Salt-tolerant rice variety adoption in the Mekong River Delta

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Abstract

Rice production plays an important role in the economy of the Mekong River Delta (MRD), but rice production is endangered by sea-level rise and the associated increased incidence of salinity intrusion. This study examines the diffusion of salt-tolerant rice varieties (STRVs) in the MRD that were promoted through Consortium for Unfavorable Rice Environment (CURE) activities. Evidence is found of widespread adoption in salinity-prone areas, with CURE related varieties covering 47% of rice area in at least one of two growing seasons surveyed, but that adopting areas are highly clustered. Multivariate analysis reveals that location characteristics associated with high risk of salinity inundation, rather than individual characteristics associated with household risk preferences, explain the observed pattern of adoption in the MRD. In particular, CURE-related varieties are disproportionately likely to be adopted in non-irrigated areas and in irrigated areas that are not protected by salinity barrier gates. The results imply that CURE has effectively targeted unfavorable rice growing environments and that efforts to further diffuse STRVs need to both increase the area of suitability through further varietal adaptation and promote adoption in existing suitable areas by taking advantage of strong neighborhood externalities in household adoption decisions. In terms of varietal performance, inconclusive evidence is found of higher yields of CURE-related varieties in a low-salinity year. Further, any yield gains are more than off-set by lower market prices for CURE-related varieties.

General audience abstract

Rice is a staple crop in the Vietnamese diet and one of Vietnam's leading exports. The Mekong River Delta (MRD) accounts for more than 90 percent of rice exports. However, rice production in the MRD is endangered by saltwater intrusion due to rising sea-levels. Farmers have adopted rice varieties that are tolerant to rice to reduce their production risk that were promoted through Consortium for Unfavorable Rice Environment (CURE) activities. This study examines the rates of adoption of these CURE-related varieties, the reasons farmers choose CURE-related varieties, and variety performance on farmers' fields.

Results from a household-level survey show at 47% of fields in salinity-prone areas of the MRD grow a CURE-related variety in at least one of the areas two main rice-growing seasons. Farmers are particularly likely to adopt CURE-related varieties on fields that are not protected against salinity intrusion by gates. Adoption decisions are also highly correlated with neighbors' decisions within villages. Finally, CURE- and non-CURE-related varieties yields are similar in a year with low levels of salinity intrusion. But revenues from CURE-related varieties are slightly lower due to their lower market price, suggesting CURE-related varieties are a relatively low-cost insurance policy for MRD rice farmers in salinity-prone areas against future salinity intrusion.

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Chapter 1. Introduction

1.1. Problem Statement

The Mekong River Delta (MRD), the most downstream region of the Mekong River (Figure A1 in Appendix A), benefits from diverse ecosystems and fertile land that produces large amounts of aquatic and agricultural products. A large volume of rice, which is a staple of the Vietnamese diet, is cultivated in the MRD. Despite encompassing only 12 percent of the total area of Vietnam, this fertile area accounts for 55 percent of planted rice and 57 percent of total rice production (General Statistics Office 2016). Moreover, Vietnam is the third largest exporter of rice in the world, preceded only by India and Thailand (USDA 2018), and the MRD accounts for more than 90 percent of rice exported (CGIAR 2016).

The rice sector showed rapid economic growth in the 1980s, but rising sea-levels and decreases in the flow of the Mekong River have threatened stable growth in rice production in the MRD. River stations at estuaries in the Mekong River suggest that average sea level rose 9-13cm in the period 1980-2007 (Marchand, Dam, and Buck 2011). Given that most of the MRD lies below one meter above sea level, the area is particularly vulnerable to saltwater inundation that can stunt the growth of rice plants. Reduced river flow from upstream dams and uncertain timing of rainfall also make it increasingly difficult for farmers to obtain freshwater for rice farming in the December to April period. As a result, salinity inundation has become a major risk to farming activities and rice production.

Recently, the MRD experienced severe saltwater intrusion from the end of 2015 to early 2016, when salinity intrusion peaked earlier than usual and lasted longer (CGIAR 2016). Saltwater penetrated 70km—and up to 85km in some locations—from the mouth of river into crop fields (Thanh 2016). A total of 215,445 hectares of rice were heavily affected by salinity and resulted in direct economic losses of VND 7,517 billion (about USD 337 million) (Baca et al. 2017).

1.1.1. Reasons of saltwater intrusion in the MRD

The principal factors that cause an increase in salinity and threaten small-scale farmers' food security are: sea-level-rise, reduced freshwater flow in the Mekong River due to a damming river, and land subsidence.

Rising average temperatures, as a result of climate change, are melting glaciers and ice sheets and gradually elevating sea levels. According to Sai Gon – Dong Nai river stations at estuaries in the Mekong River, sea level rose approximately a 4mm per year in the period of 1980-2007 (Marchand, Dam, and Buck 2011). Saltwater is now able to penetrate further inland due to this rise.

Further, rising sea-level will continue into the future. The Asian Development Bank (2011) reports that for the period of 1980-1999 to 2080-2099, sea levels in Ca Mau and Kien Giang provinces in the MRD will rise up to 70cm. Given that the flat terrain of the MRD is less than 1 meter above sea level, saltwater will inundate a wider rice-growing area and reduce rice production.

Insufficient river flow is also a key factor leading to salinity intrusion. Low river discharge from upstream causes sea water to infiltrate the river branches. These problems may have been partly caused by large dam infrastructure development on the upper Mekong River in China, Thailand, and Cambodia.

To investigate the impact of upstream dams on river flow in the MRD, water levels, after constructing six hydropower dams at Lancang cascade in China, were measured. Water levels at TanChau station located in the entrance of Tien River (Figure A2 in Appendix A) declined by approximately 1 meter after six hydropower dams were built (Binh et al. 2017a). The simulated impacts of proposed 11 dam constructions in Thailand, Lao PDR, and Cambodia show similar aspects of a decline in water discharge in the MRD from 0.5% to 3.6% (Binh et al. 2017b).

Plans to build additional dams upstream may further lower river flow in the MRD. In the past, Mekong River was largely driven by natural variations of precipitation and generated fertile land around it. However, plans to build 16 mainstream and 110 tributary dams by 2030 may decrease amplitude and maximum water level throughout the MRD (Pokhrel et al. 2018). The proposed dams can may also impede nutrient-rich sediment transport (Kondolf, Rubin and Minear 2014; Manh et al. 2015; Pokhrel et al. 2018). However, dams may also mitigate the seasonality associated with river flow. In general, an upstream dam controls river flow, reducing water discharge in the wet season while increasing it in the dry season.

Severe water shortage for farmers, caused by a decrease in flowing water volume, forces farmers to pump water from aquifer at unsustainable rates. This can lead to land subsidence and further vulnerability to salinity.

Over the past 25 years, the land in the MRD showed at 18cm drop due to subsidence with hotspots recording more than 30cm drops --Figure 1.1 -- (Minderhoud et al. 2017). Rural areas,

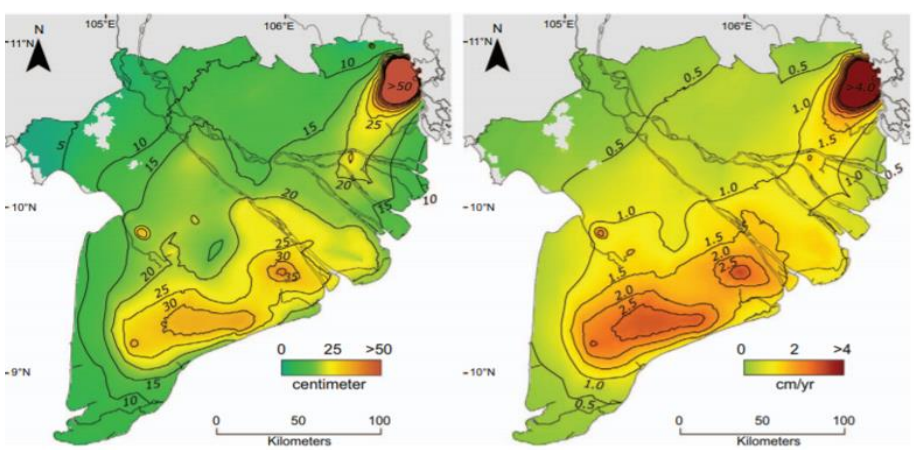

Figure 1.1. Left: Modelled cumulative subsidence caused by groundwater withdrawal from 1991 to 2016. Right: Modelled annual subsidence rates for 2015
Source: Minderhoud et al. 2017

where farming activities are intensive, recorded subsidence rates of 1-2cm per year. In addition, subsidence fluctuates up to 2cm between dry and wet seasons as the aquifer shrinks and expands (Minderhoud et al. 2017). This combination of sea-level-rise, upstream dam construction, and land subsidence results in seawater intrusion that directly impairs agricultural production.

1.1.2. Future projections

Salinity intrusion will likely be an even greater problem in the future. Khang et al. (2008) assess the combined impact of sea-level-rise and reduced flow of the Mekong River on saltwater intrusion and rice production and suggest that in the dry season 2.5 g/l saline water will reach inland 10km in the main river and 20km inland into rice field by the mid-2030's, and 20km inland in the main river and 35km inland into rice field by the mid-2090's. Similarly, Anh et al. (2018) simulate future impacts of upstream inflow changes, rainfall variability, and sea-level-rise for the 2036-2065 period and find salinity intrusion will move approximately an additional 4.9km upstream. In addition to damaging rice crops in the field, the flushing time required to leach out salt will increase, and this increase will delay seeding and reduce the productivity of rice for the subsequent cropping season.

1.1.3. Impact of the CURE project

Farmers in the MRD can plant salt-tolerant rice varieties (STRVs) to reduce their economic risk. Research institutions, including International Rice Research Institute (IRRI) and Cuu Long Delta Rice Research Institute (CLRRI), recognize this need and have actively generated STRVs locally adapted to the MRD. As a major component of this effort, the Consortium for Unfavorable Rice Environments (CURE) has evaluated varietal performance in multilocational trials and on farmers' fields and distributed promising varieties into the countries' seed multiplication system since 2002. This thesis refers to varieties evaluated under CURE as CURE-related varieties.

The CURE projects contribute to continual varietal yield improvement in the MRD. During the 1980s, varieties released had yields of 3.5-4.5 tons/ha, in the 1990s varietal yields were 4.0-5.0 tons/ha, while since 2000 they have generally been between 4.5 and 5.0 tons/ha (Brennan and Malabayabas 2011). Moreover, high yields of newly released varieties from 2005 to 2007 were fairly stable in diverse salinity-stress conditions in the MRD. At the same time, CURE disseminated STRVs to target unfavorable environments and established seed multiplication facilities. To accelerate farmers' adoption of new varieties, CURE also trained farmers and extension people and held workshops to provide the participants with a better understanding of innovative technologies and practices.

Despite considerable research and outreach efforts, few studies have explored the uptake of STRVs, and no study has examined the uptake of CURE-related varieties targeted to unfavorable salinity-prone environments. Little is known about adoption patterns and determinants of CURE-related variety adoption in the MRD. Adopting CURE-related varieties is a salinity adaption and mitigation strategy, and CURE's impact in the area depends on the spread of program generated varieties in saline prone areas in the MRD. The extent of the spread in different regions can inform seed distributors about the regions in which they need to make efforts for wider dissemination. In addition, understanding factors that contribute to adoption of CURE-related varieties can guide effective distribution to farmers. Examining determinants of adoption will also signal to seed breeders and researchers which traits should be included when improving future varieties.

1.2. Objectives

The objective of this study is to assess the uptake of CURE-related varieties in saline prone areas of the MRD. Five specific questions related to varietal uptake are explored. (1) What are rates of adoption of CURE-related varieties in salinity-prone areas? (2) What role do household characteristics play in adoption of CURE-related varieties? (3) What role does environment, particularly the risk of salinity exposure, play in adoption? (4) What role do neighbor adoption decisions play in the household adoption decisions? (5) Do CURE-related varieties outperform non-CURE-related varieties on farmers' fields?

1.3. Organization of the Thesis

The remainder of the thesis is organized as follows. The next chapter provides background information about MRD rice, salinity adaptation strategies, and the CURE project, and also includes a literature review on the prevalence of STRVs, the determinants of farmers' seed choice, and the performance of STRVs. Chapter 3 outlines the conceptual framework of the farmer's decision to adopt CURE-related varieties and the factors that influence that decision. Chapter 4 describes sample selection and data and provides descriptive statistics. Chapter 5 presents the statistical models employed and their specifications. Chapter 6 presents results of the statistical models and Chapter 7 concludes with a discussion of the findings.

Chapter 2. Background and Literature Review

This chapter provides background details on rice production in the MRD and the cropping calendar. It also presents a description of adaptation strategies employed against salinity inundation and provides an overview of the CURE project. Additionally, it reviews the existing literature on the diffusion of STRVs in the MRD, the determinants of farmers' variety adoption, and the performance of STRVs.

2.1. Background

2.1.1. Rice in salinity-prone areas of the MRD

As noted, Vietnam is a major rice producer, and the MRD plays an important role in rice production and exportation. In 2015, the rice planted area in Vietnam was 7.8 million hectares and the rice production was 45.2 million tons (Table B1 in Appendix B). In the MRD for the same year, the total rice area was 4.3 million hectares which accounts for 55% of planted area in Vietnam and the rice production was 25.7 million tons which accounts for 57% of production. The seven provinces in the study (Ben Tre, Tien Giang, Tra Vinh, Soc Trang, Bac Lieu, Ca Mau, and Kien Giang) contain areas that are salinity-prone and account for 25% of total production in the country.

The tropical monsoon climate in the MRD is characterized by the wet season from May to October and the dry season from November to April (Kotera et al. 2014). Farmers grow single rice, double rice, or triple rice crops each year within four different cropping seasons referred to as Xuan He, He Thu, Thu Dong, and Dong Xuan (Figure 2.1). Periods of salinity risks and deep

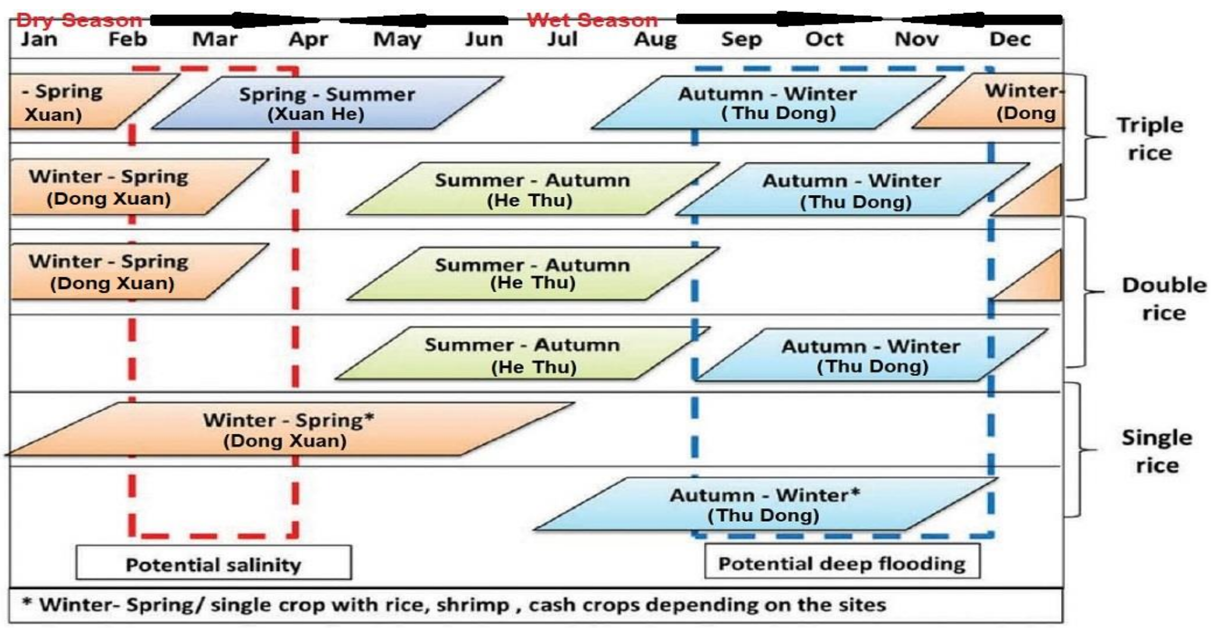

Figure 2.1. Rice cropping calendar in the MRD
Source: Vo et al. 2018

flood risks play a key role in determining area-specific cropping patterns. The double rice cropping calendar is the most common in the MRD, especially in the freshwater and slightly saline areas (Figure A3 in Appendix A). As Figure A3 shows, the provinces along the coastal line mostly have single and double rice cropping patterns, and the coastal areas that are directly and most severely affected by saltwater intrusion no longer grow rice.

The two most important rice growing seasons in the MRD are the Dong Xuan and He Thu seasons. These seasons occur before and after the salinity surge, respectively. Figure 2.2 presents salinity pattern in the MRD. Salinity levels normally begins to rise by the end of December (early dry season), reach a peak in March or April (late dry season), and fall after (CGIAR 2016). The tail end of the Dong Xuan season is affected by rising salinity. Similarly, for the He Thu season, farmers wait for rainfall to wash salinity out of the soil and irrigation water canals before planting. Historically, severe saltwater intrusions occurred in 1998, 2010, and 2016 (CGIAR

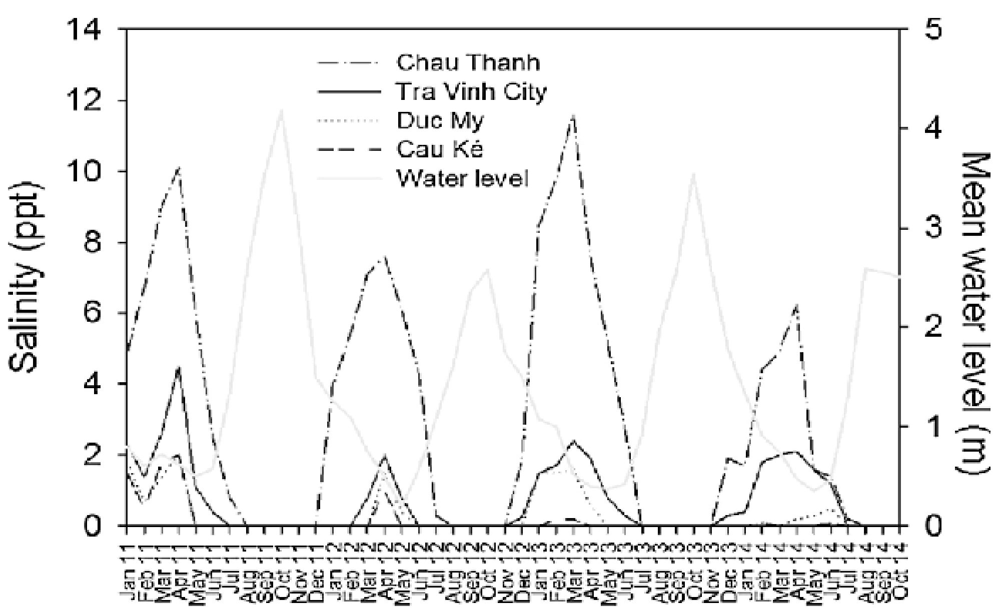

Figure 2.2. Seasonal salinity in the MRD
Note: Salinity (parts per thousand; ppt) fluctuations per month between January 2011 and October 2014 in Chau Thanh District (20 km to mouth) in Tien Giang province; Tra Vinh City (30 km to mouth), Duc My District (40 km to mouth), and Cau Ké District (40 km to mouth) in Tra Vinh province
Source: Schmitz et al. 2017

2016) when salinity levels began to rise earlier and peaked with concentration levels higher than normal. Further, some coastal areas have been exposed to consistent salinity intrusion and farmers have transitioned from rice to more salt-tolerant crops or aquaculture.

2.1.2. Salinity adaptation strategies

To reduce the economic risk of salinity intrusion, farmers and government employ various risk management strategies. Farmers diversify farming systems by planting salt-tolerant trees such as guava and papaya or adopting integrated shrimp- or fish- rice farming (Sakamoto et al. 2009). In the rice-shrimp farming model, farmers in coastal provinces let saltwater enter fields to farm shrimp in the dry season, and after rainfall removes salt from the soil, they use freshwater to grow rice in the wet season. This change in land use can be an effective strategy to adapt to increased salinity levels, as well as to generate other sources of income. However, shrimp production systems are capital intensive and face high risk of complete loss from disease, making them an unattractive option for many farm households (Braun et al. 2019).

Furthermore, the Vietnamese government provides water infrastructure, including canals, dikes, and sluices (Kam et al. 2000). Dike systems and mainstream river sluice gates, built in the MRD, play a significant role in reducing saline water intrusion. For example, the sluice gates prevent tidal inundation by shutting the sluice with rising tides.

In addition to the above risk management strategies, the very plausible and effective adaptation for farmers is to plant salt-tolerant rice varieties (Ismail 2009). By all accounts, it is considered a promising, resource saving, and economically acceptable approach. Compared to diversifying cropping systems, this adaptation only requires farmers to change their rice varieties and rice farming practices. This strategy is relatively and easily adaptable to farmers, while stabilizing rice yields in the face of moderate levels of salinity inundation.

2.1.3. CURE project

Salt-tolerant rice varieties (STRVs) have received considerable attention from research institutions as a relatively low-cost adaptation strategy. The Consortium for Unfavorable Rice Environments (CURE) is a network of ten Asian countries to support farmers living in unfavorable rice-growing environments: seven countries are from Southeast Asia (Cambodia, Indonesia, Laos, Myanmar, Philippines, Thailand, and Vietnam) and three countries are from South Asia (Bangladesh, Nepal, and India). The consortium allows for multinational and interdisciplinary sharing of research and information to generate and disseminate stress-tolerant rice varieties and associated rice management technologies (Manzanilla et al. 2017). Under CURE, research institutions and extension centers have partnered together since 2002 to test stress-tolerant rice varieties for local environments through multilocational trials. CURE activities in Vietnam focus on salinity, submergence, and upland environments and play an important role in addressing salinity-prone environments in the MRD. CLRRI, as a partner with CURE since 2005, works to generate salt-tolerant, high grain quality, and high yielding rice varieties (Manzanilla et al. 2017). The rice breeding process in Vietnam is accelerated from 5-10 years with conventional breeding to 3-5 years with CURE collaborations, in part by introgressing *Saltol* a quantitative trait locus for salinity tolerance through marker assisted breeding (Manzanilla et al. 2017). As a major component of this partnership, researchers and farmers participate in the multi-locational assessment of varietal performance (Manzanilla et al. 2017). For example, 13 STRVs were evaluated by farmers in four coastal MRD in the 2012/2013 Dong Xuan season (CURE 2013). However, the impact of these efforts on eventual farmer varietal use is unknown.

2.2. Literature Review

2.2.1. Prevalence of STRVs

Research has been conducted to reduce fluctuations in rice production through development of STRVs and resulting varieties have been disseminated to salinity-prone areas. As a result of these efforts, households can plant the improved varieties in their fields as a risk management strategy. Brennan and Malabayabas (2011) analyze the usage of new rice varieties in southern Vietnam (MRD, South East, Central Highlands, and South Central Coast) from 1985 to 2009. Among the 40 most widely grown varieties, OM89 reached the largest total area planted from 1985 to 2009, and the most widely grown variety released in more recent years was OM4900.

The noticeable pattern associated with new rice varieties in southern Vietnam was a high level of varietal diversity (Brennan and Malabayabas 2011). In the 1990s, no single variety accounted for more than 10% of the area, while the four leading varieties accounted for over 50% of the area planted in the 1980s. Similarly, Nhien (2018) find that farmers grow a wide assortment of rice varieties in the MRD. For example, in Bac Lieu province the two most popular varieties, OM5451 and OM2517, account for only 15% and 11% of seeded rice area, respectively.

However, analysis of the diffusion of improved varieties in southern Vietnam does not distinguish environmental conditions. Examination of the diffusion of STRVs and their effects on rice production needs to focus on salinity-prone areas. In addition, documenting the diffusion of STRVs by lower administrative units might help research institutions or extension centers to multiply location-specific varieties and plan research and diffusion investment strategies in specific regions.

2.2.2. Determinants of variety choice in the MRD

Previous studies have examined factors which influence the adoption decisions of new technologies. Chi (2008) investigates the determinants of adoption of new technologies in the MRD and identifies farmer education levels and perceptions of technologies as the main factors. Further, Chi finds that when the benefits and losses associated new technologies are not well understood, farmers hesitate to adopt. This suggests that learning may play a key role in technology diffusion.

Lack of access to seeds may also limit diffusion. Pham and Napasintuwong (2018) find that rice-growing farmers in the MRD had difficulty accessing certified aromatic rice-seed in the 2016/2017 Dong Xuan season. The lower selling price of STRVs in the market may also be a constraint to adoption. Manzanilla et al. (2017) found that the price of local rice in the An Giang's local market (located in MRD) is higher than for a CURE-related rice variety (OM5451) by about 5 percent or 200 VND/kg (0.01 USD/kg). The lower market price for CURE-related varieties may come from poorer taste and more difficulty in cooking traits that are also less preferred by exporters (Manzanilla et al. 2017).

However, prior research has not fully explored adoption patterns and determinants of adoption of STRVs. Little is known about which household characteristics are associated with adoption. In addition, households living in salinity-prone areas may be affected by distinct factors because their varietal choice is in response to the risk of salinity. The decision-making process must, therefore, address risk reduction as an important component of rice production.

2.2.3. Performance of STRVs in the face of salinity inundation

The diffusion of improved varieties has clearly had a major impact on rice production in the MRD. According to Manzanilla et al. (2017), the average yield of STRVs in MRD has reached 6 tons/ha in 2015, compared to 2.5 tons/ha found for traditional varieties in 1995 (Figure 2.3). Further, a yield advantage of 1.0-1.5 tons/ha, on average, is observed from STRVs compared to popular farmer varieties (Manzanilla et al. 2017). An average yield of 6.1 tons/ha was recorded for 15 STRVs in the 2015 dry season in six provinces in MRD (IRRI 2016). Further, under saline soils of 1.5 - 3‰ in the coastal MRD, yields for sensitive and moderately salt-tolerant rice varieties are 20% to 50% lower than yields for new STRVs. This means that STRVs show a yield advantage of 1-2 tons/ha under salinity exposure (Nhan et al. 2012), with little or no yield penalty under low salinity exposure.

Recently, Kai, Xuan, and Duyen (2018) investigate the impact of salinity on the profit of farmers living in Soc Trang province. They examine 214 rice-growing farmers in three different districts with similar social and natural conditions, except for different average salinity levels. In the 2015/2016 Dong Xuan season, profits in the high salinity district are VND 15.1 million per hectare, lower than profits in the low salinity district. The study does not, however, account for

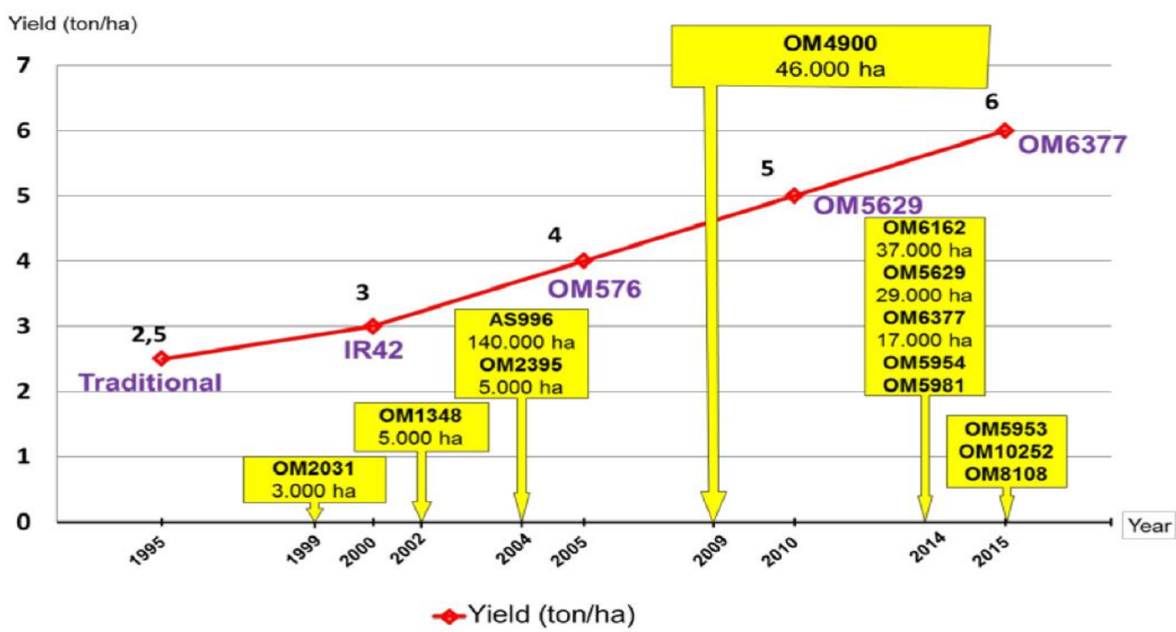

Figure 2.3. Average yield of STRVs and their planted areas in coastal southern Vietnam, MRD
Source: Manzanilla et al. 2017

changes in farmer behavior and production decisions that may result from residence in a high salinity risk environment.

Chapter 3. Conceptual Framework

The framework for the farmer decision to adopt CURE-related varieties is outlined in Figure 3.1. Farmers are assumed to trade-off more stable and possibly higher yields from CURE-related varieties against lower prices for harvested rice. Factors that influence the decision to adopt CURE-related varieties in this context include environment risk and farmers' risk preferences. Environment risk is determined mainly by risk of salinity exposure, while farmer risk preferences are largely determined by household characteristics. As part of the decision-making process, households also learn about the impact of salinity shocks on rice production and the possibility of CURE-related varieties to buffer shocks from both their own experience and the

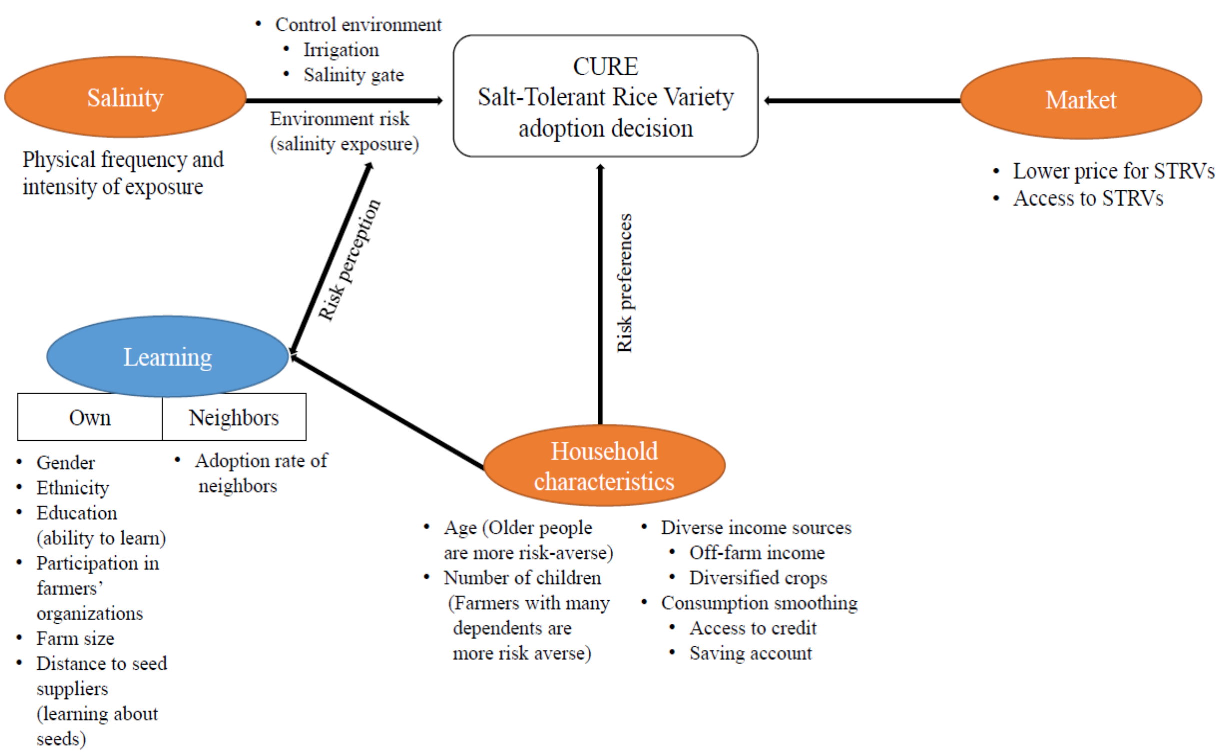

Figure 3.1. Framework for farmer salt-tolerant rice variety (STRV) decision

experiences of their neighbors. Adoption decisions are therefore characterized as arising from utility maximizing behavior under risk (Just and Zilberman 1983) and from learning (Foster and Rosenzweig 1995; Bardhan and Udry 1999).

3.1. Maximizing Utility under Risk

Salinity shock can significantly decrease the yield of rice and associated profits from rice farming. Faced with a higher danger of salinity exposure with more frequent and intense salinity shocks, farmers increasingly prefer rice varieties which produce a higher yield under salinity exposure, and, thus, lower overall variability of yield and associated lower variability in rice production income. Farmers' utility from using CURE-related varieties in salinity-prone areas can be higher than that of using non-CURE-related varieties if annual income fluctuations are reduced, even if CURE-related varieties do not generate a higher profit. In fact, CURE-related varieties fetch a lower price in the market, and adopting farmers may be willing to forgo some profit for a steadier inter-annual income stream.

The clear advantage of CURE-related varieties is that they do not generate a yield penalty during seasons with low salinity and potentially higher yields in seasons with high salinity. However, some farmers still prefer to use non-CURE-related varieties due to their high selling price in the market. A common trade-off when adopting new technologies is the benefit of lower variance of yield against higher yields (Ben-Ari and Makowski 2016). In our case, adopting CURE-related varieties is a 'risk-income' trade-off between lower variance of yield (lower risk) with possibly a higher average yield across years and a lower price to sell (lower income). It is expected that farmers growing rice in more salinity-prone areas are more willing to accept a lower selling price for a stable yield. By the same token, farmers may be less likely to adopt CURE-related varieties in rice-growing areas where they have greater control over the salinity environment through pump irrigation and, importantly, through protection from salinity barrier gates that have been installed in some salinity-prone areas.

Assuming farmers in salinity-prone areas prefer lower variance of yield, adoption decisions are influenced by farmers' risk preferences, attitudes towards risk. Farmers in developing countries are almost always risk averse (Binswanger and Sillers 1983), and the extent of risk aversion depends on household socioeconomic characteristics. More risk averse farmers have a steeper concavity of a utility function for income and are willing to pay a greater premium for certain outcomes relative to uncertain ones. In this case, more risk averse farmers are likely to put a greater value on CURE-related varieties as a safer option and are more likely to adopt them. Researchers commonly find that risk aversion decreases with the higher levels of wealth (Miyata 2003). Thus, low income farmers may be more likely to adopt CURE-related varieties. The number of children in the household is also found to increase farmers' risk preferences (Love 2009; Dohmen et al. 2011). In the face of high salinity, rice crop failure can lead to lower income and possibly food shortages. Such impacts are especially serious in families with children. Therefore, farmers who have many children may tend to be more risk averse and more likely to adopt CURE-related varieties. Similarly, Schildberg-Hörisch (2018) reviews many studies which find that individuals become more risk averse over the life cycle, suggesting older farmers may be more likely to adopt CURE-related varieties. On the other hand, age can be a proxy for farming experience, which can lower information barriers and make farmers more likely to adopt. By the same token, more experienced farmers may be more reluctant to use unknown and unproven new varieties given their larger existing knowledge base. Therefore, the relationship between farmer age and CURE-related variety adoption is left as an empirical question.

Risk preferences are also related to credit and saving capacity. In the face of salinity shocks and lower agricultural income, farmers without credit access and savings have fewer mechanisms to buffer shocks and smooth their consumption and may, thus, be more risk averse. Diversified income sources may also influence risk preferences. Household income will fluctuate less if diversified income sources are available. Diversified agricultural production and off-farm activities make households less dependent on variable income from rice production and possibly less likely to adopt CURE-related varieties. On the other hand, diverse-income sources are a risk management strategy, and more risk averse farmers may disproportionately seek these strategies to avoid environmental risk. Thus, the correlation between diversified income sources and CURE-related variety adoption is left as an empirical question.

3.2. Learning

Learning is also an important factor in the adoption decision. Farmers learn about both their salinity environment and characteristics of CURE-related varieties through their own experiences and from the experience of others (Foster and Rosenzweig 1995). Farmers incorporate learned information when they make decisions about changing rice varieties.

Farmers learn about the salinity environments from salinity shocks and adjust their expectations about the distribution of shocks accordingly (Moore 2017). This learning process is accelerated if farmers' fields are frequently and intensively affected by salinity shocks. The perception of increased salinity risk motivates farmers to adopt CURE-related varieties.

Own experimentation leads to better knowledge about characteristics of new varieties. The experimentation can be in the form of planting rice on a part of, or all of, their land. The information from own experimentation is influential because knowledge obtained from own experience is not obtained through social networks and includes less noise.

Farmers also learn information about varieties in community meetings. In the Mekong River Delta, some farmers participate in seed clubs that produce and supply seed varieties (Tin et al. 2011). Extension agents also visit the community meetings, perform demonstrations, and hold training sessions to deliver information about new variety characteristics. These diverse learning channels help alleviate uncertainty about varietal performance and diminish information barriers to the adoption. Some groups may have less access to information through these channels. For instance, female farmers may obtain less information from some social networks than male farmers, as rural community meetings and extension activities are dominated by men. In Chi's study (as cited in Gallina and Farnworth 2016), women feel alienated from training sessions, and many women interviewed are not informed where they can meet extension workers. Similarly, ethnic minorities may live in isolated areas, which limits their links to sources of varietal information.

Farmers' education level also influences learning from their own experiences. Higher education enables farmers to obtain, process, and use information relevant to changes in agricultural production (Schultz 1975). For example, they may be more adept in collecting information about variety attributes as well as optimal input levels to produce high yields with new varieties. Huffman (1977) finds that education improves farmers' ability to perceive and respond efficiently to changes in conditions. Feder, Just and Zilberman (1985) cite a number of studies which show a positive relationship between early technology adoption and education.

Field size may also influence investments in learning. According to Just and Zilberman (1983), the adoption of a new technology normally requires additional fixed costings in terms of time for learning. Larger farms are more willing to bear fixed learning costs, as potential benefits are larger, and may be more likely to adopt CURE-related varieties.

Easy access to CURE-related varieties may also facilitate learning and adoption. Farmers who live in villages in close proximity to seed suppliers are more likely to learn about new varieties and, thus, adopt them. Farmers can communicate more easily with seed suppliers in close proximity. Also, close distance and frequent communication improve the quality and reliability of information because the relationship between suppliers and consumers of seed varieties is not a one-time event. Therefore, farmers living close to seed suppliers can update information about CURE-related varieties more quickly and are more likely to adopt new varieties.

Learning can also occur through information from neighbors farming activities. Neighbors use of CURE-related varieties, therefore, create information spillovers and learning externalities (Bardhan and Udry 1999). Uncertainty about the attributes of CURE-related varieties can be reduced by knowledge generated by neighbors, making farmers more likely to adopt new varieties. Many researchers have focused on the role of learning from other farmers' adoption decisions. Feder and O'Mara (1982) construct an aggregative innovation diffusion model based on the assumption that farmers update their perceptions of new technology by observing adopters' outcomes through a Bayesian process. A farmer can skip their own experimentation stage with varieties if they acquire enough information from their adopting neighbors. Similarly, Lewis, Barham, and Robinson (2011) find spatial spillovers in the adoption decisions of organic farming systems in Wisconsin and show that neighboring farmers help to reduce uncertainty related to new technology and affect the technology adoption decisions. Thus, learning is likely to be faster with more adopting neighbors.

In summary, farmers' CURE-related variety adoption decisions are influenced by their environment, risk preferences, learning from own experiences, and learning from interactions with neighbors. Farmers in the study area are susceptible to saltwater intrusion on their fields, and suffer reduced rice yields in years of high salinity. Farmers can adopt CURE-related varieties to stabilize rice yield and reduce income variability. However, adopting CURE-related varieties entails a trade-off between stable rice yields and lower selling price at the market. More risk averse farmers place a higher value on lower variability of yield and are more likely to adopt CURE-related varieties. In the adoption decision process, farmers learn from their own experiences and from neighbors, updating their perceptions of both the probability of being exposed to salinity shocks and the attributes of CURE-related varieties.

Chapter 4. Methods and Data

This chapter presents the procedures for data collection and descriptive statistics on variables employed in the analysis. The chapter is divided into five sections. The first section describes sampling procedures, which involved selecting survey provinces, districts, villages, and households, and introduces salinity data. The second section presents descriptive statistics on survey household rice planting dates. The third section reports data on the diffusion of CURE-related varieties and leading non-CURE-related varieties. The fourth section presents a test of the spatial clustering of adoption between neighboring villages. Finally, the fifth section provides descriptive statistics on field and household characteristics of fields with and without adoption.

4.1. Sampling Procedures

Data for the analysis is drawn primarily from a random sample of 800 rice growing households conducted in June-July 2018 in salinity-prone districts of the MRD. Sampling proceeded in four sequential steps of selecting salinity-prone rice-growing provinces, districts, villages, and eventually households. First, seven salinity-prone provinces were identified based on a 2016 salinity intrusion map from the Water Resources Research Institute of Southern Vietnam (Ben

Tre, Tien Giang, Tra Vinh, Soc Trang, Bac Lieu, Ca Mau, and Kien Giang). Second, 57 salinity-prone districts in the MRD (see Figure A.1 in Appendix A) were identified based on three different sources: 1) the aforementioned map; 2) expert opinion from the CLRRI; and 3) verification with province-level officials from the Department of Water Resources. At least two out of these three sources concurred that each of these 57 districts is salinity-prone. Third, a population-weighted sample of 100 villages was randomly drawn from the 57 districts, using Agricultural Census 2016 data, along with 50 backup villages. The backup villages were used in case there was a need to replace villages where commune-level officials revealed households in the village no longer planted rice. After survey roll-out, if additional non-rice growing villages were identified, they were replaced by the closest rice-growing village in the same commune. As a result, the random sample of 100 villages are located in 38 salinity-prone districts. Fourth, eight households were selected within each village. A survey supervisor contacted a commune official or a village head in advance of the survey date to request a list of all rice-growing households in a village. If they could provide the list, the supervisor would randomly select 10 households in each village consisting of 8 households to be surveyed and 2 households as backups. However, in most cases, a complete list was not available, and the commune official or village head was asked to provide a list of 20 households, 5 of which were relatively well off, 10 of which had an average level of wellbeing, and 5 of which were less well off. Eight households were then randomly selected from this list. In the case that any household declined to be interviewed, another household from the list was randomly selected to be interviewed as a replacement. As a result, 8 households were interviewed in each village, and a total of 100 villages were surveyed, resulting in a total sample of 800 households.

The survey was conducted in collaboration with Virginia Tech, the International Center for Tropical Agriculture (CIAT), Can Tho University, and a consultant from CLRRI. Three survey teams conducted interviews, and each team consisted of four or five student enumerators and one faculty supervisor from the Department of Economics at Can Tho University. Most of enumerators were from the survey areas, which helped when communicating with farmers. Prior to the survey roll-out, enumerators were trained for four days and conducted two day-long pilots.

The structured household survey questionnaires covered household rice production activities in 2017/2018 Dong Xuan season and early stage planting activities in the on-going 2018 He Thu season. The household member responsible for managing rice production activities was surveyed. Dong Xuan season survey questions included rice production activities such as field preparation, irrigation systems, ownership status, information about varieties cultivated, production costs, and amounts harvested. For the He Thu season, most of households had already finished or planned seeding, and varietal information was collected. Along with rice production activities, the survey included questions on household demographics, occupations, education attainment, farm assets, social networks, and farmers' credit status. The household survey instrument can be found in Appendix C.

An accompanying village questionnaire (Appendix C) surveyed the commune officials or village heads on household sources of rice seed, as well as the distance to seed providers from the village. The village questionnaire also included questions on how important the seed suppliers or institutions were to farmers in terms of access to rice-seed.

Secondary data on salinity exposure over the past 15 years was collected from the National Center for Hydro-Meteorological Forecasting in Vietnam to measure historical exposure. In order to select salinity-monitoring stations, each village in the sample was matched to the most relevant station based on water-flow data from the Department of Hydrology in Central and South Vietnam, resulting in the identification of 27 stations. Salinity-monitoring stations measure minimum, maximum, and mean salinity concentrations (‰[1]) every day at hourly increments. Detailed hourly salinity readings were compiled into monthly salinity levels, and these levels were collected from February to July for the years 2003-2013 and from January to June for the years 2014-2017. The salinity levels are not measured in the other months since the salinity levels are low in those periods. For this study, we used monthly average salinity levels for the months of February to June from 2003 through 2017.

4.2. Date of Planting

Rice planting dates were more heterogeneous than expected. In this study, two seasons that start before and after the January–March salinity window are referenced to as Dong Xuan and He Thu seasons, respectively. The sample used in the analysis focuses on 809 fields (685 households) that planted rice between September 2017 and January 2018 for the Dong Xuan season, and 699 fields (598 households) that planted rice between April and July 2018 for the He Thu season. Rice crops planted in these periods are most likely to be influenced by salinity surges. The number of fields (households) with planted rice in either of these two season windows is 858 (729).

The heterogeneous planting dates still exist even after defining the range of months for seasons. For example, the average month of rice planting in each village for the Dong Xuan season is illustrated in Figure A4 (Appendix A). The map shows that farmers growing rice near the coast, having a higher possibility of being exposed to salinity intrusion in their fields, are more likely to plant rice earlier. Early seeding for the Dong Xuan season appears to be a farmer

[1] This measure is expressed as parts per thousand (ppt) or g/l.

salinity adaptation strategy because early seeding allows harvesting of rice before the salinity surge.

4.3. Diffusion of Varieties

4.3.1. Diffusion of CURE-related varieties

Survey data indicates a total of 42 rice varieties are grown by the households in either the Dong Xuan or the He Thu season; a high level of varietal diversity in salinity-prone rice growing areas of the MRD. CLRRI's expert, Dr. Liem Bui, provided characteristics for all varieties, along with whether each variety was part of CURE multilocational trials in the MRD. Of the 42 varieties, 7 (17%) were identified as CURE-related rice varieties. However, these CURE-related varieties show wide spread usage, by 45% of all households. Moreover, out of the total 1,382 hectares of sample fields, 656 hectares (47%) were cultivated with CURE-related varieties in at least one season (Dong Xuan and/or He Thu). Specifically, 37% and 41% of sample fields were planted with CURE-related varieties in the Dong Xuan season and the He Thu season, respectively. Adoption rates of CURE-related varieties also differ significantly by province (Table 4.1), ranging from 75 percent of households in Soc Trang province to 11 percent in Ben Tre province. The remaining four provinces show adoption rates between 30 and 60 percent.

Rice production and area planted under CURE-related varieties in salinity-prone areas of the MRD are extrapolated for the year 2017. First, 57 districts in seven provinces are identified as salinity-prone areas using the three aforementioned sources in the sampling procedures (section 4.1). Total rice production and total planting area in these salinity-prone districts are obtained from Statistical Publishing House (2018) for the Dong Xuan and He Thu seasons (Table B2 in Appendix B). Using field adoption rates of each season (Table B3 in Appendix B) calculated from our random sample in these salinity-prone areas, we imputed rice production and

Table 4.1. Adoption rate of CURE-related varieties by province

Province	Number of villages	Total number of households	Number of households who adopted CURE-related varieties	Adoption rate (%)
Ben Tre	22	170	18	10.59
Tien Giang	12	96	31	32.29
Tra Vinh	8	60	37	61.67
Soc Trang	20	157	117	74.52
Bac Lieu	10	77	29	37.66
Ca Mau	9	39	26	66.67
Kien Giang	19	130	69	53.08
Total	**100**	**729**	**327**	**44.86**

planting area of CURE-related varieties. The results (Table B4 in Appendix B) show that the Soc Trang and Kien Giang provinces contain the largest share of CURE-related varieties in the Dong Xuan season, with approximately 83 and 69 thousand hectares planted and approximately 535 and 406 thousand tons harvested, respectively. It is also worth noting that little rice is grown in the Dong Xuan season in Ca Mau province, but 73% of fields are under CURE-related varieties in the He Thu season. Overall, for the Dong Xuan season 197 thousand hectares are under CURE-related varieties that produce 1.2 million tons of rice. For the He Thu season the comparable figures are 239 thousand hectares producing 1.3 million tons of rice with CURE-related varieties.

Survey data also indicates that the rice-seed varieties are used for an average of 4.7 years. Figure 4.1 and Figure 4.2 are frequency distribution charts which show the number of years that CURE- and non-CURE-related varieties have been used in fields, respectively. Both the CURE- and non-CURE-related varieties have an average of 4.4 and 4.5 years, respectively, for the Dong Xuan season, and 4.7 and 5.3 years for the He Thu season. Most CURE-related varieties are relatively newer than non-CURE-related varieties, and they have narrower distributions as expected.

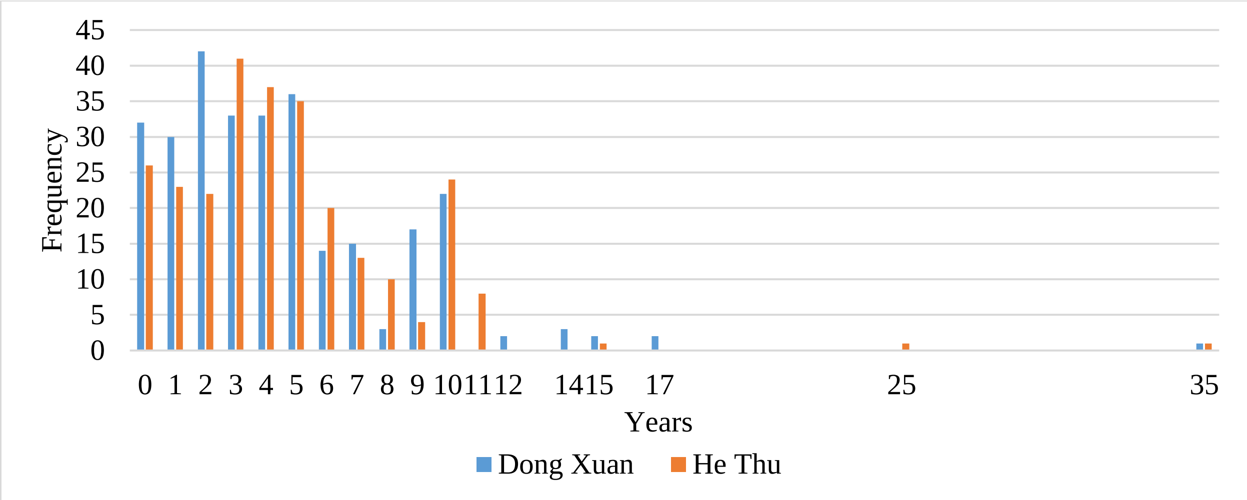

Figure 4.1. Frequency distribution of number of years: CURE-related varieties in 2017/2018 Dong Xuan and 2018 He Thu seasons

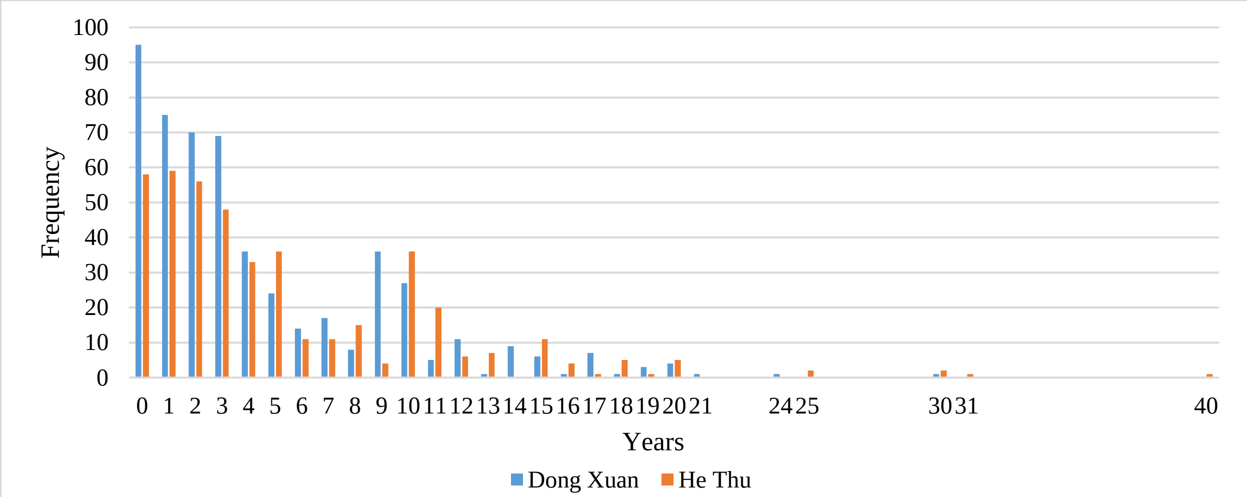

Figure 4.2. Frequency distribution of number of years: non-CURE-related varieties in 2017/2018 Dong Xuan and 2018 He Thu season

4.3.2. Leading CURE-related and non-CURE-related varieties

The concentration of CURE-related variety types in the 2017/2018 Dong Xuan and the 2018 He Thu seasons is illustrated in Figure 4.3. For both seasons, the largest area is under OM5451, followed by OM6976 and OM4900. OM5451 accounts for around 50 percent of areas planted with CURE-related varieties in the Dong Xuan season and around 70 percent in the He Thu season.

Less concentration is shown in non-CURE-related varieties. The proportion of the top eight non-CURE-related varieties, cultivated in both seasons, is illustrated in Figure 4.4. ĐS1 is widely used in the survey areas, followed by Đài Thơm 8 and OC10. These eight varieties account for about 80 percent of the area planted with non-CURE-related varieties. ĐS1 represents around 25 percent of the rice area cultivated with non-CURE-related varieties in the Dong Xuan season and around 30 percent in the He Thu season. The area planted with all CURE- and non-CURE-related varieties is shown in Table B5 and Table B6 (Appendix B).

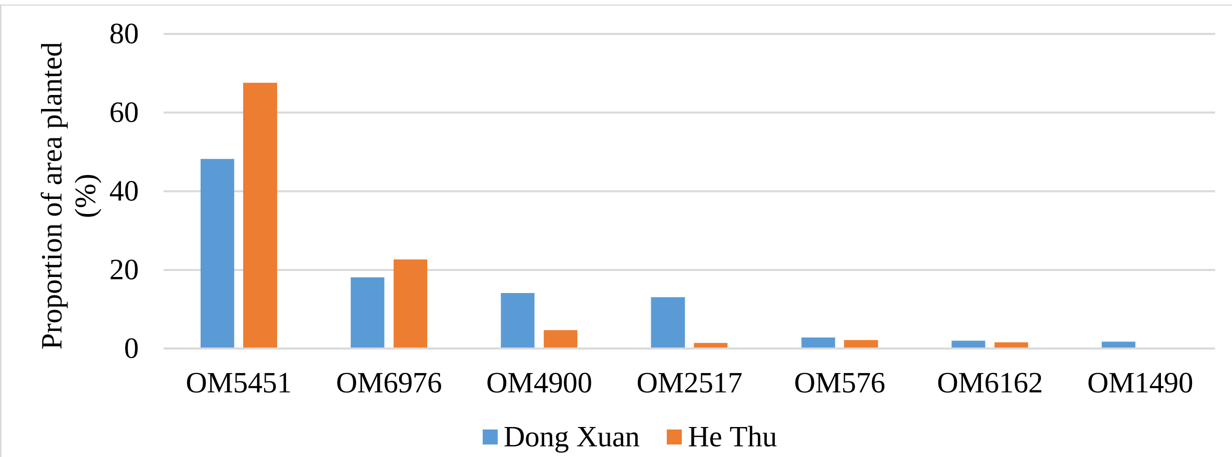

Figure 4.3. Varietal distribution of CURE-related varieties in 2017/2018 Dong Xuan and 2018 He Thu seasons

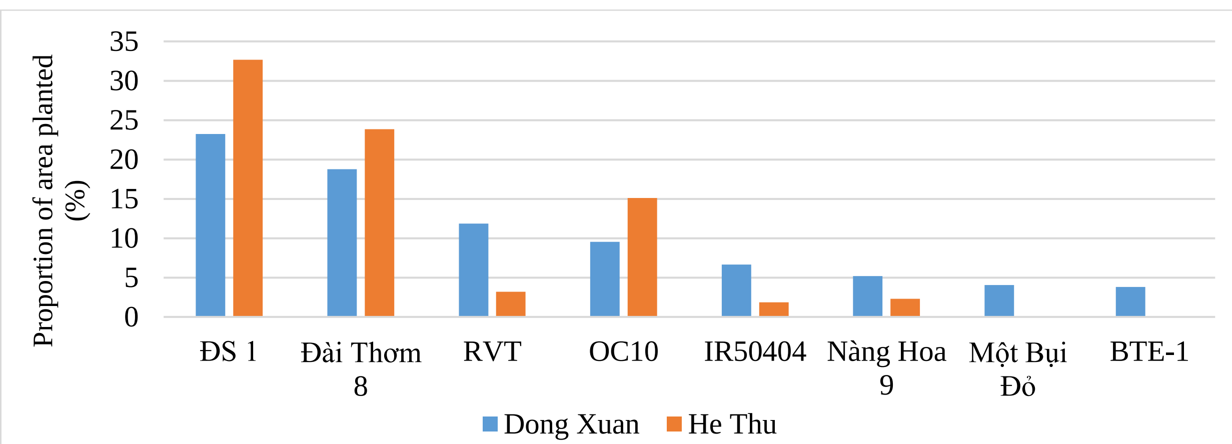

Figure 4.4. Varietal distribution of top eight non-CURE-related varieties in 2017/2018 Dong Xuan and 2018 He Thu seasons

4.4. Spatial Clustering

A map of village adoption rates of CURE-related varieties (Figure 4.5) suggests adoption rates are geographically clustered at the village level. In order to test for statistical evidence to spatial clustering, a Global Moran's I test is performed.

The Global Moran's I statistic is given as:

$$\mathrm{I} = \frac{n}{S_0}\frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{i,j}(x_i-\bar{x})(x_j-\bar{x})}{\sum_{i=1}^{n}(x_i-\bar{x})^2}$$

where $(x_i-\bar{x})$: deviation of a number of adopters for village i from its mean

$w_{i,j}$: spatial weight between village i and j

: an inverse distance weights matrix is used where the elements of the matrix is as follows: $w_{ij} = \begin{cases} \frac{1}{d_{ij}} & if\ i \neq j \\ 0 & if\ i = j \end{cases}$

n : the total number of villages

S_0 : an aggregate of all the spatial weights = $\sum_{i=1}^{n}\sum_{j=1}^{n} w_{i,j}$

In the case that close villages have similarly higher or lower adoption rates than the mean adoption rate, the index returns a positive high number. A positive value with statistical significance on the z-scores indicates that neighbors tend to have similar adoption rates. On the contrary, a negative index with statistical significance demonstrates spatial clustering is dispersed, suggesting that a village is surrounded by villages having dissimilar adoption rates. Zero index represents no spatial clustering, indicating that adoption rates by village are randomly distributed.

The results in Table 4.2 shows a positive and significant village-level spatial clustering of adoption rates for all three season categories in the study areas. If households in a village have a high (low) adoption rate, the households growing rice in the adjacent villages are more likely to adopt CURE-related varieties at a higher (lower) rate. This clustering may stem from local externalities in neighbor adoption. However, a multivariate model is needed to further examine the influence of within-village neighbors' adoption decisions along with other village-level environmental factors that influence area-wide adoption.

Table 4.2. Global Moran's I by type of season

	Dong Xuan	He Thu	Either of two seasons
Global Moran's I	0.360	0.440	0.536
(variance)	(0.006)***	(0.005)***	(0.006)***
z-score	4.837	6.321	7.206

Note: Significance of z-test is reported as *** p<0.01.

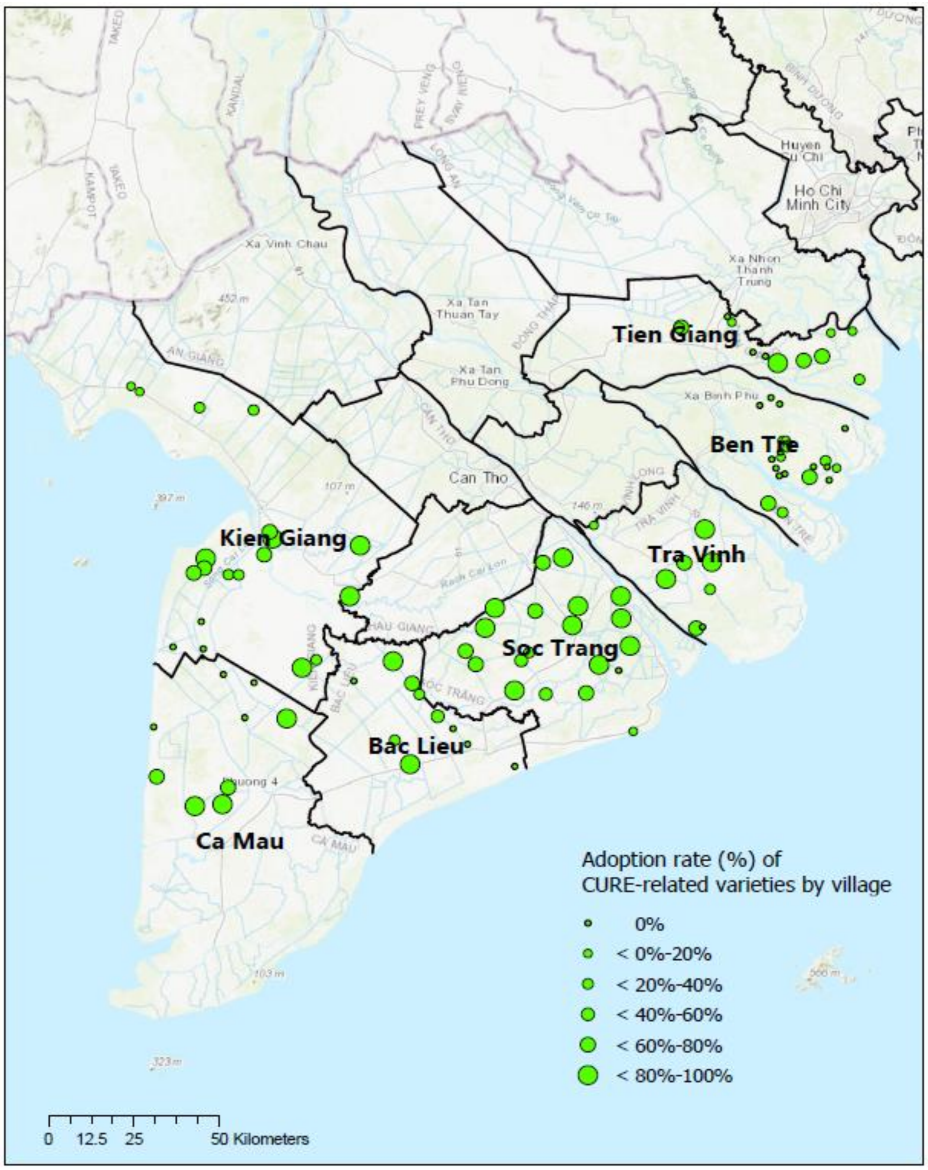

Figure 4.5. Village-level adoption rate of CURE-related varieties by households in either 2017/2018 Dong Xuan or 2018 He Thu Season in the MRD

4.5. Descriptive Statistics of Adopting Households

Descriptive statistics for all independent variables in the empirical model are provided for fields with and without adoption of CURE-related varieties separately for the Dong Xuan season (Table 4.3) and the He Thu season (Table 4.4). Table B7 in Appendix B provides similar comparisons between adopting and non-adopting households which planted in either the Dong Xuan or the He Thu season.

Several significant differences in household and field characteristics are found for the Dong Xuan season (Table 4.3). Notably, field managers planting CURE-related varieties are more likely to be from the minority Khmer ethnic group. Most field managers have primary level schooling and no statistically significant educational differences are found between fields with adoption and without adoption of CURE-related varieties. Diversity of household income sources are also similar, but managers of fields that do not adopt CURE-related varieties take part in significantly more community meetings than be managers on fields with adoption. Since CURE varieties target unfavorable environments, this finding suggests that farmers in these environments may be more socially isolated. No significant difference in number of children, access to credit, savings accounts, or field size are found.

The average distance to government and extension sources is significantly farther for fields with adoption (4.6km) than fields without adoption (3.6km), while the average distance to other seed providers is not significantly different. In line with CURE focus on unfavorable environments, fields with CURE-related varieties are more likely to be found in areas with tidal irrigation and pump irrigation without salinity barrier gates, but far less likely to be found in areas with pump irrigation that are protected by salinity gates.

Historical salinity exposure data for the 15-year period from 2003 to 2017 shows similar levels of exposure for fields with adoption and without adoption of CURE-related varieties. The result contrasts with the previous finding on irrigation system types, but it is important to remember that historic salinity exposure data is measured at the river entrance and salinity exposure at the field level is likely to be strongly influenced by irrigation type. Fields with and without CURE-related varieties also show dramatic and significant differences in terms of level of neighbor rates of adoption of CURE-related varieties. On fields with adoption, 74% of neighbors have also adopted CURE-related varieties, while on fields without adoption, only 32% of neighbors have adopted CURE-related varieties. Finally, fields with CURE-related varieties show a higher yield than fields without CURE-related varieties in the Dong Xuan season, suggesting little or no yield penalty imposed on CURE-related varieties in a year with low salinity exposure. However, no significant differences in gross and net revenues are found.

Descriptive statistics for the He Thu season at the field level (Table 4.4) overall show similar results, but with several notable differences. Fields with CURE-related varieties are more likely to have male managers, but managers show no significant difference in community meeting participation. Like for the Dong Xuan season, the average distance to government and extension sources is significantly farther on fields with adoption (5.3km) than fields without adoption (3.5km), but the average distance to other seed providers is now significantly closer for fields with adoption. Historical salinity exposure is now higher for fields that do not adopt CURE-related varieties, while the significant differences in type of irrigation found in the Dong Xuan season remain.

Table 4.3. Descriptive statistics for fields with or without CURE-related varieties, 2017/2018 Dong Xuan season

	Fields with adoption		Fields without adoption		Difference in
Variable	**Mean**	**(s.d)**	**Mean**	**(s.d)**	**Means**
Age	52.157	(11.087)	52.402	(10.938)	-0.246
Male	0.902	(0.297)	0.881	(0.324)	0.021
Eth	0.213	(0.410)	0.123	(0.328)	0.090***
Eduprim	0.422	(0.495)	0.420	(0.494)	0.002
Edusec	0.247	(0.432)	0.247	(0.432)	0.000
Eduhigh	0.139	(0.347)	0.105	(0.307)	0.034
Off	0.937	(1.108)	0.845	(1.009)	0.093
Diverse	1.895	(1.342)	1.816	(1.039)	0.079
Meeting	1.735	(1.067)	1.902	(1.136)	-0.167**
Child	0.808	(0.898)	0.808	(0.998)	-0.000
Credit	0.254	(0.436)	0.289	(0.454)	-0.035
Saving	0.226	(0.419)	0.228	(0.420)	-0.001
Size	1.708	(2.439)	1.583	(2.346)	0.125
Dis1	4.644	(5.683)	3.648	(4.273)	0.996***
Dis2	7.517	(5.328)	8.283	(6.955)	-0.765
Irri1	0.181	(0.386)	0.094	(0.292)	0.087***
Irri2	0.359	(0.481)	0.255	(0.436)	0.104***
Irri3	0.383	(0.487)	0.592	(0.492)	-0.209***
Salinity	12.150	(4.351)	12.262	(4.702)	-0.113
Nei	0.743	(0.291)	0.319	(0.341)	0.424***
Yield	6,758	(2,013)	6,391	(2,049)	367**
Gross revenue	38,216	(12,165)	38,959	(11,548)	-743
Net revenue 1	27,708	(11,900)	28,067	(11,432)	-359
Net revenue 2	22,839	(11,990)	22,507	(12,098)	332
Net revenue 3	20,430	(11,980)	19,822	(12,550)	607

Note: Asterisks denote the following: *** p<0.01, ** p<0.05, * p<0.1.
Net revenue1 = gross revenue - (input cost + water cost + land rent cost)
Net revenue2 = gross revenue - (input cost + water cost + land rent cost + machine cost + hired labor cost)
Net revenue3 = gross revenue - (input cost + water cost + land rent cost + machine cost + hired labor cost + family labor cost)

Table 4.4. Descriptive statistics for fields with and without CURE-related varieties, 2018 He Thu season

	Fields with adoption		Fields without adoption		Difference in
Variable	**Mean**	**(s.d)**	**Mean**	**(s.d)**	**Means**
Age	52.120	(10.871)	53.162	(10.943)	-1.041
Male	0.932	(0.252)	0.873	(0.333)	0.059**
Eth	0.248	(0.433)	0.129	(0.336)	0.119***
Eduprim	0.451	(0.499)	0.400	(0.490)	0.052
Edusec	0.256	(0.437)	0.238	(0.426)	0.018
Eduhigh	0.098	(0.298)	0.115	(0.320)	-0.018
Off	0.895	(1.037)	0.935	(1.063)	-0.041
Diverse	1.726	(1.212)	1.651	(0.960)	0.074
Meeting	1.816	(1.169)	1.908	(1.125)	-0.092
Child	0.835	(0.892)	0.769	(1.064)	0.066
Credit	0.248	(0.433)	0.261	(0.440)	-0.013
Saving	0.222	(0.416)	0.240	(0.428)	-0.018
Size	1.730	(2.463)	1.503	(2.472)	0.227
Dis1	5.328	(6.302)	3.513	(4.316)	1.815***
Dis2	6.712	(5.799)	8.610	(6.884)	-1.898***
Irri1	0.169	(0.376)	0.102	(0.302)	0.068***
Irri2	0.312	(0.464)	0.286	(0.453)	0.026
Irri3	0.477	(0.500)	0.589	(0.493)	-0.111***
Salinity	11.305	(4.399)	12.381	(4.773)	-1.077***
Nei	0.796	(0.258)	0.286	(0.322)	0.510***

Note: Asterisks denote the following: *** p<0.01, ** p<0.05, * p<0.1.

Chapter 5. Empirical Framework

This chapter describes the empirical approaches employed in the thesis. A multivariate model estimates the factors affecting adoption of CURE-related varieties, whereas a propensity score matching (PSM) model assesses performance of CURE-related varieties. In the first section, a random utility model of the farmers' adoption decisions is presented and two associated binary choice empirical models (linear probability model and logit model) are specified. The second section of the chapter presents the explanatory variables employed in the statistical model. The third section describes the PSM for variety performance analysis of three outcome variables: yields, gross revenues, and net revenues.

5.1. Binary Choice – Random Utility Model

The observed adoption decision is a binary choice and is represented by a random utility model. The choice among discrete alternatives means that farmers either adopt CURE-related varieties or not. The value of alternatives is measured as utility, and individual utility from adoption differs by farmer as a random variable. In the farmer i's decision rule, s/he chooses the alternative which maximizes his or her utility (U_{ni}) between two options (n=1 if the farmer adopts and n=0 if the farmer does not). The utility is broken down into two parts: observable elements ($\boldsymbol{x'}_{ni}\boldsymbol{\beta}_{ni}$) and random element ($\varepsilon_{ni}$) (equation (1)).

$$U_{ni} = \boldsymbol{x'}_{ni}\boldsymbol{\beta}_{ni} + \varepsilon_{ni} \qquad (1)$$

It is not usually possible to predict with certainty the alternative that the farmer will select, but it is possible to express the probability that the farmer will select the alternative among CURE- and non-CURE-related varieties. In the utility maximizing model, a farmer i adopts CURE-related varieties when the utility of adoption (U_{1i}) is greater than that of non-adoption (U_{0i}), and the probability that the i^{th} farmer adopts (n=1) can be expressed as:

$$P_i(n = 1) = P(U_{1i} \geq \mathrm{U}_{0i}) = P(\boldsymbol{x'}_{1i}\boldsymbol{\beta}_{1i} + \varepsilon_{1i} \geq \boldsymbol{x'}_{0i}\boldsymbol{\beta}_{0i} + \varepsilon_{0n}). \qquad (2)$$

Rearranging the equation (2) is:

$$P_i(n = 1) = P(\boldsymbol{x'}_{1i}\boldsymbol{\beta}_{1i} - \boldsymbol{x'}_{0i}\boldsymbol{\beta}_{0i} \geq \varepsilon_{0n} - \varepsilon_{1i}). \qquad (3)$$

Adoption probability depends on the difference between the utility obtained from adopting and non-adopting decisions. This difference between the utilities is known as relative utilities (Cascetta 2009). At the same time, the probability depends on the joint distribution of the difference between the random elements. Depending on functional forms of joint distribution of random variables, different random utility models can be derived (Cascetta 2009). In this regression analysis, linear probability and logit models, which are widely used in adoption model, are employed to estimate adoption probability. These models assume normal and logistic joint distributions of random variables, respectively.

5.1.1. Linear probability model

A linear probability model (LPM) is similar with ordinary least squares (OLS), except for a dependent variable that is either zero or one. This expected dependent variable y_i is transformed to the probability of having $\mathrm{y}_i = 1$ (Aldrich and Nelson 1984). The model is specified as:

$$\mathrm{E}(\mathrm{y}_i) = \mathrm{P}(\mathrm{y}_i = 1|\boldsymbol{x}_i) = \widehat{\beta_0} + \widehat{\beta_1} x_{i1} + \cdots + \widehat{\beta_k} x_{ik} \quad (4)$$

where $\mathrm{P}(\mathrm{y}_i = 1|\boldsymbol{x}_i)$ is a choice probability that farmer i adopts,

$\boldsymbol{x}_i$ represents a vector of explanatory variables,

$\widehat{\beta_0}$ is an intercept,

$\widehat{\beta_k}$ are unknown parameters.

Due to the changed form of dependent variable, the right-hand side of regression equation is interpreted as a probability. A drawback of LPM estimation with binary dependent variables is that there exists inherent heteroscedasticity. To account for heteroscedasticity, robust standard errors are estimated (Nikolla et al. 2017). Otherwise, the statistical inference would be inefficient. Another possible drawback is that predicted values in the estimated model may fall outside the [0,1] interval, which violates the basic principles of probability. However, we use the LPM model to take advantage of ease of estimation and interpretation. The robustness of the LPM estimates are explored by using a logit model as recommended by Feder, Just, and Zilberman (1985) to ensure that the dependent variable never falls below 0 or above 1.

5.1.2. Logit model

A logit model is derived assuming the random variables in equation (3) have a standard logistic distribution. The logit model is specified below:

$$\mathrm{P}(\mathrm{y}_i = 1|\boldsymbol{x}_i) = \mathrm{G}(\beta_0 + \beta_1 x_{i1} + \cdots + \beta_k x_{ik}) = \frac{e^{\beta_0+\beta_1 x_{i1}+\cdots+\beta_k x_{ik}}}{1+e^{\beta_0+\beta_1 x_{i1}+\cdots+\beta_k x_{ik}}} \qquad (5)$$

where G is logistic distribution. The primary goal of the empirical model is to explain the effects of the independent variables on the probability $\mathrm{y}_i = 1$. Since equation (5) follows the logistic function, estimated coefficients are not marginal effects like in the LPM model. If x_{ik} is a continuous variable, the partial effect of x_{ij} on the probability $\mathrm{y}_i = 1$ is calculated using the chain rule as below (Wooldridge 2013):

$$\frac{\partial \mathrm{P}(\mathrm{y}_i = 1|\boldsymbol{x}_i)}{\partial \mathrm{x}_{ij}} = \frac{\mathrm{dG}(\beta_0+\beta_1 x_{i1}+\cdots+\beta_k x_{ik})}{d(\beta_0+\beta_1 x_{i1}+\cdots+\beta_k x_{ik})} * \beta_j \qquad (6)$$

The marginal effect of variable x_{ik} depends on the derivative of the right hand side in the equation (6), and can be complex to calculate. One can calculate average marginal effects using the ‘margins’ Stata code. This approach directly estimates the change in the probability by holding all independent variable at their mean value and adding one unit to the variable of interest x_{ij} (Wooldridge 2013). From changing from x_{ij} to $x_{ij} + 1$, the marginal effect is calculated as below:

$$\mathrm{G}\big(\hat{\beta}_0 + \hat{\beta}_1 \bar{x}_{i1} + \cdots + \hat{\beta}_k (x_{ij} + 1)\big) - \mathrm{G}\big(\hat{\beta}_0 + \hat{\beta}_1 \bar{x}_{i1} + \cdots + \hat{\beta}_k (x_{ij})\big) \qquad (7)$$

Since the logit model is nonlinear binary response model, estimation of this model is conducted using the method of maximum likelihood (Wooldridge 2013).

5.2. Empirical Model Specification

The variables to be included in the statistical model of CURE-related variety adoption are specified below. The specification of the empirical model is as follows:

$$
\begin{aligned}
&P(y\ of\ farmer\ i\ in\ village\ n|\boldsymbol{x}_i) \\
&\qquad = G(\beta_0 + \beta_1 Age_i + \beta_2 Male_i + \beta_3 Eth_i + \beta_4 Eduprim_i + \beta_5 Edusec_i \\
&\qquad + \beta_6 Eduhigh_i + \beta_7 Off_i + \beta_8 Diverse_i + \beta_9 Meeting_i + \beta_{10} Child_i \\
&\qquad + \beta_{11} Credit_i + \beta_{12} Saving_i + \beta_{13} Size_i + \beta_{14} Dis1_{ni} + \beta_{15} Dis2_{ni} + \beta_{16} Irri1_i \\
&\qquad + \beta_{17} Irri2_i + \beta_{18} Irri3_i + \beta_{19} Salinity_{ni} + \beta_{20} Nei_{ni} + \varepsilon_i)
\end{aligned}
$$

where $\mathrm{P}(\mathrm{y}_i = 1|\boldsymbol{x}_i)$ is a choice probability when farmer i living in village n adopts CURE-related varieties. (·) is the LPM or logit function represented in equation (4) and (5), respectively.

Explanatory variables include 1) primary farmer's characteristics; 2) indicators of rice growing physical environments; and 3) an indicator of learning from neighbors. Characteristics of a farmer who is primarily responsible for managing rice production include age (Age_i), gender ($male_i$), ethnicity (Eth_i), education ($Eduprim_i$, $Edusec_i$, $Eduhigh_i$), off-farm worker (Off_i), diversified crops ($Diverse_i$), number of community meeting groups attended ($Meeting_i$), number of children ($Child_i$), access to credit ($Credit_i$), and savings account ($Saving_i$). Physical environments consist of an indicator of field size ($Size_i$) and years of historic exposure to salinity ($Salinity_{ni}$). Physical environments also include indicators of distance to seed dealers to obtain new rice varieties including distance between the village and government/extension ($Dis1_{in}$) and distance between the village and a combined group of farmer seed clubs, seed centers, and private markets ($Dis2_{in}$) and of irrigation system type including tidal irrigation ($Irri1_i$), pump irrigation ($Irri2_i$), and pump irrigation protected by salinity barrier gates ($Irri3_i$). Rainfed irrigation is the baseline irrigation type. Learning from neighbors is proxied by adoption rate of neighbors who use CURE-related varieties (Nei_i). ε_i represents the error term.

Below we provide definitions of variables, the rationale for including each independent variable, and the expected signs of coefficient for each variable. Brief descriptions of the variables and their expected signs are also provided in Table B8 in Appendix B.

Age of the primary farmer – This variable **(**Age_i) indicates an age of the primary farmer, a person who manages the household's rice production in the survey year, 2018. The expected relationship of the variable with CURE variety adoption decisions is unclear. As mentioned in the conceptual framework, risk aversion is assumed to increase with age, and thus more risk averse older farmers will be more likely to adopt CURE-related varieties. However, older farmers with more farming experiences may be either more likely to adopt new varieties due to their acquired information about new varieties or less likely to adopt new varieties due to adherence to their family's historical use of non-CURE-related varieties. Studies have reported inconsistent results of the impact of farmers' age on adoption decision of new varieties. For example, improved rice varieties in Nigeria are preferred by younger farmers (Saka et al. 2005), while adopters of specialty rice were older in age in the Red River Delta of Vietnam but the relationship is not statistically significant (Pham, Dao, and Theuvsen 2017).

Gender of the primary farmer – This variable identifies the gender of the person who manages the rice crop. The dummy variable is one for male ($Male_i$) while the baseline is female. As mentioned in the conceptual framework, female farmers are likely to learn information on rice varieties more slowly than male farmers due to more difficulty in the acquisition of information through social networks. Hence, male farmers are expected to be more likely to adopt CURE-related varieties, and the expected coefficient sign of male ($Male_i$) is positive.

Ethnicity of the primary farmer – This variable (Eth_i) indicates the ethnicity of the primary farmer. Vietnamese (Kinh) is a major ethnic group, whereas Khmer and Chinese are minor ethnic groups in Vietnam. In this study, Khmer are classified as the minority group, and Vietnamese and Chinese are classified as the major ethnic group. Despite a small Chinese population in the MRD (only 1.5 percent in both the survey sample and in Census data (Table B9 in Appendix B)), Chinese are classified with the major ethnic group because they are more affluent than other ethnic groups (Dollar, Glewwe, and Litvack 1998). The dummy variable (Eth_i) indicates Khmer, and the baseline is Vietnamese and Chinese, which will be referred to as 'Vietnamese' in the following context. Khmer may live in areas with greater exposure to salinity. Salinity environment will be controlled for in the study, but the Khmer may still have positive ethnic group spillovers in terms of knowledge of salinity environments and salt-tolerant rice variety performance which increases the likelihood of adoption. The expected coefficient sign of Khmer ethnic group (Eth_i) is positive.

Education of the primary farmer – The variables related to education identify the highest level of school the primary farmer has completed. Four different categories of education level include: none, primary ($Eduprim_i$), secondary ($Edusec_i$), and high school and above ($Eduhigh_i$). The baseline is no education, and the rest of education levels are represented by dummy variables. Farmers with higher education levels learn faster by collecting, processing, and embracing information obtained from their own experiences or from neighbors and thus are more likely to adopt CURE-related varieties.

Off-farm worker and diversified crops – The off-farm worker variable (Off_i) represents the number of other household members over 14 years old whose primary occupation is wage labor or self-employment. The variable of diversified crops ($Diverse_i$) is the number of all the crops that have been grown in the past 12 months. The crops may include grains, vegetables, fruit, and aquaculture[2]. Diverse income sources from off-farm work and diversified crops influence risk preferences and adoption decisions, but the expected sign is ambiguous. Farmers with mixed income sources may be less risk averse because their total income is less affected by salinity shocks. Thus, they less likely to adopt CURE-related varieties. On the other hand, farmers with diverse income sources may be more risk averse because they have already under taken ex-ante coping strategies outside of rice farming to adapt to risk. Therefore, the expected signs of indicator variables for off-farm employment and diversified cropping are uncertain.

Participation in community meetings – This variable ($Meeting_i$) is defined as the number of organizations in which the primary farmer normally participates. Organizations include community meetings at a village or commune level, women's associations, village farmer associations, commune farmer associations, commune seed groups, district seed clubs, and others. CURE-related variety adoption is expected to increase with greater participation in community meetings. If farmers participate in different organizations, they are likely to more rapidly learn information about CURE-related varieties. This learning channel reduces the opportunity costs of acquiring information and of evaluating varieties. Therefore, participating in community meetings is expected to increase the probability of adoption of CURE-related varieties, and a positive sign for the variable coefficient is expected.

Number of children – This variable ($Child_i$) is defined as the number of household members 14 years old or less. Decreased rice production and low income due to salinity shocks

[2] Specific crops may include rice, maize, vegetables, cassava, sugar cane, beans, sweet potatoes, coconut, banana, pomelo, mango, jack fruit, longa, orange, dragon fruit, pineapple, water melon, tiger shrimp, whitetail shrimp, fish, mollusks, and others.

may be more detrimental to households with children because food shortages can threaten the health of children. Farmers with more children are expected to be more risk averse and more likely to adopt CURE-related varieties. Thus, it is expected that the coefficient sign is positive.

Access to credit – This dummy variable ($Credit_i$) is constructed to indicate whether the primary farmer or anybody from the household borrows money/credit from a bank for agricultural activities. Farmers with access to credit can defer environmental risk by smoothing their consumption through credit transactions. These farmers are also likely to be less risk averse and less likely to adopt CURE-related varieties. Therefore, the expected sign of the coefficient is negative.

One might also think that access to credit allows farmers to overcome purchase barriers for new technologies. However, this potential influence does not apply in this study. Traditionally, the lack of access to credit is regarded to inhibit technology adoption due to farmers being short of money for an initial investment. However, adoption of CURE-related varieties does not require a large lump sum payment as other new technologies do. Additionally, the mean price of CURE-related varieties is slightly less than that of non-CURE-related varieties in the Mekong River Delta. Some farmers reduce their seed costs by saving seeds for use in the next cropping seasons.

Savings account – This dummy variable ($Saving_i$) indicates whether the primary farmer or anybody in the household has a savings account. The rationale to include this independent variable is the same as for access to credit. Savings can help to smooth consumption with loss of rice production from salinity inundations. Holding a savings account can thus defer risk. Therefore, farmers with savings accounts are expected to be less likely to adopt CURE-related varieties, and the coefficient sign is expected to be negative.

Field size – This variable ($Size_i$) represents a geographic size of the rice growing field in hectares. In the household-level analysis, field size represents the aggregated number of hectares the household has under rice cultivation. Although adopting CURE-related varieties is seemingly scale neutral, there may be significant fixed costs associated with learning (Feder, Just, and Zilberman 1985). Large farms may be more willing to tolerate the fixed cost of time for learning and more likely to adopt CURE-related varieties. Thus, the sign of the coefficient is expected to be positive.

Distance to seed source – These variables ($Dis1_{in}$ and $Dis2_{in}$) are continuous measures of kilometer distance between the village and two groups of seed providers from which farmers obtain new rice varieties: government and extension workers ($Dis1_{in}$) and a combined group of farmer seed clubs, seed centers, and private markets ($Dis2_{in}$). Seed providers in the second group are combined because the individual seed sources are not accessible in every village. Distances to accessible seed providers are used to calculate an average distance to seed sources. If new-rice-seed providers are located farther away from the village, farmers may have a less opportunity to learn about new varieties from suppliers. Also, increased transaction costs for accessing seeds can be a barrier to farmers' adoption decisions. The longer distance to seed sources from the village may negatively influence the adoption of CURE-related varieties, resulting in the negative sign of the coefficient.

Irrigation – These variables indicate that the rice field has a tidal irrigation system ($Irri1_i$), pump irrigation ($Irri2_i$), or pump irrigation protected by salinity barrier gates ($Irri3_i$) with rain-fed irrigation as the baseline. Farmers who can control the environment using irrigation systems are less vulnerable to weather variations and less likely to adopt CURE-related varieties.

Pumping is one water management method which enables farmers to reduce a risk of salinity exposure. This irrigation method allows farmers to pump canal water to a rice field. Pump irrigation through protection from salinity barrier gates further reduces exposure to risky environments and, thus, farmers with this irrigation type are even less likely to adopt CURE-related varieties. On the other hand, the tidal irrigation is the most susceptible to salinity impacts. Since tidal irrigation uses water directly from rivers, when salinity level is high on a river, tidal flow brings brackish water into the fields. If farmers rely on rain-fed irrigation, they usually use soil moisture obtained during the wet season (May–October). However, during the dry season (November–April), rainfall is not enough to supply water to fields, and high temperature exacerbates salinity in soil by evaporating water. Farmers might use supplementary water such as small ponds near villages, but salinity is still high in the soil and water due to lack of access to fresh water during the dry season.

Therefore, it is expected that farmers who employ tidal irrigation suffer most from salinity shocks, followed by rain-fed irrigation, and have more incentive to adopt CURE-related varieties. The coefficient sign of tidal irrigation is expected to be positive whereas the coefficients of pump irrigation and pump irrigation protected by salinity barrier gates are expected to be negative. Additionally, the absolute value of the third coefficient ($Irri3_i$) is expected to be larger than that of the second coefficient ($Irri2_i$) because salinity barrier gates provide greater protection to control the environment, which reduces an incentive for farmers to adopt CURE-related varieties .

Salinity exposure – This variable ($Salinity_{ni}$) is a continuous measure of how many years the fields in village has potentially been exposed to significant salinity shocks over the past 15 years, as measured from the most relevant proximate salinity-station. There is an issue of how best to measure salinity exposure and characterize high salinity exposure environments. In this case, the variable represents how often the average salinity levels exceed the salinity threshold of 2 ‰ (≈3 dS/m)[3] in April when salinity level reaches its peak (CGIAR 2016). The salinity data is consistent with the finding of April as the peak month. It also bears noting that salinity levels are measured at river inlets, and may not actually represent field-level salinity exposure, particularly for fields protected by salinity barrier gates.

Farmers whose fields are exposed to saltwater intrusion experience salinity impacts including yield reduction and lower revenues. A farmer whose field is historically vulnerable to salinity exposure is, thus, more likely to adopt CURE-related varieties to reduce the variance of yield.

Rate of neighbors who use CURE-related varieties – This variable (Nei_i) represents the neighbors' adoption rate of CURE-related varieties in the village. Eight farmers are surveyed in the village. The neighbors' adoption rate is calculated by dividing the number of neighbors who have used CURE-related varieties in the village (numerator, from 0 to 7), by 7 (denominator, excluding the respondent farmer in the village). High rates of neighbors' adoption of CURE-related varieties will positively affect a farmer's adoption decision. A farmer learns about performance of CURE-related varieties which were grown by their neighbors. The uncertainty about unfamiliar varieties can be reduced by observing outcomes of neighboring adopters. Consequently, the process of learning is much faster with information from

[3] A salinity threshold for rice of 2 ‰ (≈3 dS/m) is employed in this study. This threshold was first developed by Maas and Hoffman (1977) and had become a standard. For example, Bernstein (1975) find that moderately tolerant crops, including rice, maintain full yield potential in the salinity range of 2.0-3.5 dS/m. Nhan et al (2012) show that rice yield under saline soils in the range of 1.5-3 ‰ (≈2.3-4.7 dS/m) is significantly reduced in multi-location field trials in the coastal Mekong River Delta.

neighboring farmers (Bardhan and Udry 1999), and a farmer is more likely to adopt CURE-related varieties when neighbors adopt them.

5.3. Propensity Score Matching

5.3.1. Methodology

Propensity score matching is used to assess the impact of CURE-related variety adoption on yields, gross revenues, and net revenues. A mean comparison test can compare whether two groups (adopters and non-adopters of CURE-related varieties) have similar means of outcome variables. However, this method may lead to biased estimates of adoption impact due to endogenous selection. Adoption of CURE-related variety is not randomly assigned and, thus, differences in outcome variables may not only come from adoption or non-adoption, but also from differences in household and other characteristics which influence both adoption decisions and outcome variables. The PSM controls for differences in observable characteristics to address self-selection in adoption decisions.

The PSM is used to estimate average treatment effects on the treated (ATT) after matching a treatment group (adopters) and a control group (non-adopters) given a vector of observed covariates (independent variables from the adoption model). Since there are many independent variables, the multi-dimensional covariates would greatly increase complexity when matching the two groups. However, the PSM uses a one-dimensional propensity score, which is the conditional probability of exposure to treatment (adoption) given the observed covariates (Rosenbaum and Rubin 1983). Theoretically, causal effects are mean differences between the outcome that would result if a unit had received treatment and the outcome that would result if it had not received treatment. However, only a single outcome can be gathered from observational data in the real world. The PSM finds matched control units composed of similar distributions of covariates through a propensity score (Rosenbaum and Rubin 1983), allowing mean difference comparison within the matched units to estimate the causal effects of treatments. The propensity score can be estimated with several different models. The logit model is used in this study, because there is only one treatment (adoption of CURE-related varieties).

Two key assumptions underlie the use of the propensity score. The first assumption is conditional independence, which means after controlling for the observable covariates the outcome variables and treatment status are independent. Under this condition the assignment to treatment is random, and differences in outcome variables between adoption and non-adoption arise from treatment status not from differences in household and other characteristics. The second assumption is common support, which requires that there is sufficient overlap in the propensity scores of the treatment and control groups to find adequate matches.

Various algorithms use the propensity score to find close matches between a treatment group and a control group. This study uses nearest-neighbor matching and kernel matching approaches. Nearest-neighbor matching takes a fixed number of neighbors of the control group and matches them to each observation in the treatment group based on the closest propensity score. In this study, matching one nearest-neighbor with replacement is used through 'teffects psmatch' command in Stata. Matching with replacement minimizes the propensity score distance between the units in two groups (Dehejia and Wahba 2002), but allows control group observations to be matched more than once. The robustness of the estimates from nearest-neighbor matching is explored by also using kernel matching with a Epanechnikov kernel function through the 'psmatch2 with kernel option' command in Stata. Kernel matching uses a wider selection of units in the control group than one nearest-neighbor matching. Kernel matching gives lower weights to units in the control group with a larger difference in propensity score (Heckman et al. 1998), with the weights constructed with the kernel function. This matching process continues until all the units in the control group are matched with each unit in the treatment group, and, thus, it gives the advantage of achieving lower variance at the expense of precision (units in the control group are used that are poorer matches) (Caliendo and Kopeinig 2005).

5.3.2. Outcome variables

The outcome variables of interest are yields, gross revenues, and net revenues. Yields are calculated by dividing rice harvest kilograms by rice-growing area in hectares. Gross revenues are computed by multiplying rice harvest kg and selling price of rice per kg, divided by rice-growing area in hectares. Since households are both producers and consumers of rice, they consume a portion of rice they harvest. The number calculated is value of production (or expected gross revenues if farmers would not consume any rice harvested, rather than the actual gross revenues that households actually earned through rice sales. This thesis refers to value of production as gross revenues.

Net revenues (profits) are estimated on a per hectare basis based on the differences between gross revenues and total costs of rice production. Total production costs include six different types of costs: input costs (seed, herbicide, fertilizer, and insecticide); water costs (e.g. electric bills for running a motor to water fields); land rent costs (especially for tenants); machine costs; hired labor costs; and family labor costs. The three labor costs all involve field activities: field preparation, seeding, applying herbicide, fertilizer, and insecticide, weeding, retranslating, harvesting, threshing, hauling, and drying. Total costs are aggregated at three different levels: level 1) input, water, and land rent costs; level 2) level 1 plus machine and hired labor costs; level 3) level 2 plus family labor costs. Aggregated costs are used to calculate net revenue at the three levels in the analysis. Machine, hired labor, and family labor costs are related to labor expenses and may be less accurate than other costs which are relatively fixed on a per unit basis. Furthermore, family labor costs may be over- or underestimated because farmers estimate the value of their family labor based on the cost of hiring wage labor to do the same work.

Limitations associated with the comparison of CURE-related and non-CURE-related varieties should also be noted. Most notably, the 2017/2018 Dong Xuan season had relatively little salinity intrusion. Thus, any differential salinity tolerant characteristics of CURE-related varieties to high salinity is unlikely to be manifest in the comparison.

Chapter 6. Results

This chapter presents findings of the determinants of CURE-related variety adoption in the 2017/2018 Dong Xuan and 2018 He Thu seasons, and on the relative performance of CURE-related and non-CURE-related variety in the 2017/2018 Dong Xuan season. Adoption determinants are examined at the field and household levels by using linear probability and logit models. CURE-related variety performance is evaluated by comparing yields, gross revenues, and net revenues from CURE- and non-CURE- related varieties through propensity score matching.

6.1. Determinants of Adoption

LPM and logit model estimates of field-level adoption of CURE-related varieties in the 2017/2018 Dong Xuan and 2018 He Thu seasons are presented in Table 6.1. Parameter estimates are presented for the LPM and average marginal effect estimates are presented for the logit model. Table 6.2 provides similar estimation results for household-level adoption of CURE-related varieties in either the Dong Xuan or the He Thu season.

Results for the Dong Xuan season suggest that a one year increase of the farmers' age raises the probability of field CURE-related variety adoption by about 0.3%, a small but significant increase. In terms of ethnicity, contrary to the descriptive statistics, the probability of field-level CURE related variety adoption is not significantly different for the Khmer ethnic group, ceteris paribus. This result suggests that higher observed adoption on fields of the Khmer is due to their environment and characteristics rather than ethnicity per se. The results also provide some evidence that education increases the probability of adoption in the Dong Xuan season, with an increase of approximately 11 percentage point associated with post-secondary education. On the other hand, the parameter estimate for attendance at community meetings is negative and significant (p=0.10), but only in the logit model. Farmer participation in an additional community meeting is associated with a 2% decrease in the probability of CURE-related variety adoption.

The estimates also suggest that if a field has a pump irrigation system protected by salinity barrier gates in the Dong Xuan season, the likelihood of CURE varietal adoption decreases by approximately 11% (p=0.10). The impact of an extra year of high historic salinity exposure is a 0.5% increase in the probability of adoption. However, this result is only significant at the p=0.10 level in the LPM model and is not significant in the logit model. Neighbors adoption appears to generate the largest significant difference in the probability of adoption. The marginal effects imply that a 1% increase in neighbor adoption will lead to a 0.6% to 0.7% increase in adoption of CURE-related varieties at the field level in the Dong Xuan season. This strong influence of neighbors is not surprising, as village farmers must coordinate planting and harvest dates for access to mechanized land preparation and harvesting. This coordination appears to extend to choice of field seed varieties.

Table 6.1. Field level adoption decision: linear probability model and logit model by season

	Dong Xuan		He Thu	
Variable	**LPM**	**Logit**	**LPM**	**Logit**
Age	0.0030**	0.0026*	0.0015	0.0013
	(0.0014)	(0.0014)	(0.0014)	(0.0014)
Male	-0.0386	-0.0317	-0.0017	0.0085
	(0.0440)	(0.0468)	(0.0383)	(0.0518)
Eth	-0.0116	-0.0159	0.0071	0.0092
	(0.0472)	(0.0406)	(0.0415)	(0.0388)
Eduprim	0.0264	0.0244	0.0541	0.0560
	(0.0376)	(0.0385)	(0.0379)	(0.0371)
Edusec	0.0496	0.0456	0.0726*	0.0800*
	(0.0432)	(0.0442)	(0.0414)	(0.0431)
Eduhigh	0.1110**	0.1142**	-0.0219	-0.0139
	(0.0563)	(0.0530)	(0.0572)	(0.0558)
Off	0.0147	0.0109	-0.0201	-0.0201
	(0.0148)	(0.0140)	(0.0145)	(0.0138)
Diverse	0.0207	0.0191	0.0050	0.0043
	(0.0126)	(0.0130)	(0.0148)	(0.0133)
Meeting	-0.0220	-0.0239*	-0.0010	-0.0029
	(0.0136)	(0.0140)	(0.0136)	(0.0134)
Child	-0.0004	-0.0006	0.0197	0.0193
	(0.0137)	(0.0157)	(0.0155)	(0.0147)
Credit	-0.0145	-0.0076	0.0389	0.0452
	(0.0327)	(0.0322)	(0.0334)	(0.0332)
Saving	0.0256	0.0324	0.0143	0.0120
	(0.0366)	(0.0356)	(0.0339)	(0.0350)
Size	-0.0065	-0.0068	-0.0007	0.0000
	(0.0067)	(0.0069)	(0.0048)	(0.0066)
Dis1	-0.0009	-0.0007	0.0020	0.0015
	(0.0033)	(0.0028)	(0.0031)	(0.0027)
Dis2	0.0019	0.0027	-0.0029	-0.0013
	(0.0022)	(0.0023)	(0.0023)	(0.0023)
Irri1	-0.0380	-0.0420	-0.0164	0.0039
	(0.0749)	(0.0665)	(0.1076)	(0.0841)
Irri2	-0.0254	-0.0232	0.0028	0.0338
	(0.0641)	(0.0613)	(0.1022)	(0.0808)
Irri3	-0.1137*	-0.1173*	0.0614	0.0758
	(0.0610)	(0.0599)	(0.0999)	(0.0793)
Salinity	0.0055*	0.0053	-0.0036	-0.0032
	(0.0032)	(0.0035)	(0.0027)	(0.0033)
Nei	0.6724***	0.5853***	0.8070***	0.6319***
	(0.0402)	(0.0260)	(0.0403)	(0.0224)
Constant	-0.1285		-0.1160	
	(0.1263)		(0.1339)	
N	809	809	699	699
R-squared	0.308		0.422	

Note: Average marginal effect is presented in the logit model. Robust standard errors are in parentheses: *** p<0.01, ** p<0.05, * p<0.1.

Table 6.2. Household adoption decision: linear probability model and logit model in either 2017/2018 Dong Xuan or 2018 He Thu season

	Either of two seasons	
Variable	**LPM**	**Logit**
Age	0.0005	0.0004
	(0.0014)	(0.0013)
Male	0.0087	0.0172
	(0.0401)	(0.0435)
Eth	-0.0080	0.0030
	(0.0413)	(0.0432)
Eduprim	0.0501	0.0515
	(0.0365)	(0.0365)
Edusec	0.0627	0.0682*
	(0.0404)	(0.0410)
Eduhigh	0.0543	0.0684
	(0.0526)	(0.0520)
Off	-0.0051	-0.0087
	(0.0143)	(0.0135)
Diverse	0.0157	0.0148
	(0.0120)	(0.0126)
Meeting	-0.0219*	-0.0220*
	(0.0124)	(0.0133)
Child	-0.0113	-0.0122
	(0.0146)	(0.0146)
Credit	0.0064	0.0048
	(0.0326)	(0.0305)
Saving	0.0405	0.0425
	(0.0332)	(0.0343)
Size	-0.0007	0.0003
	(0.0042)	(0.0050)
Dis1	0.0020	0.0026
	(0.0030)	(0.0028)
Dis2	-0.0005	-0.0001
	(0.0023)	(0.0021)
Irri1	0.0722	0.0707
	(0.0681)	(0.0634)
Irri2	0.0526	0.0640
	(0.0636)	(0.0590)
Irri3	0.0192	0.0228
	(0.0590)	(0.0572)
Salinity	-0.0004	-0.0009
	(0.0029)	(0.0032)
Nei	0.8546***	0.6230***
	(0.0370)	(0.0141)
Constant	-0.0287	
	(0.1137)	
N	729	729
R-squared	0.469	

Note: Average marginal effect is presented in the logit model. Field size represents the aggregated number of hectares the household has under rice cultivation. If a household has access to irrigation in any field, they are classified as irrigated. If a household has irrigated fields with only some protected by salinity barrier gates, they are classified as one of these irrigation categories based on the sizes of the fields, protected versus unprotected. Robust standard errors are in parentheses: *** p<0.01, ** p<0.05, * p<0.1.

Fewer covariates are significant in the He Thu season model of field-level adoption of CURE-related varieties. Education still raises the likelihood of CURE-related variety adoption, with a 7% to 8% increase associated with secondary education. But the result is only significant at the p=0.10 level. In marked contrast with the Dong Xuan season results, salinity gate protection and historically high levels of salinity exposure in the He Thu season are not related to CURE-related variety adoption. However, neighbor adoption still strongly influences individual field adoption. A 1% increase in neighbor adoption raises the field adoption probability by between 0.6% and 0.8%.

Household level estimation results for CURE-related variety adoption in either the Dong Xuan or He Thu season (Table 6.2) also show fewer statistically significant covariates than are found at the field-level for the Dong Xu season. This suggests that salinity environment may be a field-specific determinant of CURE-related variety adoption, rather than a household level determinant. However, the strong positive estimate for neighbor adoption remains.

6.2. Performance of CURE-Related Varieties

The performance analysis is conducted at both field and household levels. Yield comparison is made in terms of kg per hectare, while gross and net revenues are compared in terms of thousands of dongs per hectare (‘000 VND/ha)[4].

[4] VND 1,000 equals USD 0.04311 at the exchange rate on January 01, 2018 (Investing 2019).

6.2.1. Performance comparison at the field level

Total number of observations for yield analysis is 809 fields in the 2017/2018 Dong Xuan season, whereas for revenue analysis the number of observations is only 766. This difference stems from the fact that for 43 fields households consumed all their rice and no selling price is observed in the survey.

The propensity score density graph explored the common support assumption by checking whether the propensity score of units in the treatment and control groups overlap with each other. Propensity score density graphs are drawn for the yield and revenue analysis (Figure 6.1) using the ‘teffects overlap’ Stata command. Slightly different graph lines between the yield and revenue analysis are due to the presence of fewer observations for the revenue analysis. The figures show that many of the fields under CURE-related varieties have propensity scores approaching 0.8, which generates some concern about a common support for comparison. However, for yield (revenue) analysis, 287 (279) units in the treatment group are matched with 136 (132) units in the control group after implementing one nearest-neighbor matching with replacement. One unit in the control group is matched twice on average and, thus, sufficient overlap exists in the propensity scores of the treatment and control groups.

After matching, it is necessary to check for covariate balance; the propensity score should have similar distributions of covariates within the treatment and control groups. Three covariate imbalance indicators (*t*-tests, standardized percentage bias, and variance ratios) are employed to assess balance in the matched units using the ‘pstest, rub’ Stata command. The propensity score appears to be balanced for both yield and revenue analysis, and detailed balance diagnostics are discussed in Appendix D.

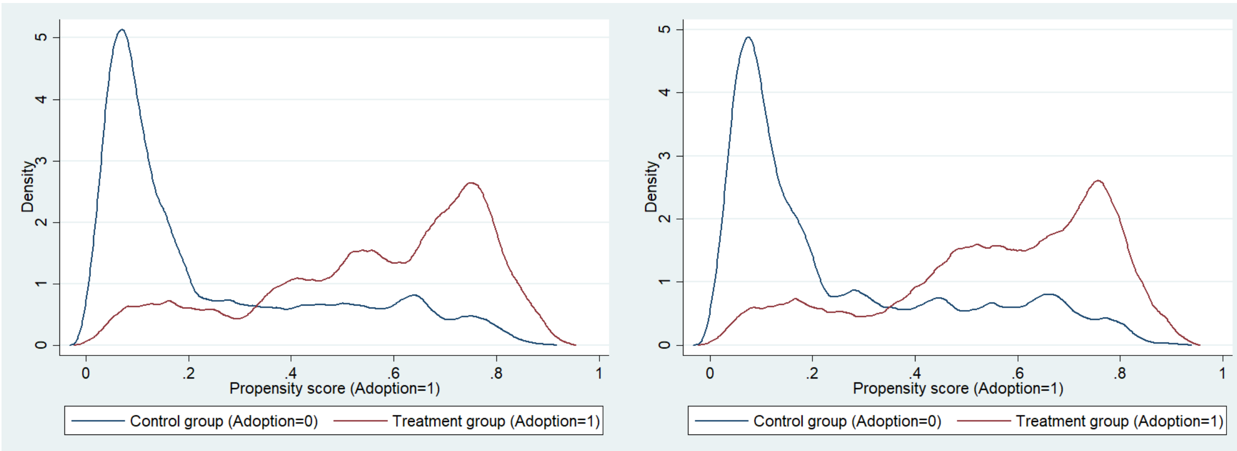

Figure 6.1. Common support for yield (left) and revenue (right) analysis using propensity score distribution: field

The simple mean comparison does not show significant differences in gross and net revenues (Table 4.3). However, the mean difference in yields between fields with and without adoption is significant at the p=0.05 level; with fields with adoption producing a higher yield of 367 kg per hectare. Conversely, the PSM model results using one nearest-neighbor matching (Table 6.3) show that the impact of adoption on outcome variables is not significant for either yields or revenues. The PSM model using kernel matching (Table 6.4) also shows a similar result to one nearest-neighbor matching except for two outcome variables: gross revenue and net revenue 3 (all types of production costs taken into account). These differences in statistical significance between two matching methods are not surprising as kernel matching has better efficiency due to wider selection of units in the control group. This result suggests that fields without adoption generated around VND 2,054,000 and VND 1,836,000 higher gross revenues and net revenues (3), respectively, than fields with adoption, but it is weakly significant at the p=0.10 level.

Table 6.3. PSM model using one nearest-neighbor matching that compares fields with and without adoption in terms of yields, gross revenues, and net revenues per hectare

Variable		Coefficient	(AI Robust s.e.)	P value
Yield	Adoption (1 vs 0)	-249.718	(58.717)	0.334
Gross revenue	Adoption (1 vs 0)	-1799.592	(1244.590)	0.148
Net revenue 1	Adoption (1 vs 0)	-896.821	(1393.406)	0.520
Net revenue 2	Adoption (1 vs 0)	-910.614	(1419.201)	0.521
Net revenue 3	Adoption (1 vs 0)	-1002.547	(1429.130)	0.483

Table 6.4. PSM model using kernel matching that compares fields with and without adoption in terms of yields, gross revenues, and net revenues per hectare

Variable		Coefficient	(Bootstrap s.e.)	P value
Yield	Adoption (1 vs 0)	91.377	(260.288)	0.819
Gross revenue	Adoption (1 vs 0)	-2053.737	(1606.070)	0.088*
Net revenue 1	Adoption (1 vs 0)	-1704.715	(1881.895)	0.174
Net revenue 2	Adoption (1 vs 0)	-1764.475	(1737.512)	0.126
Net revenue 3	Adoption (1 vs 0)	-1836.167	(1315.671)	0.051*

Note: An asterisk denotes the following: * $p<0.10$.

6.2.2. Performance comparison at the household level

In the household analysis, the total number of observations for yield analysis is 685, while 654 usable observations are kept for revenue analysis due to missing information on rice sale price for households that consumed all their rice.

To check the common support assumption, propensity score density graphs for the yield and the revenue (Figure 6.2) analysis are examined. Similar to Figure 6.1 shown in the field level result, the treatment group contains many units with a high propensity score. However, for yield (revenue) analysis, 121 (113) units in the control group are matched with 251 (246) units in the treatment group when matching to one nearest-neighbor with replacement. Sufficient units in the control group are matched with units in the treatment group, implying observations in two groups overlap each other.

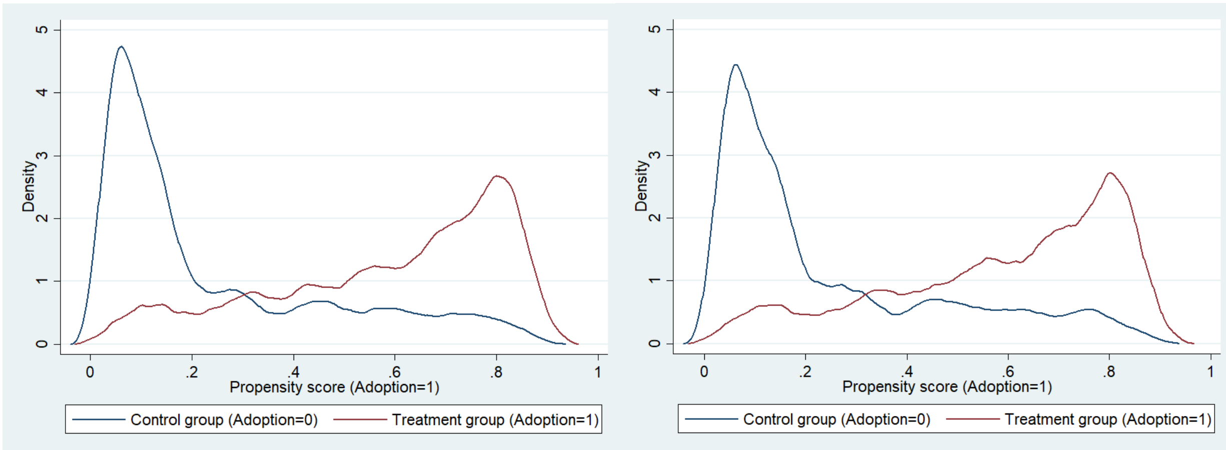

Figure 6.2. Common support for yield (left) and revenue (right) analysis using propensity score distribution: household

After matching on the propensity score, covariate balance is evaluated, and the results are discussed in Appendix D. Balance diagnostics indicate that the treatment and control groups are well balanced in the matched units.

The results at the household level are similar to the results at the field level. The simple mean comparison test shows that adopters statistically (p=0.05) produce 367 kg per hectare higher yields than non-adopters (Table 6.5), but this difference is not significant in the PSM model (Table 6.6 and Table 6.7). Gross and net revenues per hectare are not statistically different between adopter and non-adopters in the nearest-neighbor matching (Table 6.6), while kernel matching (Table 6.7) suggests that adopters have significantly lower gross and net revenues per hectare. In terms of total revenues, mean comparison of outcome variables (Table 6.8) and the PSM models, nearest-neighbor matching (Table 6.9) and kernel matching (Table 6.10), show no significant impact of the CURE-related variety adoption on households.

In conclusion, the yield difference from adoption and non-adoption of CURE-related varieties is statistically significant in mean comparison. However, this yield difference disappears when controlling for household and other characteristics which affect both adoption decisions and outcome variables through the PSM model. This finding suggests that household characteristics associated with adoption contribute to higher yields rather than CURE-related variety characteristics do themselves. In a year with relatively little salinity intrusion, using CURE-related varieties generates no observed penalty, but causes slightly lower household revenues. Farmers' adoption of CURE-related varieties in a low salinity intrusion year can be interpreted as an insurance policy against high salinity intrusion. On the other hand, farmers' not adopting CURE-related varieties also appear economically rational after taking into account the lower price of CURE-related varieties and that they live, on average, in lower salinity-risk environments.

Table 6.5. Mean comparison of household yields, gross revenues, and net revenues per hectare

	Adopters		Non-adopters		Difference in
Variable	**Mean**	**(s.d)**	**Mean**	**(s.d)**	**Means**
Yield	6,712	(2,052)	6,345	(2,071)	367**
Gross revenue	37,967	(12,362)	38,714	(11,706)	-747
Net revenue1	27,717	(11,940)	28,138	(11,490)	- 422
Net revenue2	22,862	(12,006)	22,552	(12,117)	310
Net revenue3	20,424	(12,018)	19,732	(12,632)	692

Note: Asterisks denote the following: ** $p<0.05$

Table 6.6. PSM model using one nearest-neighbor matching that compares household adopters and non-adopters in terms of yields, gross revenues and net revenues per hectare

Variable		**Coefficient**	**(AI Robust s.e.)**	**P value**
Yield	Adoption (1 vs 0)	-55.795	(217.467)	0.798
Gross revenue	Adoption (1 vs 0)	-1650.053	(1484.572)	0.266
Net revenue1	Adoption (1 vs 0)	-1672.811	(1479.078)	0.258
Net revenue2	Adoption (1 vs 0)	-1571.742	(1480.490)	0.288
Net revenue3	Adoption (1 vs 0)	-1592.146	(1461.607)	0.276

Table 6.7. PSM model using kernel matching that compares household adopters and non-adopters in terms of yields, gross revenues and net revenues per hectare

Variable		**Coefficient**	**(Bootstrap s.e.)**	**P value**
Yield	Adoption (1 vs 0)	-28.442	(306.837)	0.984
Gross revenue	Adoption (1 vs 0)	-2739.678	(1686.061)	0.030**
Net revenue1	Adoption (1 vs 0)	-2296.490	(1482.002)	0.013**
Net revenue2	Adoption (1 vs 0)	-2334.604	(1880.726)	0.076*
Net revenue3	Adoption (1 vs 0)	-2455.613	(1917.444)	0.052*

Note: Asterisks denote the following: ** $p<0.05$, * $p<0.10$

Table 6.8. Mean comparison of household gross revenues and net revenues in total

Variable	Adopters Mean	Adopters (s.d)	Non-adopters Mean	Non-adopters (s.d)	Difference in Means
Gross revenue	81,354	(109,672)	75,698	(134,567)	5,656
Net revenue1	59,624	(87,508)	53,385	(81,824)	6,239
Net revenue2	48,982	(73,738)	42,834	(64,674)	6,149
Net revenue3	45,483	(73,373)	39,893	(63,996)	5,590

Table 6.9. PSM model using one nearest-neighbor matching that compares household adopters and non-adopters in terms of yields, gross revenues and net revenues in total

Variable		Coefficient	(AI Robust s.e.)	P value
Gross revenue	Adoption (1 vs 0)	-3879.759	(9174.516)	0.672
Net revenue1	Adoption (1 vs 0)	-2407.102	(7250.000)	0.740
Net revenue2	Adoption (1 vs 0)	-2333.972	(6612.183)	0.724
Net revenue3	Adoption (1 vs 0)	-2280.672	(6600.705)	0.730

Table 6.10. PSM model using kernel matching that compares household adopters and non-adopters in terms of yields, gross revenues and net revenues in total

Variable		Coefficient	(Bootstrap s.e.)	P value
Gross revenue	Adoption (1 vs 0)	-15255.066	(17149.440)	0.321
Net revenue1	Adoption (1 vs 0)	-9220.101	(8847.175)	0.147
Net revenue2	Adoption (1 vs 0)	-8243.748	(9070.601)	0.240
Net revenue3	Adoption (1 vs 0)	-7982.220	(9262.879)	0.241

Chapter 7. Conclusion

We find a high level of diversity in rice varieties grown in salinity-prone areas of the MRD. Almost half of all area planted across the pre-salinity surge Dong Xuan season and post-salinity surge He Thu season are CURE-related rice varieties. This implies the CURE project has been very successful in generating and disseminating salt-tolerant rice varieties into the salinity-prone environment target area.

Results from a multivariate model imply that while education matters for CURE variety uptake, adoption of CURE-related varieties is more related to field-level environment such as irrigation systems and historical salinity exposures than to the characteristics of the household. Further, the contrast between the season specific field-level results and the aggregate household choice results suggests adoption is a season and field-specific choice rather than an aggregate household choice. Neighborhood effects are also particularly strong across different models and seasons. However, estimated neighborhood effects may not arise strictly from information spillovers associated with adoption decisions. As noted, use of mechanization, particularly for land preparation and harvest, requires coordination in the timing of planting, harvest and varietal duration. This coordination appears to extend to the choice of CURE-related varieties. Further, unobserved environmental characteristics likely drive both own and neighbor adoption decisions and other place-based characteristics may be captured in the estimated neighbor effect.

The results also suggest that CURE-related varieties are disproportionately adopted in high salinity risk environments with tidal irrigation and pump irrigation that is not protected by salinity barrier gates. Evidence as to whether CURE-varietal uptake is higher among better-off farmers is mixed. Uptake is generally higher among more educated field managers, but does not increase with income diversity, access to savings or credit, or field size. There is even weak evidence in the household model that adopters of CURE-related varieties have weaker social networks – which may be related to residence in more unfavorable rice-growing environments.

The strong influence of place and environment has two implications for efforts to further increase the diffusion of CURE-related varieties. First, there may be a need to adapt STRVs across a wider range of salinity-prone environments. There is also a need to understand how varietal requirements in the Dong Xuan and He Thu seasons may differ, since determinants of adoption and particularly differential adoption by salinity environment risk are not the same. Second, given the results of strong neighborhood effects on CURE-related variety adoption, varietal diffusion efforts need to focus at the village or commune level, rather than the household level. Such efforts may include village-level starter seed packages or village-level demonstrations where the multiplied seed is distributed across the village for the following year.

Results from the propensity score matching model suggest no yield difference between CURE- and non-CURE-related varieties in a low salinity year. However, given the lower market price of CURE-related varieties, adopting farmers may receive lower gross or net revenues on the field. It is also worth noting that the 2017/2018 Dong Xuan season showed relatively low incidence of salinity inundation (only 7 percent of fields reported salinity-related shocks). Thus the benefits of CURE-related varieties as an insurance policy against high salinity levels were not manifest. Further research is needed on differential CURE-varietal performance under different levels of salinity exposure across years. This analysis can be undertaken as part of a panel study for two additional years, with the same households re-surveyed. The PSM results also suggest that further varietal development research is needed to address characteristics of CURE-related varieties that bring low rice market prices. Similarly, another area for further analysis is the extent and impacts of household abandonment of rice due to increased risk of salinity inundation.

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Appendices

Appendix A: Figures

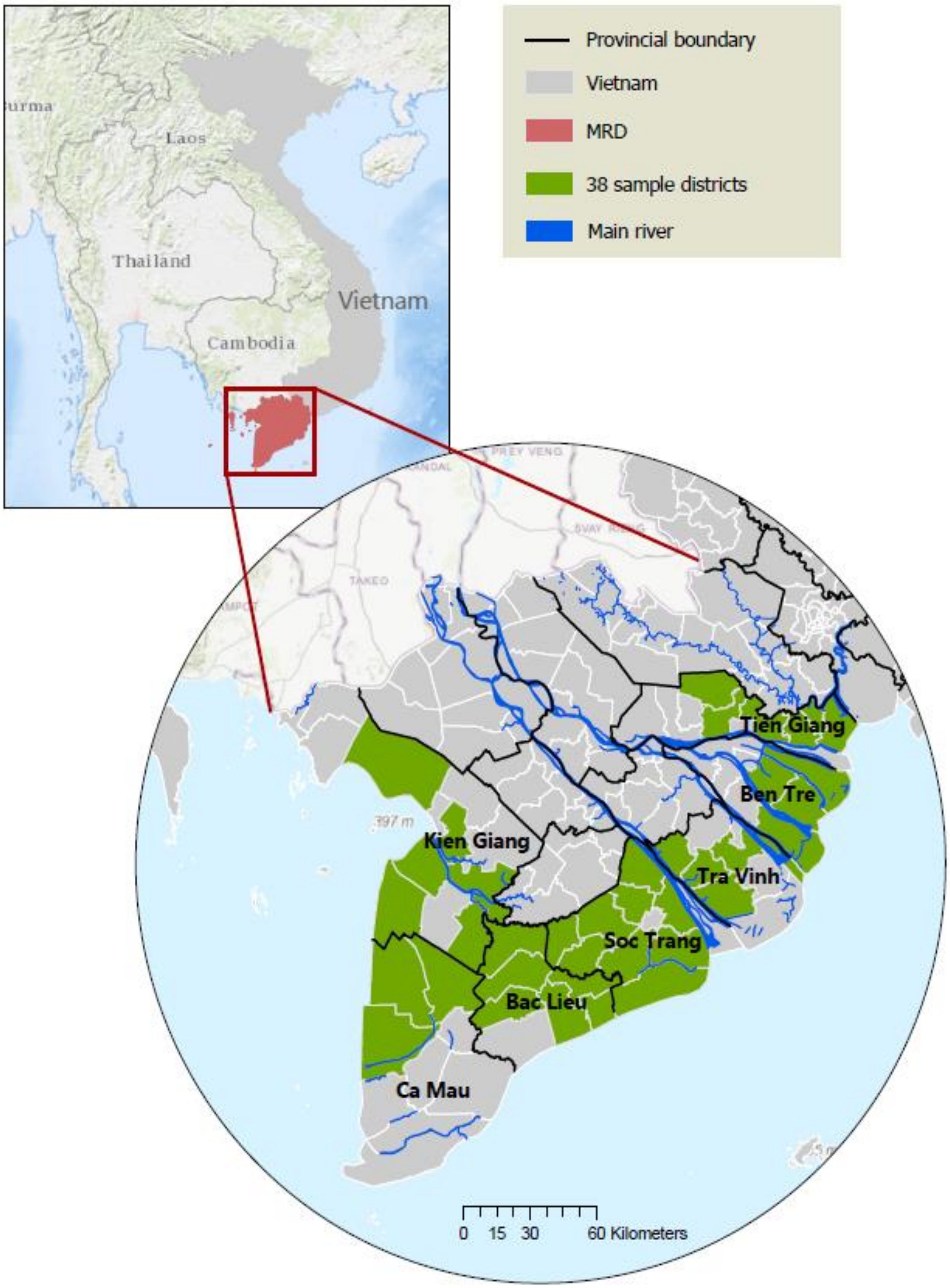

Figure A1. Map of the Mekong River Delta (MRD) and 38 sample districts

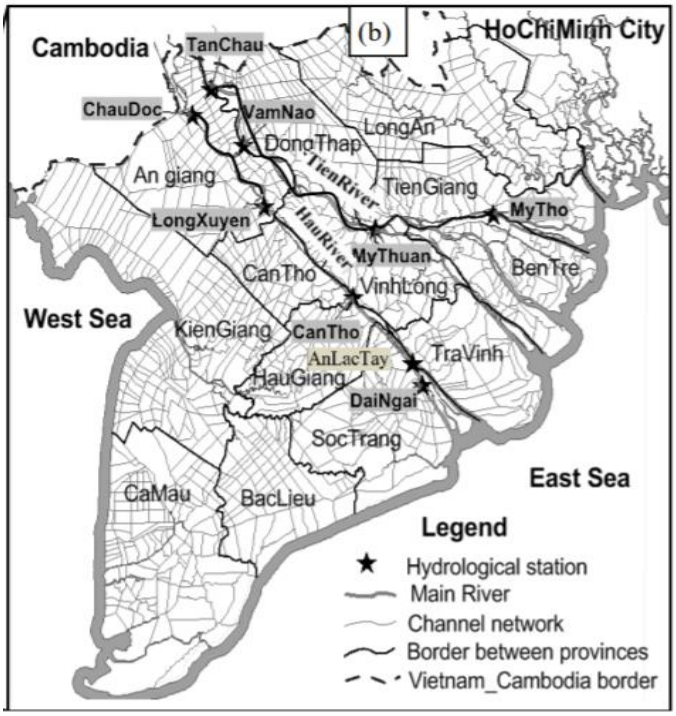

Figure A2. Mekong River Delta and hydrological stations (Binh et al. 2017b)

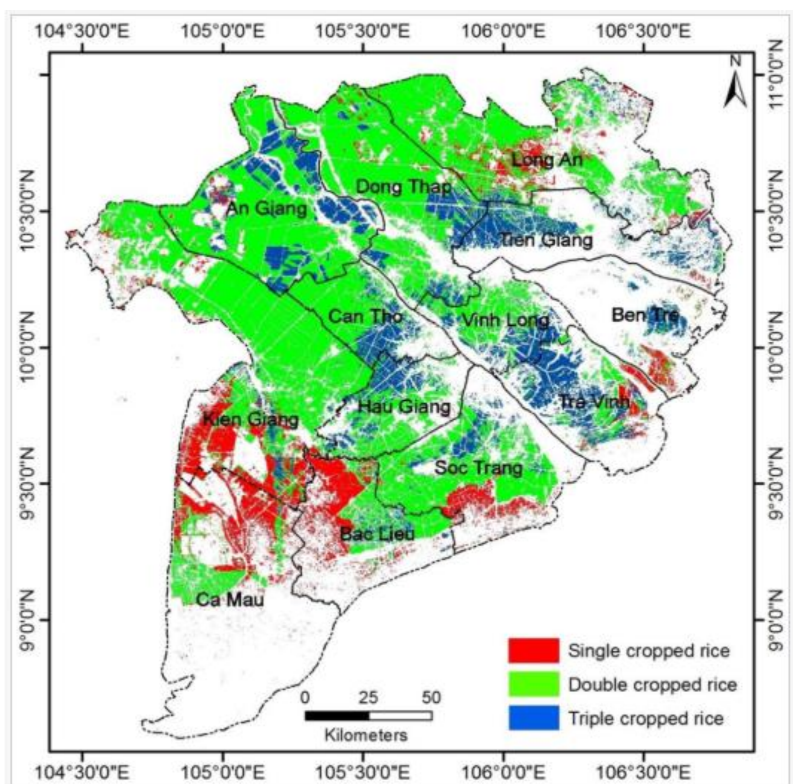

Figure A3. Map of rice cropping cycle in the MRD from 2007 to 2011 (Nguyen et al. 2015)

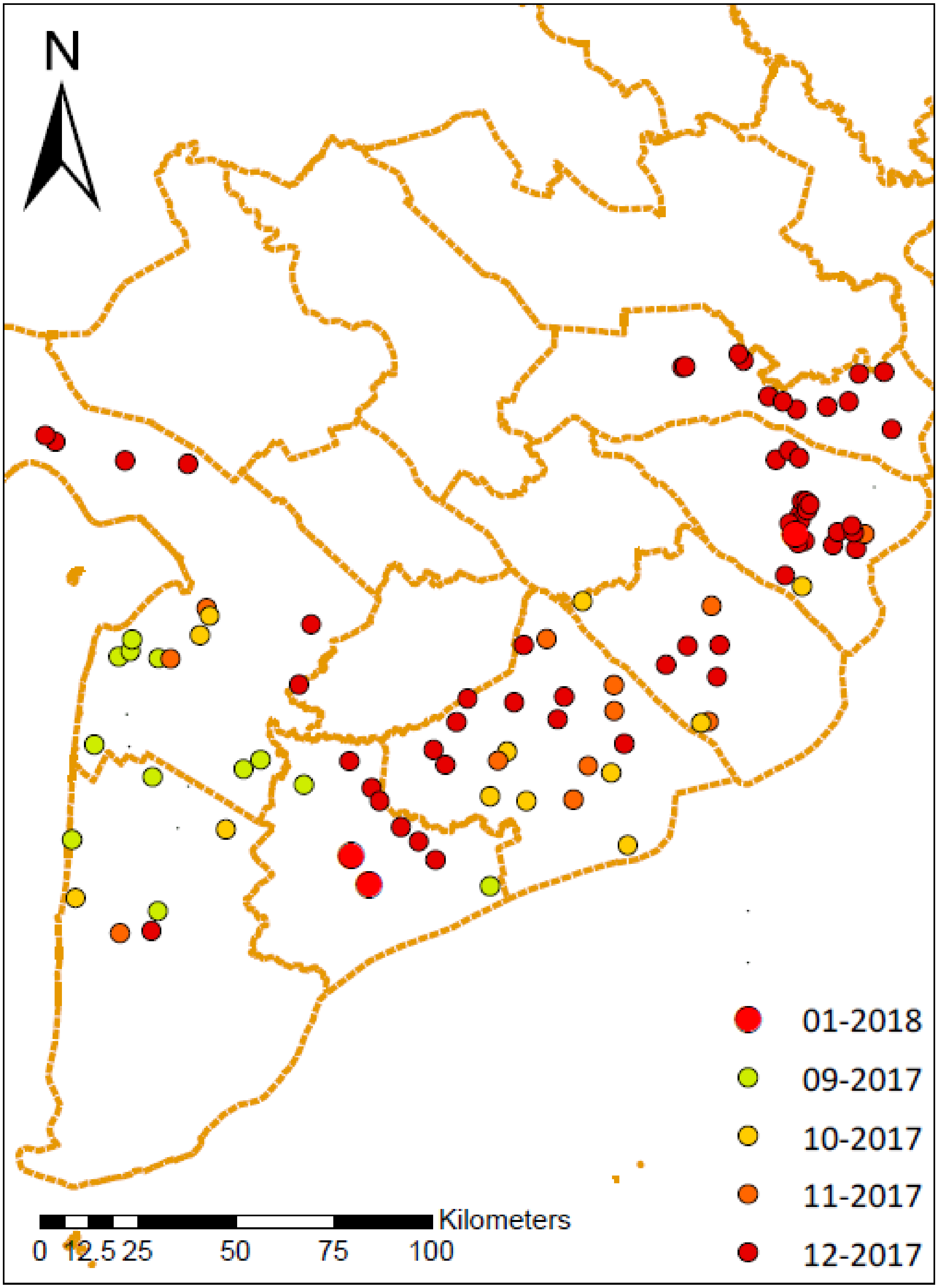

Figure A4. Distribution of rice planting month in the Dong Xuan season by village

Appendix B: Tables

Table B1. Planted area, production, and yield of paddy rice by seasons in Vietnam and the Mekong River Delta (MRD) by province in 2015 (General Statistics Office 2016)

	Total			Dong Xuan season			He Thu season			Mua season		
	Planted area	Production	Yield	Planted area	Production	Yield	Planted area	Production	Yield	Planted area	Production	Yield
	(Thous. ha)	(Thous. tons)	(ton/ ha)	(Thous. ha)	(Thous. tons)	(ton/ ha)	(Thous. ha)	(Thous. tons)	(ton/ ha)	(Thous. ha)	(Thous. tons)	(ton/ ha)
Vietnam	7834.9	45215.6	5.77	3112.4	20691.7	6.65	2785.1	14991.7	5.38	1937.4	9532.2	4.92
MRD	4308.5	25699.7	5.96	1562.3	11130.7	7.12	2360.1	12732.5	5.39	386.1	1836.5	4.76
Long An	525.1	2924.1	5.57	233.9	1569.7	6.71	286.1	1336.4	4.67	5.1	18.0	3.53
Tien Giang*	224.7	1344.4	5.98	75.1	541.0	7.20	149.6	803.4	5.37			
Ben Tre*	63.0	278.8	4.43	17.2	87.6	5.09	17.9	71.8	4.01	27.9	119.4	4.28
Tra Vinh*	237.3	1353.9	5.71	68.9	469.3	6.81	79.2	408.1	5.15	89.2	476.5	5.34
Vinh Long	180.5	1094.7	6.06	61.0	437.0	7.16	119.5	657.7	5.50			
Dong Thap	546.0	3394.2	6.22	204.9	1443.2	7.04	341.1	1951.0	5.72			
An Giang	644.2	4078.0	6.33	238.6	1804.4	7.56	400.3	2254.4	5.63	5.3	19.2	3.62
Kien Giang*	769.5	4662.6	6.06	307.3	2224.5	7.24	399.2	2154.8	5.40	63.0	283.3	4.50
Can Tho	237.9	1405.3	5.91	87.3	645.3	7.39	150.6	760.0	5.05			
Hau Giang	207.0	1277.5	6.17	80.0	618.5	7.73	127.0	659.0	5.19			
Soc Trang*	367.0	2294.7	6.25	141.5	952.4	6.73	196.9	1197.8	6.08	28.6	144.5	5.05
Bac Lieu*	180.8	1056.8	5.85	46.6	337.8	7.25	56.3	326.0	5.79	77.9	393.0	5.04
Ca Mau*	125.5	534.7	4.26				36.4	152.1	4.18	89.1	382.6	4.29

Note: The asterisks (*) denote the seven sample provinces for this study. The Mua season normally ranges from August to November classified as the Thu Dong season.

Table B2. Rice production and planting area in salinity-prone districts of 7 provinces by season, 2017

	Dong Xuan		He Thu	
	Production (thous. ton)	**Area (thous. ha)**	**Production (thous. ton)**	**Area (thous. ha)**
Ben Tre	70.131	15.915	63.526	15.236
Tien Giang	261.437	41.098	240.595	46.354
Tra Vinh	274.375	`45.486	253.764	50.710
Soc Trang	1166.809	180.309	835.835	148.215
Bac Lieu	333.251	46.290	570.562	100.787
Ca Mau	3.902	1.299	156.308	36.736
Kien Giang	1098.984	186.189	941.516	175.446
Total	**3208.889**	**516.586**	**3062.106**	**573.484**

Source: Own calculation using data from Statistical Publishing House 2018.

Table B3. Adoption rate at the field level in 2017/2018 Dong Xuan and 2018 He Thu season

	Dong Xuan	**He Thu**
Ben Tre	8.525	6.747
Tien Giang	29.435	28.433
Tra Vinh	48.189	49.679
Soc Trang	45.846	73.160
Bac Lieu	21.650	28.649
Ca Mau	47.542	72.781
Kien Giang	36.912	20.286
Total	**36.748**	**40.711**

Table B4. Imputed rice production and planting area of CURE-related varieties in salinity-prone districts of 7 provinces by season, 2017

	Dong Xuan		He Thu	
	Production (thous. ton)	**Area (thous. ha)**	**Production (thous. ton)**	**Area (thous. ha)**
Ben Tre	5.979	1.357	4.286	1.028
Tien Giang	76.954	12.097	68.409	13.180
Tra Vinh	132.218	21.919	126.067	25.192
Soc Trang	534.938	82.665	611.497	108.434
Bac Lieu	72.148	10.022	163.459	28.874
Ca Mau	1.855	0.617	113.763	26.737
Kien Giang	405.657	68.726	190.993	35.590
Total	**1229.748**	**197.403**	**1278.474**	**239.036**

Table B5. Area planted with CURE-related varieties in 2017/2018 Dong Xuan and 2018 He Thu season

	Dong Xuan		He Thu	
Variety name	**Area planted (ha)**	**Percentage (%)**	**Area planted (ha)**	**Percentage (%)**
OM5451	241.30	48.23	316.02	67.56
OM6976	90.63	18.12	105.85	22.63
OM4900	70.46	14.08	21.85	4.67
OM2517	65.24	13.04	6.62	1.42
OM576	13.86	2.77	10.18	2.18
OM6162	10.07	2.01	7.26	1.55
OM1490	8.71	1.74		
Total	**500.26**	**100**	**467.78**	**100**

Table B6. Area planted with non-CURE-related varieties in 2017/2018 Dong Xuan season and 2018 He Thu season

	Dong Xuan			He Thu		
Variety name	**Area planted (ha)**	**Percentage (%)**	**Rank**	**Area planted (ha)**	**Percentage (%)**	**Rank**
ĐS 1	200.22	23.25	1	222.64	32.68	1
Đài Thơm 8	161.47	18.75	2	162.54	23.86	2
RVT	102.09	11.86	3	21.88	3.21	5
OC10	82.07	9.53	4	102.81	15.09	3
IR50404	57.12	6.63	5	12.77	1.87	10
Nàng Hoa 9	44.83	5.21	6	15.82	2.32	8
Một Bụi Đỏ	34.90	4.05	7			
BTE-1	32.67	3.79	8			
ST21	22.59	2.62	9	11.92	1.75	11
ML202	20.43	2.37	10	18.03	2.65	7
OM7347	20.19	2.34	11	28.90	4.24	4
ST5	19.62	2.28	12			
Siêu Hàm Trâu	12.90	1.50	13	18.49	2.71	6
Lùn Kiên Giang	9.10	1.06	14			
MTL110	8.63	1.00	15	8.63	1.27	12
IR4625	7.85	0.91	16	8.05	1.18	13
Jasmine 85	4.29	0.50	17			
HD6	3.75	0.44	18	4.95	0.73	16
Bụi Vàng	3.40	0.39	19	1.60	0.23	21
Trắng Tép	2.15	0.25	20	2.60	0.38	19
Loc Troi 1	2.00	0.23	21			
Tím Sóc Trăng	1.80	0.21	22	5.70	0.84	15
IR42	1.55	0.18	23	5.85	0.86	14
Loc Troi 5	1.40	0.16	24			
ST20	1.18	0.14	25	0.66	0.10	23
OM98	1.00	0.12	26			
ST24	0.65	0.08	27	13.95	2.05	9

Tài Nguyên	0.55	0.06	28	0.40	0.06	25
OM1348	0.40	0.05	29			
OM1352	0.28	0.03	30	1.53	0.22	22
Nàng Chá				4.70	0.69	17
OM418				3.84	0.56	18
Trắng Hòa Bình				2.15	0.32	20
Lúa Đỏ				0.45	0.07	24
OM3536				0.40	0.06	25
Total	**861.08**	**100**		**681.25**	**100**	

Table B7. Descriptive statistics by adopters and non-adopters of CURE-related varieties in either 2017/2018 Dong Xuan or 2018 He Thu season

	Adopters		**Non-adopters**		**Difference in**
Variable	**Mean**	**(s.d)**	**Mean**	**(s.d)**	**Means**
Age	52.122	(11.008)	53.764	(10.935)	-1.641**
Male	0.920	(0.271)	0.853	(0.354)	0.067***
Eth	0.187	(0.390)	0.095	(0.293)	0.092***
Eduprim	0.416	(0.494)	0.396	(0.490)	0.020
Edusec	0.263	(0.441)	0.241	(0.428)	0.022
Eduhigh	0.119	(0.325)	0.109	(0.313)	0.010
Off	0.865	(1.051)	0.866	(1.029)	-0.000
Diverse	1.914	(1.303)	1.833	(1.038)	0.081
Meeting	1.746	(1.102)	1.968	(1.106)	-0.221***
Child	0.789	(0.855)	0.791	(1.081)	-0.002
Credit	0.260	(0.439)	0.279	(0.449)	-0.019
Saving	0.226	(0.419)	0.226	(0.419)	-0.000
Size	2.122	(2.609)	1.712	(3.285)	0.410*
Dis1	5.071	(5.896)	3.407	(3.798)	1.663***
Dis2	7.277	(5.697)	8.430	(6.927)	-1.153**
Irri1	0.187	0.390	0.090	0.286	0.097***
Irri2	0.327	0.470	0.234	0.424	0.093***
Irri3	0.425	0.495	0.602	0.490	-0.177***
Salinity	11.541	(4.409)	12.624	(4.821)	-1.083***
Nei	0.739	(0.288)	0.214	(0.281)	0.525***

Note: Field size represents the aggregated number of hectares the household has under rice cultivation. If a household has access to irrigation in any field, they are classified as irrigated. If a household has irrigated fields with only some protected by salinity barrier gates, they are classified as one of these irrigation categories based on the sizes of the fields, protected versus unprotected. Asterisks denote the following: *** p<0.01, ** p<0.05, * p<0.1.

Table B8. Description of the study variables

Category	**Variable**	**Description**	**Unit**	**Type**	**Expected sign**
Dependent variable	Adoption (Y_i)	Adoption of CURE-related variety	1 if adopt, 0 otherwise	Discrete	
Primary farmer's (managing the household's rice production) characteristics	Age (Age_i)	Age of a primary farmer	Years	Continuous	Inconclusive
	Gender ($Male_i$)	Gender of a primary farmer	1 if male, 0 if female (Female is a baseline)	Discrete	+
	Ethnicity (Eth_i)	Ethnicity of a primary farmer is Khmer	1 if Khmer, 0 otherwise (the ethnic major group including Vietnamese and Chinese is a baseline)	Discrete	Inconclusive
	Education ($Eduprim_i$)	A primary farmer has finished his/her education in a primary school	1 if yes, 0 otherwise (No education is a baseline)	Discrete	+
	Education ($Edusec_i$)	A primary farmer has finished his/her education in a secondary school	1 if yes, 0 otherwise (No education is a baseline)	Discrete	+
	Education ($Eduhigh_i$)	A primary farmer has finished his/her education in a high school or post high school	1 if yes, 0 otherwise (No education is a baseline)	Discrete	+
	Off-farm work (Off_i)	Number of household members who work as a wage laborer or self-employed	Number	Continuous	-
	Diversified crops ($Diverse_i$)	Number of crops that are being grown in the past 12 months	Number	Continuous	-
	Community meeting ($Meeting_i$)	Number of organizations in which a primary farmer normally participates	Number	Continuous	+

Table B8. Continued

Category	Variable	Description	Unit	Type	Expected sign
	Number of children ($Child_i$)	Number of children in the household who are 14 and under	Number	Continuous	+
	Access to credit ($Credit_i$)	Any member in the household borrow credit from bank for agricultural activities	Number	Continuous	-
	Saving account ($Saving_i$)	Any member in the household has a saving account	Number	Continuous	-
Rice growing physical environments	Field size ($Size_i$)	Size of field	Hectare	Continuous	+
	Distance ($Dis1_{in}$)	Distance to government extension from a village to obtain new rice varieties	km	Continuous	-
	Distance ($Dis2_{in}$)	Average distance to the accessible seed club, seed center, and private market from a village to obtain new rice varieties	km	Continuous	-
	Irrigation ($Irri1_i$)	Irrigation system is tidal	1 if yes, 0 otherwise (rainfed irrigation is a baseline)	Discrete	+
	Irrigation ($Irri2_i$)	Irrigation system is pump irrigation not protected by salinity barrier gates	1 if yes, 0 otherwise (rainfed irrigation is a baseline)	Discrete	-
	Irrigation ($Irri3_i$)	Irrigation system is pump irrigation protected by salinity barrier gates	1 if yes, 0 otherwise (rainfed irrigation is a baseline)	Discrete	-

Table B8. Continued

Category	Variable	Description	Unit	Type	Expected sign
	Salinity ($Salinity_i$)	Number of years which a salinity level on April exceeded the salinity threshold	Years	Continuous	+
Learning from neighbors	Adoption rate of neighbors (Nei_i)	A ratio of adopting neighbors to total number of neighbors (= 7 neighbors) in the village where a farmer *i* lives	Ratio	Continuous	+

Table B9. Population by ethnic groups in 7 provinces in the Mekong River Delta in 2009

Province	Total	Total			Rural Total	Rural		
		Kinh	Khmer	Chinese (Hoa)		Kinh	Khmer	Chinese (Hoa)
Ben Tre	1,255,946	1,251,364	578	3,811	1,131,632	1,129,295	472	1,712
		(99.6)	(0.0)	(0.3)		(99.8)	(0.0)	(0.2)
Tien Giang	1,672,271	1,667,459	744	3,863	1,443,305	1,441,804	589	758
		(99.7)	(0.0)	(0.2)		(99.9)	(0.0)	(0.1)
Tra Vinh	1,003,012	677,649	317,203	7,690	849,316	558,346	289,262	1,436
		(67.6)	(31.6)	(0.8)		(65.7)	(34.1)	(0.2)
Soc Trang	1,292,853	830,508	397,014	64,910	1,042,280	662,196	343,929	35,896
		(64.2)	(30.7)	(5.0)		(63.5)	(33.0)	(3.4)
Bac Lieu	856,518	765,572	70,667	20,082	632,559	573,540	51,784	7,127
		(89.4)	(8.3)	(2.3)		(90.7)	(8.2)	(1.1)
Ca Mau	1,206,938	1,167,765	29,845	8,911	960,674	932,381	25,603	2,469
		(96.8)	(2.5)	(0.7)		(97.1)	(2.7)	(0.3)
Kien Giang	1,688,248	1,446,455	210,899	29,850	1,233,228	1,043,096	173,823	15,761
		(85.7)	(12.5)	(1.8)		(84.6)	(14.1)	(1.3)
Total	**8,975,786**	**7,806,772**	**1,026,950**	**139,117**	**7,292,994**	**6,340,658**	**885,462**	**65,159**
		(87.0)	**(11.4)**	**(1.5)**		**(86.9)**	**(12.1)**	**(0.9)**

Source: Central Population and Housing Census Steering Committee (2010)

Note: parenthesis indicates the percentage of ethnic group of total population in each province.

Appendix C: Household survey and village questionnaires

Household survey

Consent statement

Hello my name is _______________. I am a student at Can Tho University and part of a research team conducting a study of the impact of new rice varieties developed as part of the Cuu Long Rice Research Institutes collaboration in the international Consortium for Unfavorable Rice Environments (CURE). The impact assessment is part of a broader study of the effectiveness of the Consortium in improving rural livelihoods. We will be surveying 800 rice growing households in salinity prone areas of the Mekong Delta and would like to talk with the household member in charge of the overall management of household rice production.

Does your household grow rice? Yes____, No_______
[If no. "Thank you for your time."] [If yes – continue with statement of consent]

If you agree to participate, I will ask a series of survey questions about your household farming activities over the past year. Either I or a colleague will then follow up with an additional set of questions next year right after the completion of the Dong Xuan rice season harvest. I will leave you with a diary for recording the information we will be collecting on rice activities in the next Dong Xuan season.

Today's survey will take approximately 45 minutes to complete. The follow-up survey will take approximately the same amount of time. No promise or guarantee of benefits is made to encourage you to participate. But your participation will help to identify both benefits of CURE related research, as well as areas where further investment in agricultural technologies needed.
All survey responses will remain confidential and at no time will researchers release identifiable results of the study to anyone other than individuals working on the project.

It is important for you to know that you are free to withdraw from this study at any time without penalty. You are free not to answer any questions that you choose or respond to what is being asked of you without penalty. Please indicate if you provide your verbal consent to participate in the survey.
Yes ___ No___

The requirements for the household interviewed: (checkbox)
(a) The household interviewed has at least one rice season in the past year (in the past 12 months)
(b) The household interviewed grows rice and the respondent more than 18
Team:
Enumerator name:
Date of interview:
Province: District: Commune: Village:
Household ID:

D0. How many rice plots from Dong Xuan 2017–2018 to He Thu 2018?											
D1. Plot ID	**D2. Unique description to identify the plot in the next year survey**	**M2C. Area unit**	**M2D. Area**	**D3. Household member making the decision in this plot**	**D4. Transportation mode**	**D5. Distance from home (minutes)**	**D6. Irrigation system**	**D7. Ownership status**	**D7_2. Hire cost in the past year (if D7=3)**	**D8A. He Thu season crops**	**D8B. Dong Xuan season crops**
1											
2											
3											
4											
		(1) Hecta (2) M^2 (3) Công nhỏ ($1000m^2$) (4) Công lớn ($1300m^2$) (5) Sào Nam bộ ($100\ m^2$)		(1) Respondent (2) Spouse of respondent (3) Parent of respondent (4) Son/daughter of respondent (5) Sister/Brother of respondent (6) Other relative of respondent (7) Other non-relative of respondent (8) Jointly between Respondent and his/her Spouse	(1) Walking (2) Motorbike (3) Bicycle (4) Other, specify		(1) Rainfed (2) Pump (3) Tidal (4) Other, specify	(1) Own with title (2) Own but no title (3) Rented-in (4) Other, specify		(1) Rice – already seeded (2) Rice – land preparation but not seeded yet (3) Aquaculture, specify (4) Aquaculture with rice – already seeded (5) Aquaculture with rice – land preparation but not seeded yet (6) Nothing at this plot this time	(1) Rice (2) Aquaculture, specify (3) Aquaculture with rice, specify (4) Nothing at this plot this time

Dong Xuan 2017 – 2018

Plot code	**Land preparation**					**Seed variety**							
	F3A. Power	**F3B. Power cost (‘000 dongs)**	**F3C. Type of labor**	**F3D. Family labor costs (‘000 dongs)**	**F3E. Hired labor costs (‘000 dongs)**	**F4A. Seed variety name**	**F4B. Where**	**F4C. Does the household use certified seed?**	**F4D. Number kg**	**F4E. Cost (‘000 dongs)**	**F4F. How found about (checkbox)**	**F4H. Years using variety (years)**	**F4I. Reasons chosen (checkbox)**
1													
2													
3													
4													
	(1) Hand (2) Animal (3) Power tiller (4) Tractor (5) Other, specify		*(1) Own (2) Hire (3) Both*				*(1) Purchased – seed club (2) Purchased - merchant (3) Purchased – farmers (4) Purchased - seed centers (5) Purchased – extension centers (6) Purchased – research institutes (7) Own seed (8) Given – family (9) Given – friend (10) Given – seed center (11) Given – extension center (12) Given – research institutes (13) Other, specify*	*(1) Yes (2) No*			*(a) Friend (b) Extension (c) Demonstration (d) Seed club (e) Family (g) Seed merchant (f) Other, specify*		*(A) High yielding (B) Good grain quality (C) Low price (D) Salinity tolerant (E) High market price (F) Other, specify*

Plot code	**Herbicide**					**F6. Seeding method**	**If F6=2 (Transplant)**								
	F5A. Herbicide (yes/no)	**F5B. Cost of herbicide ('000 dongs)**	**F5C. Type of labor**	**F5D. Family labor cost ('000 dongs)**	**F5E. Cost of hired labor ('000 dongs)**		**F6A1. Planting date**			**F6A2. Days between seeding and planting**	**F6A3. Transplant method**	**F6A4. Machine cost ('000 dongs)**	**F6A5. Labor for seeding**	**F6A7. Family labor cost ('000 dongs)**	**F6A6. Hired labor cost ('000 dongs)**
							Day	**Month**	**Year**						
1															
2															
3															
4															
	(1) Yes (2) No		*(1) Own (2) Hire (3) Both*			*(1) Direct seeding (2) Transplant*					*(1) Hand (2) Machine*		*(1) Own (2) Hire (3) Both*		

Plot code	If F6=1 (Direct seeding)										Fertilizer application				
	F6B1. Direct seed – Wet/ Dry	F6B2. Planting date			F6B3. Planting method	F6B4. Machine cost (‘000 dongs)	F6B5. Labor for seeding	F6B6. Family labor cost (‘000 dongs)	F6B7. Hired labor cost (‘000 dongs)	F6A6. Hired labor cost (‘000 dongs)	G3A. Number of applicati ons	G3B. Cost of fertili zer	G3C. Type of labor	G3D. Family labor cost (‘000 dongs)	G3E. Hired labor cost (‘000 dongs)
		Day	Month	Year											
1															
2															
3															
4															
	(1) Wet (2) Dry				*(1) Broadcast blower (2) Broad cast hand (3) Drum seeding*		*(1) Own (2) Hire (3) Both*						*(1) Own (2) Hire (3) Both*		

Plot code	Weeding			Insecticide					Re-transplanting				Harvesting		
	G5A. Type of labor for weeding	G5B. Family labor cost (‘000 dongs)	G5C. Hired labor cost (‘000 dongs)	G6A. Number of applications	G6B. Cost of insectici de (‘000 dongs)	G6C. Type of labor	G6D. Family labor cost (‘000 dongs)	G6E. Hired labor cost (‘000 dongs)	G7A. Re-transplan ting times	G7B. Type of labor for re-transpla nting	G7C. Family labor cost (‘000 dongs)	G7D. Hired labor cost (‘000 dongs)	H3A. Method	H3B. Equip ment – cost (‘000 dongs)	H3C. Type of labor
1															
2															
3															
4															
	(1) Own (2) Hire (3) Both (4) No weeding					*(1) Own (2) Hire (3) Both*				*(1) Own (2) Hire (3) Both*			*(1) Combine (2) Other machine (3) Hand*		*(1) Own (2) Hire (3) Both*

Plot code	**Harvesting**		**Threshing**					**Hauling**					**Drying**		
	H3D. Family labor cost ('000 dongs)	**H3E. Hire labor cost ('000 dongs)**	**H4A. Method**	**H4B. Equipment cost ('000 dongs)**	**H4C. Type of labor**	**H4D. Family labor cost ('000 dongs)**	**H4E. Hired labor cost ('000 dongs)**	**H5A. Method**	**H5B. Equipment – cost ('000 dongs)**	**H5C. Type of labor**	**H5D. Family labor cost ('000 dongs)**	**H5E. Hired labor cost ('000 dongs)**	**H6A. Method**	**H6B. Equipment – cost ('000 dongs)**	**H6C. Type of labor**
1															
2															
3															
4															
			(0) Sold all fresh at the field (1) Hand (2) Machine		*(1) Own (2) Hire (3) Both*			*(0) Sold all fresh at the field (1) Machine (2) Animal Draft (3) Human*		*(1) Own (2) Hire (3) Both*			*(0) Sold all fresh at the field (1) Sun (2) Machine*		*(1) Own (2) Hire (3) Both*

Plot code	Drying		Irrigation									
	H6D. Family labor cost ('000 dongs)	H6E. Hired labor cost ('000 dongs)	I3. Is the field irrigated (if D6=2 or 4) or rain-fed (if D6=1 or 3)?	I3B. Water source	I4. Total water cost for season ('000 dongs)	<u>(If I3B = 1 or 2)</u> I5. Is the canal/river protected by gate?	I6. Who control the opening/closing of the gate?	I7. Was salinity a problem in the past season?	<u>(If I7=1)</u> I8. Actions taken I8A. Change the planting date	I8B. Change the harvest date	I8C. Change variety	I8D. Other, specify
1												
2												
3												
4												
			(1) Irrigated *(2) Rainfed*	*(1) Canal* *(2) River* *(3) Well* *(4) Other, specify*		*(1) Yes* *(2) No*	*(1) Farmer* *(2) Community* *(3) Village FA* *(4) Commune FA* *(5) Gate officer* *(6) Government* *(7) Other, specify*	*(1) Yes* *(2) No*	*(1) Yes* *(2) No*	*(1) Yes* *(2) No*	*(1) Yes* *(2) No*	*(1) Yes* *(2) No*

Plot code	Output harvested		Output used					Output affected by salinity	
	K3. Fresh paddy (bags)	K4. Fresh paddy (kg)	K5A. Kg sold	K5B. Price per kg ('000 dongs)	K5C. Total money received ('000 dongs)	K5D. Kg for consumption	K5E. Kg kept for seeding	K6. Supposed you harvested 10 paddy bags, how many bags would be harvested if there were no salinity problem?	K7. Supposed you harvested 10 bags, how many bags do you think would decrease if there were salinity problem in DX season?
1									
2									
3									
4									

Plot code	Aquaculture if (D8B = 3)				
	How much did you receive for the fish or shrimp (aquaculture) grown in this rice plot? ('000 dongs)	**What were your total input costs specific to the fish or shrimp (aqua culture on the plot)? ('000 dongs)**	**Type of labor devoted to the fish or shrimp?**	**Family labor cost ('000 dongs)**	**Hired labor cost ('000 dongs)**
1					
2					
3					
4					
5					
6					
			(1) Own *(2) Hire* *(3) Both*		

He Thu 2018

Plot code	**Land preparation**					**Seed variety**							
	E3A. Power	**E3B. Power cost ('000 dongs)**	**E3C. Type of labor**	**E3E. Family labor costs ('000 dongs)**	**E3D. Hired labor costs ('000 dongs)**	**E4A. Seed variety name**	**E4B. Where**	**E4C. How found about**	**E4D. Does the household use certified seed?**	**E4E. Number kg**	**E4F. Cost ('000 dongs)**	**E4G. Years using variety (years)**	**E4H. Reasons chosen**
1													
2													
3													
4													
	(1) Hand (2) Animal (3) Power tiller (4) Tractor (5) Other, specify		*(1) Own (2) Hire (3) Both*				*(1) Purchased – seed club (2) Purchased - merchant (3) Purchased – farmers (4) Purchased - seed centers (5) Purchased – extension centers (6) Purchased – research institutes (7) Own seed (8) Given – family (9) Given – friend (10) Given – seed center (11) Given – extension center (12) Given – research institutes (13) Other, specify*	*(a) Friend (b) Extension (c) Demonstration (d) Seed club (e) Family (f) Other, specify*	*(1) Yes (2) No*				*(A) High yielding (B) Good grain quality (C) Low price (D) Salinity tolerant (E) High market price (F) Other, specify*

Plot code	Herbicide					E6. Seeding method	If E6=2 (Transplant)								
	E5A. Herbicide (yes/no)	E5B. Cost of herbicide ('000 dongs)	E5C. Type of labor	E5D. Family labor cost ('000 dongs)	E5E. Cost of hired labor ('000 dongs)		E6A1. Planting date			E6A2. Days between seeding and planting	E6A3. Transplant method	E6A4. Machine cost ('000 dongs)	E6A5. Labor for seeding	E6A6. Family labor cost ('000 dongs)	E6A7. Hired labor cost ('000 dongs)
							Day	Month	Year						
1															
2															
3															
4															
	(1) Yes (2) No		*(1) Own (2) Hire (3) Both*			*(1) Direct seeding (2) Transplant*					*(1) Hand (2) Machine*		*(1) Own (2) Hire (3) Both*		

Plot code	If E6=1 (Direct seeding)									
	E6B1. Direct seed – Wet/Dry	E6B2. Planting date			E6B3. Planting method	E6B4. Machine cost ('000 dongs)	E6B5. Labor for seeding	E6B6. Family labor cost ('000 dongs)	E6B7. Hired labor cost ('000 dongs)	E6A6. Hired labor cost ('000 dongs)
		Day	Month	Year						
1										
2										
3										
4										
	(1) Wet (2) Dry				*(1) Broadcast blower (2) Broad cast hand (3) Drum seeding*		*(1) Own (2) Hire (3) Both*			

Food consumption score

	L1. Could you please tell me how many days in the past week your household has eaten the following food?	**L2. Number of days the amount consumed was 1 tablespoon or less per person?**
Glutinous rice, white rice, maize, cassava, other roots and tubers		
Fish, other aquatic animals, poultry, pork, red meat, wild meat, eggs		
Pulses, nuts, bean curd		
Green leafy vegetables, bamboo, other vegetables		
Oil and fats		
Fresh fruits		
Sugar		
Milk and milk products		

B0. List all the crops that are being grown in the field in the past 12 months?		
(A) Rice	(B) Maize	(C) Vegetables
(D) Cassava	(E) Sugarcane	(F) Beans (soybean, green bean, black bean, etc.)
(G) Sweet potatoes	(H) Coconut	(I) Banana
(K) Pomelo	(L) Mango	(M) Jack fruit
(N) Longan	(O) Orange	(P) Dragon fruit
(Q) Pineapple	(R) Water melon	(S) Tiger shrimp
(T) Whitetail shrimp	(U) Fish	(W) Mollusks/clams
(X) Other 1, specify	(Y) Other 2, specify	(Z) Other 3, specify

Household Information

A2. Name of the household head: ____

A3a. Respondent (if a person managing rice production is not the household head): ____

A3b. Respondent's relation to household head: [1] Spouse [2] Parent [3] Son/daughter [4] Sister/brother [5] Other relative [6] Non-relative

Household Demographics

For respondent managing the household's rice production:

A7a. Gender: [1] Male [2] Female

A7b. Age in years: ____

A7c. Years living in commune: ____

A7d. Ethnic Group: [1] Kinh/Vietnamese [2] Khmer [3] Cham [4] Chinese [5] Other, sp

A7e. Education level: [1] None [2] Primary [3] Secondary [4] High School [5] Above High School

A7f. Marital status: [1] Married [2] Single [3] Divorced [4] Widowed

A7g. If married, spouse education: [1] None [2] Primary [3] Secondary [4] High School [5] Above High School

A8. Number household members in each age group

A8a. Over 14: ____ A8b. 5-14: ____ A8c. Less than 5: ____

Household Occupations

A9. Primary occupation of manager: [1] Crop/Livestock Agriculture [2] Fishing/Aquaculture [3] Wage labor [4] Self-employment
[5] Unemployed/Retired [6] Other, sp

A10. Number of other household members over 14 years' old with primary occupation

A10a. Crop/Livestock Agriculture:

A10b. Fishing/Aquaculture:

A10c. Wage labor:

A10d. Self-employment:

A10e. Student:

A10f. Other, sp:

Housing

A11. Toilet type: [1] None [2] Temporary toilet [3] Outdoor toilet [4] Toilet with plumbing

A12. Domestic water source: [1] River, canal [2] Rain water [3] Well [4] Tap

A13. Electricity: [1] No [2] Yes

A14. Household Assets (check all): [ ] Radio [ ] Television [ ] Computer [ ] Internet connection [ ] Refrigerator [ ] Paddle boat [ ] Motor boat
[ ] Motorbike

Farm Assets

A15. [ ] Tractor [ ] Hand tractor [ ] Pump [ ] Harvesting Machine [ ] Thresher [ ] Sprayer

Livestock Assets

A16. Number of each: a. Oxen/Buffalos (draft animals)____ b. Cows____ c. Pigs____ d. Chickens____ e. Sheep____ f. Goats____
g. Rabbits____ h. Ducks____ i. Beehives____ k. Other livestock 1 (name) ____, number____
l. Other livestock 2 (name) ____, number ____ m. Other livestock 3 (name) ____, number____

Negative Shocks to Agricultural Production in Past Year

A17a. Most severe: ____

A17b. 2nd most severe: ____

A17c. 3rd most severe: ____

Codes: [0] None [1] Drought [2] Flooding [3] Pests [4] Diseases [5] Salinity intrusion [6] Storage loss [7] Inputs not available
[8] High input prices [9] Low output prices [10] Cyclones [11] Storms [12] High temperature [13] Low temperature [14] Other, sp

Social Networks

A18. Indicate organizations in which you normally participate:

A. Community meetings B. Womens' Association C. Farmer Association

D. Commune Seed Group E. District Seed Club F. Other organization/social activities

H. No organization

Agricultural Credit

A19. Do you or anybody from your household have a saving account? [1] Yes [2] No

A20a. Did you or anybody from your household borrow money/credit from a bank for agricultural activities in the past year? [1] Yes [2] No

A20b. Did you or anybody from your household borrow money/credit from a private lender for agricultural activities in the past year?
[1] Yes [2] No

A20c. Did you or anybody from your household borrow money/credit your family, relatives, or friends for agricultural activities in the past year? [1] Yes [2] No

A20d. Did you or anybody from your household buy agricultural inputs on credits from a supplier in the past year? [1] Yes [2] No

GPS and contact information

A5. Cell phone number (verify number works): ____

A5b. Confirm that the number works: [1] Yes [2] No

A6. GPS reading

A6a. GPS machine code: ____

A6b. Wave point number: ____

A6c. Latitude: ____

A6d. Longitude: ____

Village Questionnaires

Instructions to supervisors: The interview should be conducted by the team supervisor. In this questionnaire, we want to gather information about general daily wages and rice seed availability in the village. Please interview the village head or other community leader who assisted in sample selection.

Province: ____________ District: ___________ Commune: ____________ Village: ____________

Supervisor: ______________ Village Head: ________________ Cell No.: ___________________

Please specify the typical daily wage rate for the hired labor for the following activities in your village:

Activity	**Daily wage ('000 VND)**
Rice field preparation	
Planting and transplanting	
Weeding and maintenance	
Harvesting	
Pesticide application	

Rice seed availability

How important are the following institutions for obtaining new rice varieties?

Institution	**Very Important**	**Somewhat Important**	**Not Important**
Farmer Seed Club			
Seed Center			
Private Market			
Government - Extension			
Government - Research			
Farmer to Farmer exchanges			

Distance (km) to nearest farmer seed club_______

Distance (km) to nearest seed center__________

Distance (km) to nearest private seed store________

Distance (km) to nearest extension worker_________

Appendix D: Covariate balance after matching

T-tests compare the covariates means between matched units with the null hypothesis that the difference is zero (Hagen 2016). Since the goal of matching is to eliminate differences in covariate means, it is desired not to reject the null hypothesis. The first columns in each matching method in Table D1 to Table D4 show that most differences are not statistically significant at the 10% level. A few variables in one nearest-neighbor matching are statistically different between the matched units, but most of these differences are weakly significant.

Variance ratios comparing a covariates' variance between matched units assess whether the distributions of covariates are similar between the treatment and control groups. When two groups are perfectly balanced, the variance ratio is one (Rubin 2001). In this study, the 'pstest' Stata command does not generate variance ratios for each variable. Alternatively, using the 'rubin' option in Stata command, the variance of the residuals orthogonal to the linear index of the propensity score in the treatment group over the control group is calculated (Rubin 2001). In the field level, 4 out of 20 covariates are of concern while 5 to 9 out of 20 covariates are of concern in the household level.

Standardized % bias are standardized differences in means between matched units taking into account sample variances. This measure is preferred when assessing covariate balance because this measure does not depend on sample size. Rosenbaum and Rubin (1985) recommend that standardized biases be less than 20%. After matching to one nearest-neighbor, only one covariate for yield analysis (Table D1) and two covariates for revenue analysis (Table D2) have a standardized bias greater than 20% while all standardized biases lie below 20% after implementing kernel matching (Table D3 and Table D4). Only one to two out of 20 covariates have standardized bias of 20% or higher, and thus covariates are as good as balanced.

Table D1. Covariate balance of two matching methods: yield at the field level

	One nearest-neighbor matching			Kernel matching		
Variable	p>|t|	Variance ratio: V_e(T)/V_e(C)	% bias	p>|t|	Variance ratio: V_e(T)/V_e(C)	% bias
Age	0.878	1.19	1.2	0.494	1.34*	5.5
Male	0.887	1.04	-1.1	0.745	0.94	2.6
Eth	0.021	0.84	-22.5	0.545	1.01	-5.7
Eduprim	0.612	0.99	4.2	0.769	0.99	-2.5
Edusec	0.448	0.91	-6.5	0.966	0.99	-0.4
Eduhigh	0.058	0.73*	-18.1	0.832	0.98	-1.9
Off	0.039	1.21	-18.1	0.947	1.07	0.6
Diverse	0.785	1.52*	2.3	0.768	1.47*	2.5
Meeting	0.449	1.05	-6.0	0.845	0.97	-1.6
Child	0.138	1.25*	11.0	0.935	1.11	0.6
Credit	0.561	1.11	4.7	0.936	0.98	-0.7
Saving	0.623	0.93	-4.2	0.693	0.96	-3.3
Size	0.373	1.98*	-6.5	0.202	1.42*	-9.6
Dis1	0.935	1.13	-0.7	0.470	1.03	6.8
Dis2	0.067	0.80	13.8	0.741	0.71*	2.6
Irri1	0.260	1.18	10.2	0.782	1.02	2.6
Irri2	0.729	0.97	-3.0	0.863	1.01	-1.5
Irri3	0.204	0.97	-10.7	0.973	1.00	-0.3
Salinity	0.297	1.06	8.3	0.880	1.14	-1.2
Nei	0.804	1.05	-1.9	0.916	0.98	0.8

Note: Asterisks denote the following: * if 'of concern', i.e. variance ratio in [0.5, 0.8) or (1.25, 2]
** if 'bad', i.e. variance ratio <0.5 or >2

Table D2. Covariate balance of two matching methods: revenue at the field level

	One nearest-neighbor matching			Kernel matching		
Variable	p>|t|	Variance ratio: V_e(T)/V_e(C)	% bias	p>|t|	Variance ratio: V_e(T)/V_e(C)	% bias
Age	0.038	1.15	17.0	0.689	1.20	3.3
Male	1.000	1.00	0.0	0.787	0.95	2.3
Eth	0.004	0.92	-28.9	0.565	1.02	-5.4
Eduprim	0.393	0.99	-7.3	0.601	1.02	-4.4
Edusec	0.624	1.05	4.1	0.670	1.10	3.6
Eduhigh	0.111	0.73*	-15.3	0.914	0.98	-1.0
Off	0.486	1.11	-6.1	0.615	1.15	4.3
Diverse	0.174	2.13**	11.0	0.654	1.43*	3.9
Meeting	0.411	1.02	6.0	0.997	1.03	0.0
Child	0.960	1.14	0.4	0.980	1.08	-0.2
Credit	0.230	1.21	9.7	0.888	1.06	1.2
Saving	0.001	0.99	-29.6	0.696	0.95	-3.3
Size	0.296	2.17**	-7.0	0.291	1.49*	-7.9
Dis1	0.808	0.88	2.4	0.446	1.07	7.2
Dis2	0.659	0.75*	3.4	0.637	0.71*	3.7

Irri1	0.913	1.00	1.0	0.708	0.99	3.5
Irri2	0.165	0.87	-12.4	0.996	1.00	0.0
Irri3	0.541	1.05	5.1	0.833	0.96	-1.8
Salinity	0.245	1.18	9.0	0.872	1.11	-1.3
Nei	0.951	0.99	-0.5	0.951	1.06	-0.5

Note: Asterisks denote the following: * if 'of concern', i.e. variance ratio in [0.5, 0.8) or (1.25, 2]
** if 'bad', i.e. variance ratio <0.5 or >2

Table D3. Covariate balance of two matching methods: yield at the household level

	One nearest-neighbor matching			Kernel matching		
Variable	p>|t|	Variance ratio: V_e(T)/V_e(C)	% bias	p>|t|	Variance ratio: V_e(T)/V_e(C)	% bias
Age	0.062	1.28*	16.1	0.443	1.26*	6.6
Male	0.003	3.03**	-19.4	0.947	1.02	-0.5
Eth	0.324	0.94	-10.2	0.264	1.12	-11.7
Eduprim	0.653	0.97	-4.0	0.928	1.00	-0.8
Edusec	0.278	0.98	-10.1	0.781	0.96	-2.5
Eduhigh	1.000	1.00	0.0	0.760	1.10	2.7
Off	1.000	1.44*	0.0	0.997	1.11	0.0
Diverse	0.834	1.34*	2.0	0.804	1.50*	2.3
Meeting	0.458	1.28*	6.1	0.549	1.30*	5.1
Child	0.586	1.27*	-4.3	0.982	1.13	0.2
Credit	0.406	1.12	7.2	0.520	0.90	-5.8
Saving	0.183	0.88	-12.3	0.635	0.96	-4.3
Size	0.197	1.79*	-9.5	0.322	1.44*	-7.5
Dis1	0.959	0.82	0.6	0.250	1.02	11.5
Dis2	0.405	0.71*	7.1	0.628	0.73*	4.1
Irri1	0.478	1.11	7.1	0.763	1.00	-3.1
Irri2	1.000	1.00	0.0	0.773	1.00	-2.8
Irri3	0.465	0.94	-6.6	0.843	1.05	1.8
Salinity	0.536	1.29*	-4.9	0.771	1.23	2.4
Nei	0.965	1.09	-0.4	0.931	0.97	0.7

Note: Asterisks denote the following: * if 'of concern', i.e. variance ratio in [0.5, 0.8) or (1.25, 2]
** if 'bad', i.e. variance ratio <0.5 or >2

Table D4. Covariate balance of two matching methods: revenue at the household level

	One nearest-neighbor matching			Kernel matching		
Variable	p>|t|	Variance ratio: V_e(T)/V_e(C)	% bias	p>|t|	Variance ratio: V_e(T)/V_e(C)	% bias
Age	0.116	1.30*	13.4	0.544	1.26*	5.2
Male	0.537	0.82	5.4	0.826	1.09	-1.8
Eth	0.082	1.00	-18.6	0.220	1.11	-12.9
Eduprim	0.784	1.00	2.5	0.895	1.01	-1.2
Edusec	0.840	0.96	-1.9	0.857	0.97	-1.7
Eduhigh	0.318	1.27*	8.8	0.659	1.14	4.0
Off	0.831	1.09	-1.9	0.871	1.13	-1.5

Diverse	0.402	1.59*	7.7	0.762	1.49*	2.8
Meeting	0.474	1.12	6.2	0.475	1.33*	6.1
Child	0.664	1.15	3.5	0.840	1.19	1.6
Credit	0.194	0.86	-11.9	0.576	0.92	-5.0
Saving	0.350	0.91	-8.6	0.673	0.97	-3.8
Size	0.866	1.93*	-1.2	0.365	1.40*	-6.9
Dis1	0.666	0.81	4.7	0.317	0.99	10.1
Dis2	0.285	0.79*	8.9	0.544	0.72*	5.2
Irri1	0.432	0.96	-8.3	0.808	1.00	-2.5
Irri2	0.217	1.14	11.7	0.897	1.00	-1.2
Irri3	0.407	0.91	-7.6	0.962	1.01	0.4
Salinity	0.488	1.22	-5.5	0.806	1.24	2.0
Nei	0.474	1.15	-5.8	0.993	1.01	-0.1

Note: Asterisks denote the following: * if 'of concern', i.e. variance ratio in [0.5, 0.8) or (1.25, 2]
** if 'bad', i.e. variance ratio <0.5 or >2