the first panel wave. The use of salinity tolerant varieties (STV) on the field, field protection by salinity barrier infrastructure (Gate), and historical salinity level are focal variables. Historical Salinity is now a long-term continuous measure of the number of years out of the last 15 when the average salinity level in the peak month of April exceeds 3 parts per mille. Historical information on salinity is employed instead of the current levels because farmers likely make the decision to stop growing rice before the season based on the salinity intrusion over past years. Additionally, controls are specified for other field features in the first year of the panel (field profits using the net revenue2 measure, field size, and field distance in terms of time travel from residence), as well as characteristics of the household in the first panel year including age, ethnicity, and secondary education or above of the primary farmer, number of household adult members working in household agriculture, share of adult household members working off farm, and diversity of crops grown.[2]

As mentioned, the impact of neighbors ceasing to grow rice on the farmer's decision to stop growing rice is captured through a measure of the share of other households in the same village cluster of the sample who stop growing rice in the Dong Xuan season between the two panel years. In a second specification, this variable is instrumented for with neighbor averages for farmer age, farmer education level, household number of children, field size, and field distance. In a third specification, a village-level rice transition model is estimated where the dependent variable is the share of village rice fields in panel wave one that do not grow rice in panel wave two. Independent variables in the village-level specification are village averages for all other independent variables used in the initial field-level specification (except for share of other village fields that stop growing rice).

Descriptive statistics

Intensive adaptation

Table 2 presents descriptive statistics on changes in STV use at field level over the two survey years. The result highlight that rice varietal change is a very dynamic process in the MKD region. Initially, in the 2017/18 Dong Xuan season 41% of fields are seeded with STVs. Surprisingly, the overall level of STV use then decreases significantly from the 2017/18 Dong Xuan season to the 2018/19 Dong Xuan season. Out of 765 fields, 40 fields do not use STVs in the 2017/18 Dong Xuan season, but adopt them for the 2018/19 season. By contrast, 167 fields using STVs in the 2017/18 Dong Xuan season, but do not use them in the 2018/19 Dong Xuan season. Descriptive statistics for production outcomes at field level in 2017/18 and 2018/19 Dong Xuan seasons are provided in Table 1. Notably, average rice yields in the MKD are high, at 6.5 metric tons per hectare and 73% of fields are protected by salinity barrier infrastructure.

Table 2. Salinity tolerant variety use in Dong Xuan 2017/18 and Dong Xuan 2018/19.

	STVs Dong Xuan 18/19		
STVs Dong Xuan 17/18	No	Yes	Total
No	409	40	449
Yes	167	149	316
Total	576	189	765

Extensive adaptation

Table 1 – panel B provides descriptive statistics for the sample of 899 fields that grow rice in the 2017/18 Dong Xuan season. In the sample 15% of fields do not grow rice in the following season. A map of village-level rates of rice abandonment is provided in Figure 3. Villages near the coast and in Ben Tre province show the highest rates of abandonment of rice cultivation. A Global Moran I test confirms that this pattern of village rice abandonment is spatially clustered ($p = .01$). Almost 40% of the fields use STVs and 69% are protected by salinity barrier infrastructure in the sample. Average field profits under the net revenue2 measure that does not include the imputed value of family labor inputs are 21 million VND (around USD 900) per hectare for the season.

Regarding the households' characteristics, on average 2.8 adults work in household agriculture and 18% of household adults work off-farm. The average age of the primary farmers is 52 years of age and 12% have completed high school. The descriptive statistics of variables for village-level data are displayed in Table 1 – panel C, with village-level averages generally similar to those in the field-level data.

Results

Intensive adaptation

Table 3 presents the fixed effect model estimates of STV impacts on rice production outcomes for fields that grew rice in both the 2017/18 and 2018/19 Dong Xuan seasons. Panel A presents results for all fields, while Panel B and Panel C present results for fields at are protected and not protected by salinity barrier infrastructure, respectively. Production outcomes include yield, gross revenues per hectare, and three different measures of net revenues per hectare. The results for all fields (Panel A) show that STV use increases yields by 364 kg per hectare on average. However, gross revenues and net revenues are not significantly different with STV use. In terms of period trends, no significant difference in yields is found between the two-panel periods, but gross revenues and net revenues are significantly lower in the Dong Xuan 2018/19 season than in the 2017/18 season. January salinity levels are also found to have no impact on production outcomes. This result is not surprising, as mentioned salinity measurements at the inlets of main salinity barrier gates are

Table 3. Salt-tolerant variety impacts on production outcomes.

VARIABLES	Yield	Gross revenue	Net revenue1	Net revenue2	Net revenue3
Panel A: All fields (*N* = 1530)					
STV	363.7**	966.8	507.5	236.0	191.4
	(165.3)	(1019)	(1073)	(1090)	(1130)
Salinity	156.8	2058	846.3	276.3	−43.25
	(250.1)	(1709)	(1820)	(1815)	(1928)
DX1819	−1.437	−4551***	−6125***	−6117***	−6251***
	(119.8)	(777.8)	(780.6)	(776.4)	(828.7)
Constant	6328***	36,961***	27,092***	22,116***	19,530***
	(105.8)	(630.6)	(696.5)	(698.7)	(748.6)
R-squared	0.009	0.114	0.166	0.164	0.163
Panel B: Salinity barrier infrastructure fields (*N* = 1118)					
STV	333.1	1051	−234.7	−370.5	−364.3
	(215.2)	(1355)	(1459)	(1463)	(1500)
Salinity	256.1	3365	1518	769.0	541.1
	(325.0)	(2153)	(2339)	(2370)	(2508)
DX1819	−111.3	−5412***	−7240***	−7181***	−7544***
	(155.0)	(926.8)	(934.9)	(945.4)	(995.2)
Constant	6690***	39,084***	29,040***	24,068***	21,447***
	(131.1)	(820.8)	(928.1)	(934.4)	(987.6)
R-squared	0.011	0.137	0.196	0.195	0.201
Panel C: Fields without salinity barrier infrastructure (*N* = 412)					
STV	453.7*	1154	2181*	1611	1514
	(233.2)	(1336)	(1294)	(1335)	(1390)
Salinity	126.4	663.4	1102	987.0	990.4
	(333.3)	(2214)	(2010)	(1833)	(1961)
DX1819	260.3	−2650**	−3381***	−3449***	−3001**
	(157.9)	(1069)	(1145)	(1110)	(1147)
Constant	5255***	30,369***	20,958***	16,042***	13,381***
	(161.3)	(938.6)	(865.2)	(862.6)	(946.9)
R-squared	0.029	0.062	0.097	0.089	0.071

Clustered standard errors in parentheses; ***$p < .01$, **$p < .05$, *$p < .1$.

weak indicators of salinity exposure at the field level. Alternative evidence of salinity impacts across rice-growing environments can be found in the comparison of regression results for fields that are protected by salinity barrier infrastructure (Panel B) and fields that are not protected by salinity barrier infrastructure (Panel C). Weak evidence is found that STV has higher yields and net revenues when excluding labor costs ($p = .10$) on fields without salinity barrier protection, but not on fields with salinity barrier protection. These results imply STV benefits maybe greater in unfavorable environments with higher salinity risk.

Returning to the full sample, the higher yield – but similar net revenue performance – of STV can be at least partially explained by STV price differences. As noted, one of the main drawbacks of STVs, that may also account for recently observed dis-adoption among farmers, is perceived poorer quality and cooking traits and a corresponding lower market price. We test for differences in market prices between STVs and other varieties, as well as for changes in market prices between panel periods. The results in Table 4 confirm that STVs receive a lower market price of VND 372 per kilogram (about 7% lower). Further, a general decline in rice prices of around 14% is observed between the first and the second panel years. This price decline accounts for the estimated drop in profits and net revenues, but unchanged yields, between the 2017/18 and 2018/19 Dong Xuan seasons in the fixed effect regressions.

Table 4. Salt-tolerant variety price differences.

VARIABLES	Price
DX1819	−0.769***
	(0.078)
STV	−0.372***
	(0.077)
stv_dx1819	−0.108
	(0.137)
Constant	5.971***
	(0.068)
Observations	1530
R-squared	0.135

Clustered standard errors in parentheses.
***$p < .01$, **$p < .05$, *$p < .1$.

As a robustness check, we incorporate several additional time-variant controls in the intensive adaptation analysis; farm labor, off-farm labor rate, livestock asset, and wealth index that are potentially correlated with field changes in STV use (Table A.1). As a second alternative, we employ neighbor STVs adoption, measured by STV adoption on fields of other households in the same sample village, as an instrumental variable to address potential time-variant endogeneity in STV adoption (Table A.2). Both alternative specifications yield similar significant impacts of STVs adoption on yield in Dong Xuan seasons. However, adoption of STVs shows a larger impact in the panel instrumental variable model for yield, and is also weakly significant ($p = .10$) in the gross revenue and net profit 1 equation estimates. This result implies that unobserved time-variant heterogeneity may lead to conservative estimates of STV impacts.

We also test whether input costs differ for STVs, using the three different measures of costs that underlie the three net revenue variables (Table A.3). No evidence of changes in input costs with STV usage is found, suggesting that lower risk associated with STVs does not spur intensification of input use. Input costs also rise between the two panel periods, which, along with falling rice prices, contribute to estimates of lower net revenues in the second panel period.

Extensive adaptation

Estimation results for the decision to cease rice production on fields in the 2018/19 Dong Xuan season are presented in Table 5. Base Probit model results are in column 1. First stage IV-Probit model results for the share of neighbors not growing rice in the 2018/19 Dong Xuan are presented in column 2, IV-Probit model second-stage parameter estimates are presented in column 3, and associated marginal effect estimates are presented in column 4. Both Probit and IV-Probit models find that STV usage in the 2017/18 Dong Xuan season does not significantly reduce the rate of abandonment of production on the same fields in the following year. Field characteristics with significant associations with the decision to cease rice production are similar in the two models. As expected, fields not protected by salinity barrier infrastructure are more likely (8% points) to cease rice production on fields. Historical salinity exposure is not significant in the Probit, but is weakly negative ($p = .10$) in the IV Probit model, suggesting some pressure to move away from rice cultivation in areas with higher historical levels of salinity exposure. Again, this result should be interpreted with caution, as historic levels of salinity exposure at the nearest monitoring station may be a weak proxy for field-level salinity exposure.

Table 5. Determinants of decision to stop growing rice.

	PROBIT	*IV-PROBIT*		
VARIABLES	Rice abandon	First stage	Rice abandon	Margins
Plot characteristics				
STV	−0.034	−0.051**	−0.151	−0.020
	(0.021)	(0.021)	(0.145)	(0.019)
Historical salinity	−0.002	0.003	−0.015*	−0.002*
	(0.001)	(0.003)	(0.008)	(0.001)
Gate	−0.091***	−0.077**	−0.588***	−0.076***
	(0.026)	(0.039)	(0.177)	(0.025)
Net revenue2	−0.000***	−0.000***	−0.000**	−0.000**
	(0.000)	(0.000)	(0.000)	(0.000)
Size	−0.032***	−0.003	−0.191***	−0.025***
	(0.009)	(0.003)	(0.069)	(0.009)
Distance	0.002**	−0.000	0.015**	0.002**
	(0.001)	(0.000)	(0.007)	(0.001)
Diverse	−0.009	0.009	−0.067	−0.009
	(0.010)	(0.009)	(0.070)	(0.009)
Household characteristics				
Age	0.001	0.001	0.006	0.001
	(0.001)	(0.001)	(0.008)	(0.001)
Eth	−0.042	0.007	−0.322	−0.042
	(0.030)	(0.050)	(0.205)	(0.026)
Edu	−0.019	−0.002	−0.119	−0.015
	(0.027)	(0.017)	(0.176)	(0.023)
Farm labor	−0.005	0.001	−0.041	−0.005
	(0.010)	(0.007)	(0.071)	(0.009)
Off rate	−0.006	−0.027	−0.017	−0.002
	(0.039)	(0.049)	(0.272)	(0.035)
Nei_abandon	0.372***		3.611***	0.467***
	(0.024)		(0.455)	(0.045)
Nei_Age		0.007		
		(0.004)		
Nei_Edu		−0.106		
		(0.088)		
Nei_Child		−0.128**		
		(0.057)		
Nei_Size		−0.029**		
		(0.012)		
Nei_Distance		0.009**		
		(0.003)		
Constant		−0.025	−0.880*	
		(0.304)	(0.520)	
Pseudo R-square	0.378***			
Wald χ^2 (13)	344.310		204.140	
Log pseudolikelihood	−234.210		−112.939	
Wald test of exogeneity: χ^2			3.930**	3.930**
Crag-Donald *F*-stat		25.8		
Observations		899	899	899

Clustered standard errors in parentheses; ***$p < .01$, **$p < .05$, *$p < .1$.

Higher net revenues on the rice field in the first panel year season are also found to significantly lower the probability of ceasing rice production on the same field the following year. However, marginal effects estimates suggest the economic effect is rather small; one million VND (USD 45) increase in profits reduces the probability of not growing rice by about 0.15% points. By the same token, moving from average profits of 20.8 million VND to zero profits increases the probability of rice field abandonment by 3.1% points. Households with larger overall rice field holdings are less likely to cease rice production on a given field, while farmers are more likely to cease rice production on fields that are farther away from the home in terms of travel time. Characteristics of the household member who is the primary manager of the field have little impact on the decision to cease rice cultivation on a field. The number of household members who work in agriculture and the share of household members engaged in off-farm labor are also not associated with the decision to cease rice production, implying labor constraints do not drive the decision to stop growing rice.

In the Probit model, the share of other households in the village who abandon rice fields (Nei_abandon) shows a very large and significant association with the probability that a household ceases rice production on a field. This result is not surprising, given the strong role government plays in land use decisions and the need for collective action in the cropping choices and timing of agricultural activities undertaken by farmers. As discussed, the neighbor abandonment variable is also likely endogenous both because the choice on rice cultivation for the observed field influences the neighbors' choices and because other unobserved variables influence both the observed field choice and choices of neighbor fields within the village. The IV-Probit model instruments for neighbor rice cultivation choice in the second-panel wave using averages of the neighbors' characteristics in the village that influence average neighbor choice on rice cultivation (but do not directly influence the observed household's field choice). The IV-Probit results yield a similar large parameter estimate for the Nei-abandon coefficient. The parameter estimate implies that if all neighbors in the village cease rice production, a farmer is 47% points more likely to also cease rice production on their field. Further, signs and significance levels for other variables remain largely unchanged, suggesting endogeneity in the Nei-abandon variable is not strongly influencing point estimates for other variables.

Table 6. Determinants of decision to stop growing rice at village-level ($N = 99$).

VARIABLES	V_Rice_abandon
V_STV	−0.176**
	(0.075)
V_Salin	−0.006
	(0.005)
V_Gate	−0.233**
	(0.102)
V_Profit	−0.000***
	(0.000)
V_Size	−0.069***
	(0.025)
V_Distance	0.009
	(0.006)
V_Diverse	−0.082*
	(0.044)
V_Age	0.006
	(0.005)
V_Eth	−0.075
	(0.087)
V_Edu	−0.017
	(0.155)
V_Farm	−0.095
	(0.064)
V_Off	−0.511
	(0.329)
Constant	1.016**
	(0.453)
R-squared	0.425

Standard errors in parentheses; ***$p < .01$, **$p < .05$, *$p < .1$.

Results for the alternative village-level regression with the percentage share of fields in a village that cease rice production as the dependent variable are presented in Table 6. Village-level variables are obtained by averaging all field observations in the same village. In this specification, village-level use of STVs has a strong negative impact on the abandonment of rice cultivation. If all village fields use STVs, as opposed to none, the village share of fields that cease rice production in the 2018/19 Dong Xuan season decreases 18% points. Salinity barriers also remain a strong deterrent to abandonment of rice cultivation. If all fields in the village are protected by salinity barriers, as opposed to none, the share of field in the village that cease rice production drops 23% points. Similar to the results in the household regressions, higher average profits per hectare across village fields and larger average field hectarage under rice cultivation both deter movements out of rice production. Greater diversity in the average number of crops cultivated by village households now also reduces the share of fields in the village that cease to cultivate rice. This result suggests that in terms of production at the village level diversification into other crops does not come strictly at the expense of rice.

Discussion and conclusions

Survey results demonstrate the rapid adaptation occurring in MKD rice production in response to an increasingly unfavorable environment punctuated by the severe salinity inundation event of 2015/16. Several other studies have inferred significant adaptive responses post 2015/16 from qualitative recall data (e.g. Tran et al., 2019), cross-sectional data (e.g. Dang et al., 2021; Paik et al. 2019), and remotely sensed land use changes (e.g. Vu et al., 2022). Our study adds a panel data perspective to rigorously document major intensive and extensive adaptions.

STVs are one of the most widely employed adaptations to the increased threat of salinity inundation. Like Paik et al. (2019), we find that several factors constrain the uptake of STVs. At the village level, high incidence of STV use is associated with lower rates of exit from rice production. But this STV effect is not seen at the field level, and there is actually a pronounced movement away from STV use over the panel period. The findings on STV performance highlight the difficult choice farmers face of either implementing intensive adaptation strategies or of moving out of rice production in unfavorable areas. Weak evidence is found that STVs may be more profitable than other rice varieties on fields without salinity barrier protection, even in years with relatively moderate levels of salinity inundation. But these same unprotected areas are more likely to see transitions out of rice production.

Lack of clear economic benefits from STV usage, despite higher yields in unfavorable environments, may partially explain the observed movement away from STVs. Farmers are well aware of the negative cooking qualities associated with many STVs and the corresponding lower market price (Paik et al. 2019). This price penalty may be a more observable and persistent economic signal to farmers than potential higher yields in years with high levels of salinity inundation when evaluating potential STV use. This is particularly true when farmers experience several years, like 2016/2017 and 2017/18, where salinity inundation is limited and advantages from STV are largely not manifest. Incorporation of preferred consumer attributes through adaptive varietal breeding is an important step for reducing the price penalty associated with STV use and spurring more widespread adoption.

In terms of extensive adaptations, around 15% of fields cease growing rice. A dramatic change for the short one-year period is captured in the analysis. During this period, rice prices fall and input costs increase. Farmers frequently commented when accounting for input use there was 'nothing left' in terms of profits. This squeeze on profits may be a contributing factor to the observed sharp movement out of rice production during the survey panel period. Farmers clearly respond to economic incentives. However, the estimated magnitude of the response to low profits at the household level is limited due to inertia generated by government land use plans, by the need for collective land-use decisions at the community level, and by the fact that global rice prices fluctuate and have generally rebounded from 2019 lows (FAO, 2022).

The rising incidence of salinity inundation is a more persistent threat to rice production in coastal areas of the MKD than transient low rice prices. Parameter estimates for the relationship between continuing to grow rice and historical salinity threats are consistently negative and statistically significant in the instrumental variable specification. However, these results should be viewed with caution, given the short period of the survey and the use of a historic salinity measure based on the closest gate rather than at the field. Dam (2021) finds stronger statistical evidence of negative salinity impacts on rice production using field-level salinity measures in a North-Central coastal area of Vietnam, although with a small sample of cross-sectional data. As expected, the presence of salinity barrier infrastructure and scale in rice holdings lock households into rice production and, again, highlight the dilemma faced by farmers of whether to intensify production in order to combat an increasingly unfavorable environment or to search for land use strategies that are more compatible with the changing environment. Other studies like Nguyen et al. (2019a) highlight how this intensify or exit dilemma shapes broader changes in land use in the MKD.

A number of factors associated with farmer decisions to cease rice production are not captured in the analysis. Most importantly, rice first policies that promoted intensified rice production are slowly being replaced by policy support for agricultural diversification in salinity prone areas (Nguyen et al., 2020). The 2013 Government Vietnam Mekong Delta Plan and subsequent Government of Vietnam Resolution 120 and Decision 417 establish pathways for agricultural diversification in the MKD over the next 100 years through both hard infrastructure investments to preserve rice production in upland and midland areas less affected by salinity and soft investments to support land use changes and other farmer adaptations in more salinity prone coastal areas (Bayrak et al., 2022; Government of Vietnam, 2013; Smajgl et al., 2015).

Most projects associated with this agricultural policy shift in salinity-prone areas are still in early stages of development. The current survey does not capture farmer exposure to various sources of information and policies and programs that generate incentives for agricultural diversification in salinity-prone areas. But study results do imply that farmers will rapidly alter land usage in response to economic opportunities. Appropriate economic incentives, as well as technical assistance, will be crucial for lowering farmer costs of extensive adaptations in heavily impacted salinity-prone areas. Lessons for coastal area transitions will also be instrumental in generating policies and programs to support similar adaptations in midland areas of the MKD that will soon face significant risks of salinity inundation due to the combined impacts of continued sea-level rise and land subsidence.

Future research can help to clarify options and provide guidance on investments in both intensive and extensive adaptations. STV performance is crucial for intensive adaptation. Can adaptive breeding successfully address characteristics of STVs that lead to lower market prices? Relatedly, will STVs combined with infrastructure investments enable farmers to maintain profitable rice production in midland areas that will increasingly come under risk of salinity inundation? Answers to this later question can be used to identify specific regions within the changing landscape that warrant future infrastructure investments for continued intensive rice cultivation. Extensive adaptation will be driven by the profitability of rice relative to alternative land uses. What should farmers do with their fields if they cease rice production and under what conditions are these alternative uses are more profitable than rice production? Just as importantly, under what conditions are farmers able to successfully navigate government and community constraints to land-use changes, when rice ceases to be the most viable land-use option? Answers to these questions can help to guide local investments and policies to better support farmer adaptations, while preserving gains from viable long-term rice infrastructure investments in remaining favorable rice production areas. Given the immediacy of the impacts of sea-level rise in the MKD, lessons from Vietnam's management of transitions will be of significant interest to other countries facing increasingly unfavorable agricultural environments due to climate change.

Notes

1. As a summary of sample size, the first wave survey was conducted with 800 rice-growing households and 788 of these households were successfully re-surveyed in the second wave. Initially, 771 households (899 fields) were growing rice in Dong Xuan season in the first wave, and 658 households (765 fields) continued to grow rice in Dong Xuan season in the second wave.
2. We use the net revenue 2 measure, as it reflects the net monetary earnings after all cash expenditures, including hired labor, but does not suffer from measurement errors associated with self-imputed value of family labor contributions.

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Appendix

Table A.1. Salt-tolerant variety impacts on production outcomes with additional time-variant controls ($N = 1530$).

VARIABLES	Yield	Gross revenue	Net revenue1	Net revenue2	Net revenue3
STV	373.8**	1014	612.9	358.0	305.7
	(165.6)	(1019)	(1073)	(1087)	(1126)
Salinity	171.3	2134	824.6	240.4	−85.48
	(253.9)	(1723)	(1820)	(1819)	(1933)
DX1819	6.183	−4511***	−6192***	−6207***	−6344***
	(118.5)	(794.5)	(794.4)	(790.3)	(845.4)
Farm	−48.87	−235.4	229.4	317.9	366.5
	(102.6)	(580.2)	(585.3)	(583.6)	(590.0)
Off_rate	606.3	3391	3090	3695	3472
	(385.1)	(2585)	(2740)	(2752)	(2774)
TLU	12.55	60.13	91.94	94.04	95.71
	(13.32)	(69.83)	(83.64)	(83.62)	(81.65)
wealthQ	−38.84	−114.2	−396.0	−419.5	−348.9
	(56.66)	(318.4)	(352.8)	(355.3)	(373.5)
Constant	6336***	36,698***	27,424***	22,360***	19,580***
	(233.1)	(1280)	(1397)	(1415)	(1492)
Observations	1530	1530	1530	1530	1530
R-squared	0.016	0.117	0.169	0.168	0.166
Number of plotid	765	765	765	765	765
F test	0.0752	3.88e-07	0	0	0

Clustered standard errors in parentheses; ***$p < .01$, ** $p < .05$, * $p < .1$.

Table A.2. Salt-tolerant variety impacts on production outcomes using neighbor adoption as instrumental variable ($N = 1530$).

VARIABLES	Yield	Gross revenue	Net revenue1	Net revenue2	Net revenue3
STV	1369**	6948*	6765*	6155	5600
	(571.7)	(3954)	(3711)	(3812)	(4166)
Salinity	81.94	1612	380.2	−164.6	−446.1
	(280.5)	(1906)	(1953)	(1935)	(2039)
DX1819	174.7	−3503***	−5029***	−5080***	−5303***
	(161.0)	(1063)	(1042)	(1032)	(1089)
Constant	5933***	34,612***	24,634***	19,792***	17,406***
	(236.8)	(1570)	(1547)	(1589)	(1748)
Observations	1530	1530	1530	1530	1530
Number of plotid	765	765	765	765	765
F test	0.0727	4.48e-10	0	0	0

Clustered standard errors in parentheses; ***$p < .01$, **$p < .05$, *$p < .1$.

Table A.3. Salt-tolerant variety impacts on cost ($N = 1530$).

VARIABLES	Cost 1	Cost 2	Cost 3
STV	459.3	730.8	775.3
	(712.1)	(723.3)	(772.9)
Salinity	1211*	1781**	2101**
	(712.9)	(809.9)	(830.3)
DX1819	1574***	1566***	1700***
	(375.4)	(394.6)	(442.5)
Constant	9870***	14,845***	17,431***
	(384.4)	(406.9)	(434.9)
R-squared	0.063	0.057	0.061

Clustered standard errors in parentheses; ***$p < .01$, **$p < .05$, *$p < .1$.