

Le, Hanh-My; Ludwig, Markus

**Conference Paper**

## The Salinization of Agricultural Hubs: Impacts and Adjustments to Intensifying Saltwater Intrusion in the Mekong Delta

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# Working Paper

## The Salinization of Agricultural Hubs: Impact of and Adjustment to Intensifying Saltwater Intrusion in the Mekong Delta\*

Hanh My Le<sup>†</sup>      Markus Ludwig<sup>‡</sup>

August 2022

### Abstract

Intensifying saltwater intrusion poses multiple threats to agricultural economies of coastal deltas. We study the impact of salinization in the Vietnamese Mekong delta, a large rice exporter known as the ‘Rice Bowl’. Inland dispersion of saltwater is identified using river salinity data recorded by coastal stations and distances along the region’s canal network. We find significant negative effect of salinization on rice production and higher salinization is estimated to increase the production of salt-resistant industrial crops. Salinization is further shown to reduce land used and partly labor supply in agriculture. While the effects on household income and consumption are negative, our estimate signals increased spending on education in response to salinity shocks. For adaptation smoothing mechanisms, we find mixed evidence on labor migration to urban areas for off-farm work and suggestive evidence on the role of credit access in easing farmers’ income losses.

**Keywords:** salinization, climate change, agriculture, adaptation, technological change.

**JEL Codes:** O13, Q01, Q12, Q16, Q54, Q55.

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<sup>†</sup>Institute of Economics, Technical University Braunschweig; email: hanh-my.le@tu-braunschweig.de.

<sup>‡</sup>Institute of Economics, Technical University Braunschweig; email: markus.ludwig@tu-braunschweig.de.

# 1 Introduction

Inhabited by more than 500 million people, coastal deltas around the globe are experiencing pronounced environmental changes (Giosan et al., 2014). As sea level is projected to rise by 0.3-1.32 meters by the end of the century, substantial parts of these low-lying lands will likely be submerged (Clark et al., 2016; Horton et al., 2020). With fertile soils deposited by river sediment and dynamic ecological systems, coastal deltas are highly productive agricultural regions. While projected inundation signals future loss of these valuable lands, other extreme weather events happening at shorter time scales such as fluvial and coastal flooding (Tessler et al., 2015) and increasing salinization (Rahman et al., 2019) are already putting both global food security and the livelihoods of local farmers at risk.

In this paper, we focus on the process of increasing saltwater intrusion, which entails the transient shock of less freshwater due to riverine salinization and the longer-term consequence of soil salinization. Because many coastal deltas rely on salt-sensitive crops such as rice, it is crucial to assess the economic impact of salinization on their production. We further look to find evidence of adjustments both outside agriculture such as labor reallocation into other sectors and within agriculture such as crop/production diversification, given the inherent rich biodiversity of coastal deltas and the available technological progress.

We study the impact of salinization on the agricultural production, labor decisions and welfare of farmer households in the Vietnamese Mekong delta (MKD). MKD is known as the country's 'Rice Bowl'; the delta alone contributed to over 90% of national rice exports with Vietnam being the third largest global rice exporter (Dao et al., 2020). The region is one of the most low-lying areas worldwide with average elevation of 80 cm above sea level (Minderhoud et al., 2019). Characterized by tropical monsoon climate, MKD experiences recurring saltwater intrusion during the dry season, which however intensified in recent years (Eslami et al., 2019). Mean salinity level measured at hydro-stations along rivers in the last decade peaked in 2016 and 2020 as salinity intrusion severely affected livelihoods and welfare of households in wider areas (World Bank, 2017).

To identify the temporal variation and spatial dispersion of salinization, we use the river salinity data recorded during the dry seasons between 2010-2020 at 38 hydro-stations across MKD coastal provinces. Because the delta has an extensive canal network used for irrigation that leads river water into villages, we measure households' exposure to salinization by constructing an inverse canal-distance weighted salinity index (SI) at the commune<sup>1</sup> level using the river salinity data recorded at the stations. For the economic variables we use pooled cross-

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<sup>1</sup>Commune is the smallest administrative unit in Vietnam, below province and district. A commune is typically larger than 30  $km^2$  and contains villages.

sections of household data from four waves of the Vietnam Household Living Standards Survey between 2012 and 2018.

Our analysis shows five main results. First, for agricultural production, exposure to higher salinity (i.) decreases the productivity and revenue share of rice crop, (ii.) decreases aquaculture production but (iii.) increases the revenue share of industrial crops, which are mainly coconut—a salt-resistant crop. Because new salt-tolerant rice varieties are increasingly introduced and adopted in MKD (Paik et al., 2020), the adverse effect of salinization on rice production could have been dampened by this adjustment. The result on industrial crops points to new crop adoption and crop switch as mechanisms for risk diversification that can help farmers, especially those relying disproportionately on rice production, secure their income against salinization shocks. Second, for agricultural land used, we find that higher salinity intrusion is associated with decreases not only in farmers' land used for rice but also in their general land used reported for agriculture.

Third, we find evidence of salinization's effects on labor supply. While salinity shock is estimated to decrease labor supply in agriculture for those without agricultural land, labor supply for those with agricultural land does not response to higher salinity. Yet for this group, salinization is estimated to increase labor supply through additional (secondary) jobs. Fourth, salinization is found to reduce farmer households' income and consumption. However, the estimated effect on household spending on education is positive, potentially implying farmers' increased investment to acquire new skills. Fifth, we test two channels for adaptation smoothing: migration and credit access. While the evidence on out-migration for off-farm work in urban centers is mixed, our results support the hypothesis that a more developed local credit market plays a positive role in easing the income losses incurred by farmers during salinization shocks.

Our research contributes to the literature that aims to quantify the impacts of salinization on agricultural production in coastal deltas. Dasgupta et al. 2014 measures soil salinity variation at sub-district level in the Bangladesh Ganges delta and their effects on the production of high-yielding rice. Using sub-district level panel data for rice production between 2000-2012, they find that soil salinity above the threshold of 4 dS/m<sup>2</sup> reduces rice productivity by about 15.6%. They also find that rice price decreases by 0.06-0.08% with each 1% increase in salinity yet soil salinity has no statistically significant effects on labor or land use.

Chen and Mueller 2018 also study the effects of soil salinization in the Bangladesh Ganges delta. They use soil sample data collected in 2000 and 2009 to determine soil salinity at upzila level and pooled cross-section household data for agricultural variables. Their results show that

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<sup>2</sup>The technical measurement of soil salinity is electrical conductivity with unit dS/m. Soil with salt accumulation above 4 dS/m or mmhos/cm is classified as saline soil, which can impair crop productivity, see Dasgupta et al. 2014 and USDA 1954.

soil salinity reduces households' revenue from crops but increases their share of revenue received from aquaculture; as no effects on total farm revenue is found, their results suggest farmers' successful production conversion to aquaculture to mediate the losses caused by higher salinity. Furthermore, they find that salinization significantly induces internal migration within rural areas. Medellín-Azuara et al. 2014 study the agricultural losses from salinity in the American Sacramento-San Joaquin delta using the Delta Agricultural Production model combining hydrodynamic, water salinity and agro-economic modelling. They estimate that salinity changes from sea level rise could reduce total crop revenue by less than 1% of the current value. They propose that the estimated losses are small because only the lower-value crops are grown in the most salt-affected areas of the delta and because farmers can effectively vary their crop mix as salinization increases.

We note that the literature studying economic impact of salinization shocks, especially with regard to adapting strategies and structural changes, is still scarce. Our aim is to contribute insights through a comprehensive analysis which uses more granular data, detailed econometric estimation and looks at further outcome variables and adaptation processes.

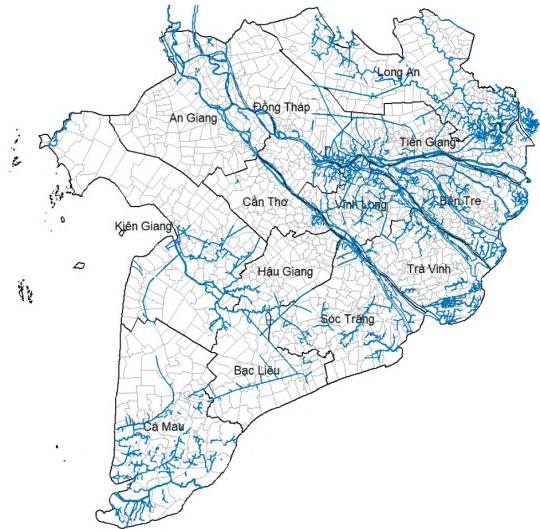
More broadly, we join the literature that studies the impacts of extreme weather events and climate change on agriculture production and development. Adverse effects of short-term weather changes are widely documented (Lobell et al., 2011; Dell et al., 2012, 2014; Auffhammer and Schlenker, 2014) and adjustments to these shocks include employment shifts to non-agricultural sectors (Colmer, 2018; Blakeslee et al., 2020) or migration (Feng et al., 2010; Chen and Mueller, 2018). While salinization can be viewed as a weather shock, it also resembles a process that induces persistent changes and studying the adjustments involved is relevant for understanding long-term adaptation.

We acknowledge the crucial importance in distinguishing between short-term weather variability and climate change when analyzing the impacts and adjustments involved (Auffhammer and Schlenker, 2014; Burke and Emerick, 2016; Hsiang, 2016), yet point to the longer-term consequences of increasing saltwater intrusion for agricultural production in the form of soil salinization, degradation and loss. Evidence of adaptation to long-term climatic change or environmental catastrophes is limited with only out-migration as the dominant coping strategy (Hornbeck, 2012; Burke and Emerick, 2016). However, as technological progress is a critical mechanism for climate change adaptation (Cruz et al., 2021), there is evidence in the literature of how directed innovation effects and transforms an agricultural economy's ability to tackle long-term environmental shocks (Olmstead and Rhode, 2011; Moscona and Sastry, 2021). For this research, our question is also whether farmers, with technologies and increased investment on human development, could adapt to reduce the negative impact and even leverage the potential opportunities brought by salinization.

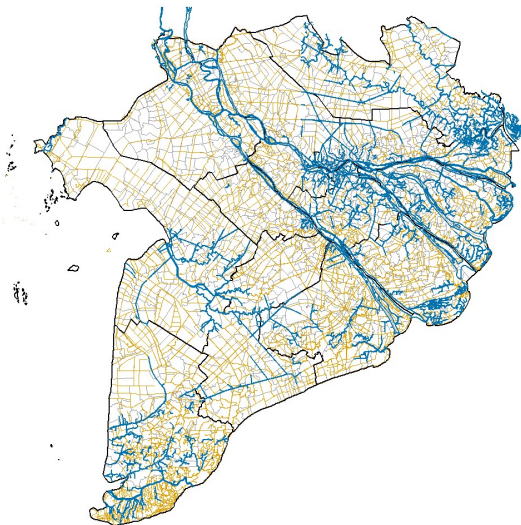
## 2 Background

### 2.1 Study Area

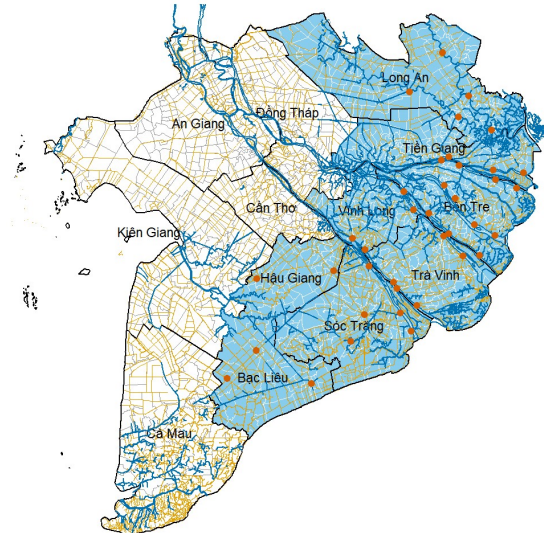
Mekong river of approximately 4,900 km in length is the longest river in South East Asia, flowing from China through Myanmar, Lao, Thailand, Cambodia and entering the sea in south Vietnam (MRC). Vietnamese Mekong delta has the total area of 40,816 km<sup>2</sup> and total population of 17.4 million, accounting for 12.3% and 17.7% of national total respectively (GSO) – figure 1 shows MKD's provinces at the commune level and its river system. In 2019, MKD contributed to about 56% of national rice output and 70.1% of national aquaculture production (GSO). The delta produces over 90% of Vietnam's total rice exports, which was valued at 2.2 billion USD in 2018 (Dao et al., 2020). Other crops grown in the region include perennial fruits, cash-



**Figure 1:** MKD provinces at commune level and river system. Commune borders are grey lines.



**Figure 2:** MKD communes and canal network: Canals are in yellow lines. Geodata provided by Can Tho University.



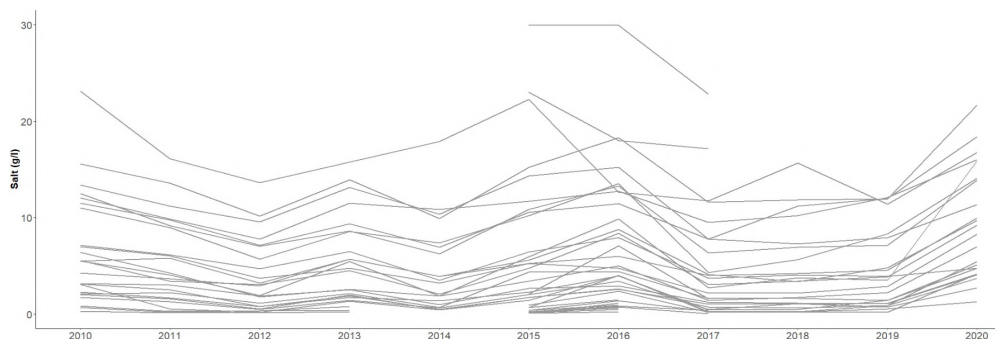
**Figure 3:** Studied provinces and river stations. Studied provinces are in blue-shaded area. Geodata provided by Can Tho University.

and industrial crops (CCAFS SEA, 2016).

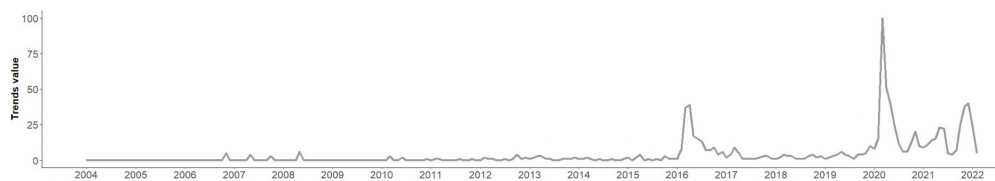
Surface water from the river system is the main source of water used for irrigation, followed by groundwater and to a lesser extent harvested rainwater (Ozdemir et al., 2011; Dang et al., 2014; Nguyen et al., 2021). The delta has a dense canal network built in the last 300 years chiefly for irrigation consisting of main, secondary canals and on-farm systems (Hoanh et al., 2012) – MKD canal network is mapped in figure 2. Our study area includes eight provinces shown in figure 3. Long An, Tien Giang, Ben Tre, Tra Vinh, Soc Trang and Bac Lieu share the coastline to the sea east of Vietnam. Vinh Long and Hau Giang, although not among the coastal provinces, are also affected by saltwater intrusion to certain degrees.

## 2.2 Saltwater Intrusion

Located within the monsoon climate, MKD normally experiences rainy season from July to October while its dry season typically lasts from December to May. Saltwater intrudes during the dry months with April being the driest and most saline when upstream flow discharge rates are lowest (Le et al., 2007). In recent years, salinity intrusion tends to last longer and with higher intensity. Documented reasons include stronger tidal flooding induced by rising sea level and sediment starvation caused by anthropogenic impacts of hydro-power dams located upstream and local sand extraction (Khang et al., 2008; Eslami et al., 2019; Schmitt et al., 2021).



**Figure 4:** Mean river salinity measured at 38 stations, 2010-2020, g/l.



**Figure 5:** Google Trends data for search term "han man", 2004-2021.

We use the daily data of river salt content measured from 2010 to 2020 at 38 hydro-stations of Vietnam Meteorological and Hydrological Department – the stations are mapped in figure 3. Stations measure salinity data daily or every two-three days during the dry season. The measuring starts with the dry season determined by stations’ observation on temperature and precipitation levels. Our calculations show that mean river salinity levels of almost all stations peaked in the two years 2016 and 2020. Figure 4 shows the mean salinity levels calculated from station data. The stations of which recorded salinity did not peak in 2016 and 2020 are also outliers in the data: they are located in Bac Lieu province which lies farther from the major branches of Mekong and, thus, could have experienced different discharge rates of the upstream flood and resulted different mean levels of river salinity. Retrieving the Google Trends data for search term “han man” which means “salt drought”, in figure 5 we observe the similar spikes in the relative Google traffic given to this search term in the two years 2016 and 2020 when saltwater intrusion was intense. Furthermore, from the data it can be noticed that while stations on average recorded salinity from January to July, in 2016, several reported data from November of the previous year, signaling the early onset of salinity intrusion. The resulted longer duration of salinity intrusion into riverine system could cause more severe episodes of fresh water shortage and simultaneously increase the possibility of soil salinization.

### 3 Empirical Methods

#### 3.1 Identifying Households’ Exposure to Salinization

We measure households’ exposure to salinity intrusion at the commune level. A salinity index is constructed by inverse-distance weighting using river salinity recorded at hydro-stations and distances between the communes and hydro-stations across the irrigation canal network. The formula for the inverse distance-weighted index follows.

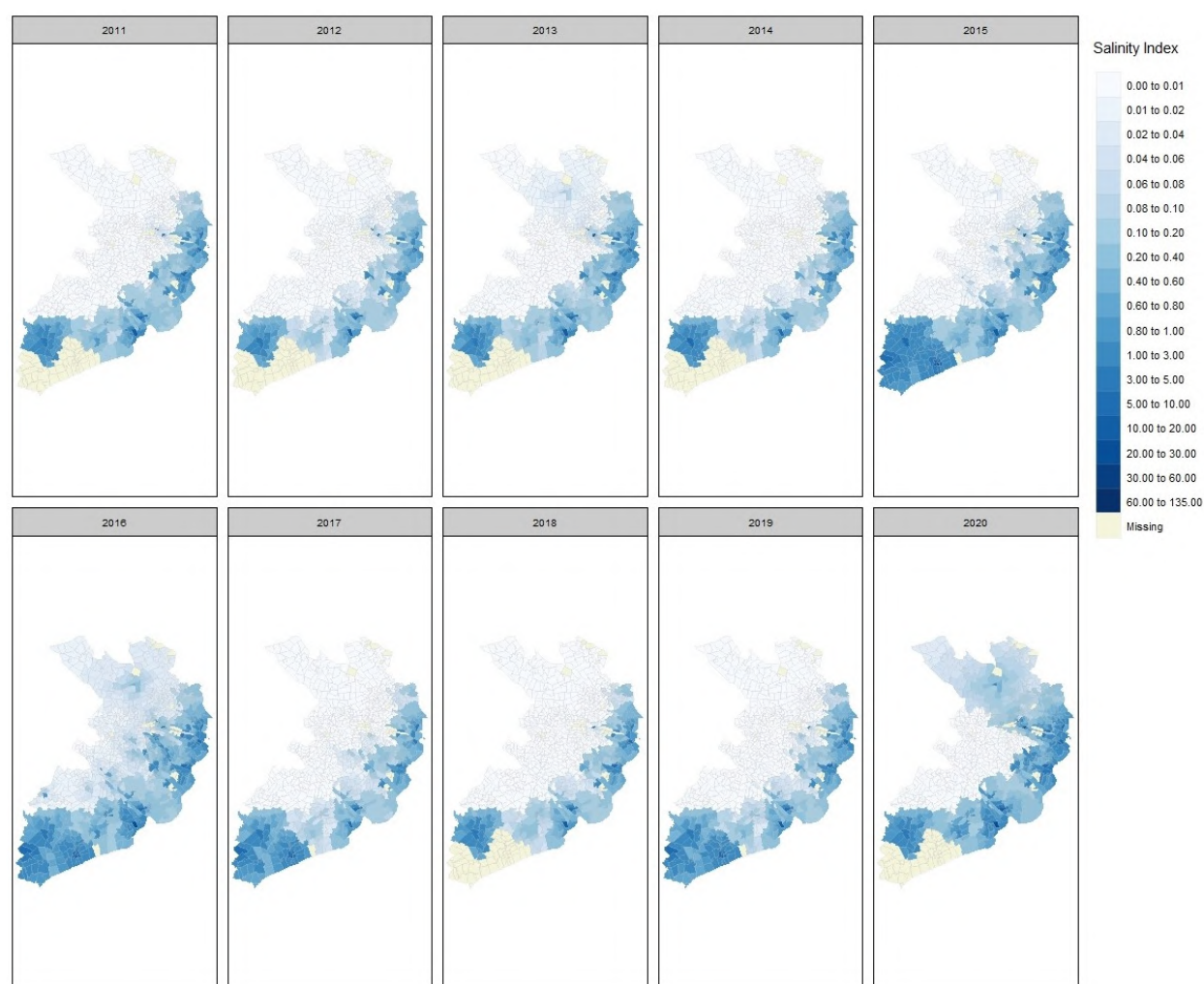
$$SI_{cst} = Distance_{cs}^{-1} \times Salinity_{st}. \quad (1)$$

$SI_{cst}$  is the salinity index measured for commune  $c$  in year  $t$ . Subscript  $s$  denotes the hydro-station closest to the centroid of commune  $c$  by canal distance.  $Distance_{cs}$  is the canal distance between the centroid of commune  $c$  and its closest hydro-station  $s$ .  $Salinity_{st}$  is the average river salinity content recorded at station  $s$  in year  $t$ . The annual average level of river salinity is calculated by averaging across the daily data reported for the respective year.

Our identification strategy rests on three key assumptions. First, because the extensive canal network in place serves as the main channel connecting river water to farms for irrigation, we



reason that it is also the channel that disperses saltwater into households' farmland and therefore employ the canal distance to characterize this proposition. Second, because river salinity content measured at coastal hydro-stations is driven by tidal forces, upstream discharges and local sand mining as shown by Eslami et al. 2019, we argue that the constructed SI is exogenous in the context of testing for all the agricultural outcome variables estimated in this study, yet acknowledge the endogeneity threat for other outcomes that have a reverse causal link with local sand mining activities. Third, because saltwater intrusion causes the issue of saline soil (FAO, 1989), using river salinity to construct SI at the commune level can help us identify the average level of soil salinization induced by environmental changes<sup>3</sup> that farmers are exposed to.



**Figure 6:** Salinity intrusion mapped using SI for years 2011-2020.

<sup>3</sup>Here we distinguish between primary soil salinization caused by environmental factors such as saltwater intrusion or droughts and secondary soil salinization caused by human activities such as brackish irrigation practices, see e.g., FAO, 1989; USDA, 1998

Figure 6 maps the extent of salinity intrusion for the study area using our constructed SI and shows alignment with reported salinity border included in appendix A. We also compare the constructed SI with salinity data of 184 in situ water- and soil samples collected across farm areas in April 2016 by Can Tho University and find Pearson correlation coefficients of about 0.4 between SI and ground truth data in logarithm. Appendix A presents the reported correlation coefficients and plots of in situ data at different soil depths against the salinity index measured for April 2016, March 2016 and the period of November 2015 to April 2016.

There exist two caveats for our identification. First, for missing data of river salinity not reported by stations, which are detectable in figure 4, we assign zeros for stations that reported relatively low average salinity for available periods and keep the missing values of stations which on average reported higher level of salinity such as those in Bac Lieu province. To our knowledge, hydro-stations base on a number of environmental factors such as temperature and precipitation to determine the start of the dry season. The measure of river salinity only starts with the observed onset of the dry season and thus in most cases, non-recorded data reflect marginal or zero salinity intrusion. The second caveat follows that in practice there are sluice gates in MKD river and irrigation canal systems, which can be closed to slow the intrusion of saltwater. Yet due to the lack of data on the locations of sluice gates, this factor is not accounted for in our identification of using canal distance to characterize salinity dispersion. Nevertheless, we also argue that because the operation of sluice gates is likely correlated with the development of local agricultural production, the inclusion of this factor in the construction of SI may introduce endogeneity problem.

### 3.2 Economic Outcome Variables

**Household Data.** For economic outcome variables, we use pooled cross-section data from the Vietnam Household Living Standards Survey (VHLSS). The survey is conducted by General Statistics Office Vietnam nationwide every two years since 2002. Data on demographic, employment, income, expenditures and development are collected at commune and household levels from random samples of representative households and communes within each province. Each survey wave is conducted in four sub-waves in March, June, September and December of the survey year. To match the salinity data available, we use four waves of VHLSS: 2012, 2014, 2016 and 2018. For each of these survey waves, the full sample reporting demographic data in the studied region is 978 households selected from 326 communes, which are chosen out of the total 993 communes in the eight studied provinces.

#### **Variable Construction.**

For rice production, *Rice Yield per Squared Meter* is household's reported rice yield in kilo-

gram divided by the reported area of cropland used for rice cultivation. *Rice Producer* is a binary variable which equals unity if the household reported non-zero revenue from rice production, and zero otherwise. Here revenue is defined to be the monetary amount received from selling or exchanging the produced rice. *Revenue Share from Rice* is the fraction of revenue gained from rice production in the total agricultural revenue from all crops and aquaculture.

For aquaculture and the production of industrial crops, fruits, and other grains and vegetables (OGV), *Producer* is a binary variable which equals unity if the household reported non-zero revenue from the respective production, and zero otherwise. *Revenue Share* is the fraction of revenue gained from the respective production in the total agricultural revenue. *Total Revenue* is the sum of revenue from all crops (including rice) and aquaculture that the household reported.

For agricultural land use, *Rice Cropland* is the cultivation area for rice production reported by the household. *Crop/Aquaculture Land* is a binary variable which equals unity if the household reported non-zero cultivation area for the respective crop or aquaculture, and zero otherwise. Because the cultivation areas for industrial crops and fruits, unlike for rice and OGV, could be reported in either squared meter or number of trees, it is not possible to calculate the precise cultivation areas for these two crop types. The variable *Agricultural Land* used in the estimation is the aggregate area of general agricultural land reported by household and is not the sum of cultivation areas for all crops and aquaculture due to the problem in calculating the areas for some crop types.

For labor supply, the estimation is on individual- instead of household level and three outcome variables are included in the estimation. *Working in Agriculture as Primary Job* is a binary variable which equals unity if the individual reported that the occupation which they spent the most time working is a job in agriculture, and zero otherwise. *Working in Agriculture* is a binary variable which equals unity if at least one of the occupations (primary or secondary occupations) reported by the individual is a job in agriculture, and zero otherwise. Whether a job is classified to be in agriculture is determined based on the occupation code that the individual reported together with the respective job. *Working a Secondary Job* is a binary variable which equals unity if the individual reported to have a secondary job, and zero otherwise.

For household income and expenditures, *Total Income* is household's aggregate income received from agricultural production, wages and all other sources<sup>4</sup>. The expenditures to estimate include four categories. Two categories for less-essential spending *Non-Food Goods Expenditures* and *Festive Food Expenditures* measure household spending on non-food items and on

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<sup>4</sup>Because the role of local finance sector is tested as one of the channels to help smoothing income losses incurred by the household, it is remarked that variable *Total Income* does not include loan as a part of household income.

food for festive occasions respectively. Because expenditures on food are reported by the household for the past 30 days instead of the past 12 months in the survey, this spending category is not included in the estimation. *Expenditures on Health* is the total spending on medical goods and services. *Expenditures on Education* is the total spending of the household on children's schooling and on education and training activities taken up by adult members.

**Samples Used in Estimation.** For agricultural revenue binary indicator, revenue share, land use binary indicator and variables on household income and expenditures, the sample used in estimation include all agricultural producers. Agricultural producers are defined to be households who reported non-zero revenue from any crop or aquaculture. To balance the sample, revenue from crop or aquaculture not reported by the household is assumed to be zero. Estimation using this sample allows the measure of extensive margin on agricultural production. Estimation using heterogeneous samples of single crop producers such as rice, on the other hand, gives indicators on the intensive margin of the production. Heterogeneous samples are also used as the robustness check for the outcome of revenue share as the assumption of zero-revenue can be discarded. For labor supply outcomes, the main full sample is all household members participating in the survey. The estimation also covers sub-samples of individuals residing in households with agricultural land and without agricultural land to test for heterogeneous effects on labor supply.

### 3.3 Control Variables

**Demographic Controls.** For estimation of outcome variables on household level, household size, household head's age and years of education are included as controls. For estimation of outcome variables on individual level, individual's gender, age, years of education and household size are included as controls. Data for the demographic controls are extracted from VLHSS and matched with the household or individual by location, household codes and year.

**Weather Controls.** Omitted variable problem discussed by Auffhammer et al. 2013; Auffhammer and Schlenker 2014 is acknowledged in our estimation which focuses on the impact of salinity intrusion as a single weather variable. Other weather/climatic factors such as temperature and rainfall are likely correlated with salinity intrusion and also impact our interested economic outcomes, especially agricultural production. Annual average temperature and precipitation at the commune level are thus controlled for in our estimation. Data for temperature at  $0.5 \times 0.5$  degree grid resolution is from the Climatic Research Unit Gridded Time Series (CRU-TS) by Harris et al. 2020 and downloaded via Copernicus Climate Data Store. Data for precipitation at  $0.25 \times 0.25$  degree grid resolution is from CRU-TS, down-scaled with WorldClim 2.1 by Fick and Hijmans 2017 and downloaded via WorldClim.

### 3.4 Variables on Adaptation Smoothing Mechanisms

To test for channels that help farmers adapt to salinization shocks, our estimation up to this point includes the following two variables.

**Distance to Urban Centers.** The distance between communes and urban centers is estimated to see whether being closer to large cities further induces labor to leave the agricultural sector or migrate in response to salinization. An urban center is defined to be self-governed municipality or provincial city of classes 1 or 2<sup>5</sup>.

**Development of Local Finance Sector.** The development indicator of local financial market is estimated to test whether fewer credit constraints help farmers to better adapt to salinization through production switching or diversifying and thus to better mediate income losses. To characterize the level of local finance sector development, we measure the number of firms operating in the finance sectors, i.e., banks and other firms offering financial services, per 10,000 inhabitants for a district.

Table 1 summarizes the data sources of all the discussed variables.

**Table 1: Data Sources.**

Variable/Information	Data source
Household economic outcomes	Vietnam Living Standards Survey 2012, 2014, 2016, 2018 General Statistical Office
Household demographic controls	Vietnam Living Standards Survey 2012, 2014, 2016, 2018 General Statistical Office
River salinity data	Hydro-stations 2010-2020 Vietnam Meteorological and Hydrological Department
Temperature and precipitation	CRU Monthly gridded Time Series 2010-2020 University East Anglia (Source) and WorldClim (Rescaling)
Firm data - Finance sector	Vietnam Enterprise Survey 2012, 2014, 2016 General Statistical Office
District population data	Vietnam Census 2009 General Statistical Office
Administrative borders and codes	GADM and General Statistical Office
River and canal network shapefiles	Can Tho University
Salinity data for in situ water- and soil samples	Can Tho University

<sup>5</sup>Provincial cities in Vietnam are classified into five classes with class 1 being the most developed and class 5 the least developed.

### 3.5 Econometric Model

Our main specification to estimate the impact of salinity intrusion on economic outcomes is:

$$Y_{ict} = \alpha + \beta SI_{c\tilde{t}} + \delta T_{c\tilde{t}} + \gamma P_{c\tilde{t}} + \eta \mathbf{X}_{ict} + \lambda_c + \theta_t + \epsilon_{ict}. \quad (2)$$

$Y_{ict}$  is the economic outcome to estimate for household or household member  $i$  who resided in commune  $c$  in survey year  $t$ . It is worth noting that economic data is reported by households for the past twelve months in the survey, for example, the survey question to collect the information on rice yield asks “What is the yield from rice production in the last twelve months?”. Therefore,  $Y_{ict}$  captures the economic outcome of both the contemporaneous year  $t$  and the previous year  $t - 1$  if the survey is conducted for the household in sub-waves of March, June or September in year  $t$ . To match this characteristic of the outcome variables, we use the average value of contemporaneous year  $t$  and past year  $t - 1$  for the weather variables of salinity index  $SI$ , temperature  $T$  and precipitation  $P$ . The average value is denoted with the subscript  $\tilde{t}$ .

$$Weather_{c\tilde{t}} = \frac{1}{2} \times (Weather_{ct} + Weather_{c,t-1}). \quad (3)$$

Salinity index  $SI$  in the estimated equation in 2 is standardized in all regressions and the estimated coefficient of interest which is reported in the results is  $\hat{\beta}$ . The main specification also includes  $\mathbf{X}_{it}$  as the vector of demographic controls discussed in the previous section. All regressions include commune fixed effect  $\lambda_c$  and year fixed effects  $\theta_t$  to account for time-fixed commune heterogeneity and secular trends which potentially affect the estimated outcome. Unobserved time-variant shocks are captured by the error term  $\epsilon_{ict}$ .

Regressions with continuous outcome variables are estimated using method of ordinary least-square. Because the *Revenue Share* variables are with corner solutions for having a substantial number of zero values, Poisson maximum-likelihood estimation is also performed for these variables as additional test. Regressions with binary indicator variables are estimated as linear probability models (LPM) using OLS. As additional test for these variables, probit MLE is performed and marginal effects are computed to compare with coefficients from LPM estimation. The main results report estimates from OLS and LMP while estimates from MLE methods are given in the appendix. Standard errors are clustered at the commune level in all regressions.

## 4 Results

In this section, estimation results for rice production, production of aquaculture and other crops, agricultural land used, labor supply, household income and expenditures and adapta-

tion smoothing channels are presented. Because SI is standardized in all regressions, the sample used for the specific outcome is taken into account when interpreting the estimated effect.

#### 4.1 Rice Production

Table 2 reports results for three outcomes on rice production. Column 1 reports the estimated intensive margin effect on rice productivity for the sample of rice producers. Within this sample, one standard deviation increase in salinity index is estimated to decrease rice yield per cultivated squared meter by about 5%. The effect is statistically significant at the 1% level. This result is in line with the findings of Dasgupta et al. 2014. Because rice is grown along the year in three cropping seasons in MKD, production in early season (December-March) and midseason (April-July) can be highly affected by salinity intrusion given the salt-sensitive nature of rice <sup>6</sup>.

**Table 2: Estimated Impact on Rice Production.**

	Dependent variable:		
	Log Rice Yield per m <sup>2</sup>	Rice Producer Yes/No	Revenue Share from Rice
	OLS	LPM	OLS
	(1)	(2)	(3)
SI	-0.052*** (0.011)	-0.008*** (0.003)	-0.011*** (0.003)
Observations	1,198	2,367	2,367
R <sup>2</sup>	0.414	0.520	0.574
Controls	✓	✓	✓
Commune & Year FE	✓	✓	✓

NOTES—Robust standard errors are in the parentheses, adjusting for clustering at the commune level. Weather controls are temperature and precipitation measured for the commune. Household controls are household size, household head's age and years of education. All regressions control for commune- and year fixed effects. Significance level: \*p<0.1; \*\*p<0.05; \*\*\*p<0.01.

Columns 2 and 3, table 2, report the estimated effects of salinization for the sample of agricultural producers on the probability of farmers receiving revenue from rice production and the fraction of agricultural revenue from rice production respectively. One S.D. increase in SI in this sample is estimated to decrease the probability of receiving revenue from rice by 0.8

<sup>6</sup>Salt-tolerance levels of crops in MKD are mentioned in e.g., (CCAFS SEA, 2016); Blom-Zandstra et al. 2017 detail salt-related characteristics of grown crops and alternative crops for MKD.

percentage points and to decrease the revenue share from rice production by 1.1 percentage points. Both estimates are statistically significant at the 1% level. While the estimated effect for the probability of reporting rice revenue signals the negative extensive-margin effect of salinity intrusion on rice production, the estimate for revenue share potentially captures both negative extensive- and intensive-margin effects because revenue shares include both zero values for non-producers and non-zero values recorded for producers.

In the additional tests, probit MLE and Poisson MLE are performed for the two variables probability of reporting rice revenue and revenue share from rice respectively and similar patterns emerge. As the results show the reduced portion of agricultural revenue from rice in response to higher salinity, in the next part results on other crops and aquaculture are presented to discuss potential within-agriculture adjustments.

## 4.2 Aquaculture and Other Crops

Table 3, columns 1 and 2, show the estimated effects of salinity on the probability of reporting revenue and the revenue share for aquaculture production. Because integrated agriculture-aquaculture, e.g., rice-shrimp or rice-fish farming, is a widely adopted production model in the region, aquaculture is the other focus of MKD beside rice (see e.g., Brennan et al. 2002). Aquaculture is also a well mentioned strategy for food production in other coastal areas (see e.g., Costello et al. 2020). While Chen and Mueller 2018 find the positive effect of salinization on the revenue share of aquaculture in the Ganges delta, our estimates are negative for both variables tested for this production category. One S.D. increase in SI is estimated to decrease the probability of reporting revenue from aquaculture by 0.7 percentage points and to decrease the revenue share by 0.4 percentage points. Both estimates are statistically significant at the 5% level. Although moderate level of salinity can benefit aquaculture, salinity above certain thresholds adversely affects the production. To our knowledge, for example, shrimp farming requires tedious management of salinity level in farming ponds. Therefore, saltwater intrusion in intense years can significantly reduce farmers' chance of receiving any revenue from this production.

Estimates in columns 3 and 4, table 3, show that salinity increases farmers' probability of receiving revenue and the revenue share for industrial crops. More than 90% of the industrial crops reported by households in the sample are for coconut production, which is relatively salt-tolerant and is widely planted in MKD coastal provinces such as Ben Tre. One S.D. increase in SI is estimated to increase the probability of receiving revenue for this crop type by 2.1 percentage points and to increase its revenue share by 1.8 percentage points. Both estimates are statistically significant at the 1% level. These results imply the role of crop switching or diversifying in securing farmers' income, especially for those who rely more on rice production.



**Table 3: Estimated Impact on Agricultural Production.**

	Dependent variable:								
	Aquaculture		Industrial Crops		Fruits		Other Grains		Log Total Revenue
	Producer Y/N	Revenue Share	Producer Y/N	Revenue Share	Producer Y/N	Revenue Share	Producer Y/N	Revenue Share	
	LPM	OLS	LPM	OLS	LPM	OLS	LPM	OLS	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	
SI	-0.007*** (0.002)	-0.004** (0.002)	0.021*** (0.008)	0.018*** (0.004)	-0.006*** (0.002)	-0.004 (0.006)	0.002 (0.004)	0.001 (0.003)	-0.022 (0.019)
Obs.	2,367	2,367	2,367	2,367	2,367	2,367	2,367	2,367	2,367
R <sup>2</sup>	0.462	0.626	0.451	0.544	0.414	0.569	0.292	0.387	0.288
Ctr.	✓	✓	✓	✓	✓	✓	✓	✓	✓
TWFE	✓	✓	✓	✓	✓	✓	✓	✓	✓

NOTES—Robust standard errors are in the parentheses, adjusting for clustering at the commune level. Weather controls are temperature and precipitation measured for the commune. Household controls are household size, household head's age and years of education. All regressions control for commune- and year fixed effects. Significance level: \*  $p < 0.1$ ; \*\*  $p < 0.05$ ; \*\*\*  $p < 0.01$ .

We expected to find similar offsetting effects from fruit crops since many are also salt-resistant, yet the estimates for this crop type – reported in columns 5 and 6, table 3– are either negative or imprecise. The estimated effects of salinity on the production of crops for other short-term grains and vegetables are not statistically significant as reported in columns 7 and 8, table 3. Alternative estimations using probit or Poisson MLE show the similar result patterns for aquaculture and all crop types.

Overall, in part similar to Chen and Mueller 2018, we do not find significant effects of salinization on total farm revenue from all crops and aquaculture – results in column 9, table 3. Our results however suggest that one of the underlying production-conversion mechanisms in the case MKD is shifting to salt-resistant industrial crops rather than aquaculture like in the study for Ganges delta.

### 4.3 Agricultural Land Use

Column 1 of table 4 reports the estimated intensive-margin effect of salinization on land used for rice production. One S.D. increase in SI in the sample of rice producers is estimated to decrease cropland for rice by about 16%. The effect is statistically significant at the 1% level. In terms of magnitude, the estimated salinity-elasticity of land use is about three times larger than the estimated salinity-elasticity of yield for rice reported in column 1, table 2, implying that land used for rice production decreases at a higher rate than rice productivity in response to salinity

shocks. In column 2 of table 4, the estimated effect is on the general land used for agriculture reported by households. Although the variable is not the sum of land used for aquaculture and all crops as discussed in the variable construction part, the estimate presents evidence on the general land use pattern for agriculture. Here one S.D. increase in SI is estimated to decrease the general land used for agriculture by about 1.3% and the estimate is statistically significant at the 1% level.

Columns 3 to 7, table 4, report the estimated extensive-margin effect of salinization on land used for the production of all crop types and aquaculture. While higher salinity signals lower probability of households reporting cropland for rice production, it increases the probability of households reporting cropland for industrial crops. One S.D. increase in SI is estimated to decrease the probability of households reporting cropland for rice production by 0.8 percentage points while increase that for industrial crop production by 2.5 percentage points. Both estimates are statistically significant at the 1% level. These results agree with those reported for the revenue variables in the previous section and give further suggestive evidence for farmers' crop switching in response to salinity shock. The estimates for aquaculture, fruits and OGV are not statistically significant, which mostly repeat the patterns of the estimated effects for the revenue variables.

**Table 4: Estimated Impact on Land Used in Agriculture.**

	Dependent variable:						
	Log Rice	Log Agri.	Crop/Aquaculture Land Yes/No				
	Cropland	Land	Rice	Aquaculture	Industrial	Fruits	Other Grains
	OLS	OLS	LPM	LPM	LPM	LPM	LPM
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
SI	-0.171*** (0.051)	-0.013*** (0.005)	-0.008*** (0.003)	0.001 (0.003)	0.025*** (0.003)	-0.002 (0.007)	0.007 (0.011)
Observations	1,198	2,277	2,367	2,367	2,367	2,367	2,367
R <sup>2</sup>	0.414	0.358	0.514	0.288	0.404	0.347	0.228
Controls	✓	✓	✓	✓	✓	✓	✓
TWFE	✓	✓	✓	✓	✓	✓	✓

NOTES—Robust standard errors are in the parentheses, adjusting for clustering at the commune level. Weather controls are temperature and precipitation measured for the commune. Household controls are household size, household head's age and years of education. All regressions control for commune- and year fixed effects. Significance level: \*p<0.1; \*\*p<0.05; \*\*\*p<0.01.

## 4.4 Labor Supply

Table 5 presents results on whether salinity intrusion induces changes in labor supply in agriculture. Panel A, table 5 reports results on the probability of individuals working in agriculture as primary job. In column 1, panel A, no effect is found for the full sample. Estimation for sub-samples allows measuring the heterogeneous effects on labor supply. Column 2, table 5, reports the estimated effect on labor supply in agriculture for the sub-sample of individuals residing in households reporting land use for general agriculture or any crop. The estimate for this sub-sample is statistically insignificant, signaling that labor supply could be more inelastic with regards to salinization shocks for this group because they are tied to land.

For the sub-sample of those without agricultural land, statistically significant negative impact of salinization on labor supply in agriculture is reported in column 3, table 5. One S.D. increase in SI for this sample is estimated to reduce the probability of individuals working in agriculture as primary job by about 1 percentage point. For this group of those who are less tied to agricultural land, the probability to leave agriculture as the main occupation increases with salinization. This result may capture the effects for both those who switched jobs and those who became unemployed. In panel B of table 5, the outcome variable is whether an individual worked in agriculture at all, either as their primary or secondary occupation. The similar patterns of estimated effects are reported for the three samples.

In panel C, table 5, we test whether those who work mainly in agriculture took additional jobs in response to salinization shock. The full sample in this panel include all individuals reporting to work in agriculture as their primary job. Statistically significant positive effects are reported in columns 1 and 2 for the full sample and the sub-sample of those with agricultural land. The sample sizes suggest that most of those working primarily in agriculture also reported having land use in agriculture and the effect estimated for full sample in column 1 is thus driven by the estimate for this sub-sample in column 2.

Because most secondary jobs reported for this sample of farmers with agricultural land are low-skill occupations in agriculture, two mechanisms can be hypothesized to explain the effect. First, this group may have opted for extra jobs to offset income losses in their primary agricultural work induced by salinization in the short run. Specifically, farmer households may increase their labor in the crop and aquaculture seasons after the salinity shock (earlier in the same year) to cover losses. Second, the result may hint at the spillover labor-demand effects resulted from salinity shocks, i.e., higher demand for freshwater may induce the provision of new agricultural services such as groundwater pumping or freshwater transportation and hence increase labor supply. Column 3 of panel C, table 5, reports the probability of working a secondary job for the sub-sample of those reporting to work primarily in agriculture yet have no agricultural land. The sample size is small, which can partly explain why the estimate is imprecise.

**Table 5: Estimated Impact on Labor Supply.**

<b>Panel A</b>	Dependent variable: Working in Agriculture as Primary Job Yes/No Full sample: All Individuals		
	Full Sample	Sub-sample: Landholding	Sub-sample: Landless
	LPM (1)	LPM (2)	LPM (3)
SI	0.00004 (0.004)	-0.003 (0.006)	-0.010** (0.005)
Observations	13,593	9,836	3,757
R <sup>2</sup>	0.191	0.168	0.217
Controls	✓	✓	✓
Commune & Year FE	✓	✓	✓
<b>Panel B</b>	Dependent variable: Working in Agriculture Yes/No Full sample: All Individuals		
	Full Sample	Sub-sample: Landholding	Sub-sample: Landless
	LPM (1)	LPM (2)	LPM (3)
SI	-0.001 (0.004)	-0.003 (0.006)	-0.012** (0.006)
Observations	13,593	9,836	3,757
R <sup>2</sup>	0.220	0.184	0.252
Controls	✓	✓	✓
Commune & Year FE	✓	✓	✓
<b>Panel C</b>	Dependent variable: Working a Secondary Job Yes/No Full sample: Individuals Working In Agriculture as Primary Job		
	Full Sample	Sub-sample: Landholding	Sub-sample: Landless
	LPM (1)	LPM (2)	LPM (3)
SI	0.009*** (0.003)	0.009*** (0.003)	-0.079 (0.076)
Observations	4,257	3,904	353
R <sup>2</sup>	0.174	0.174	0.355
Controls	✓	✓	✓
Commune & Year FE	✓	✓	✓

NOTES—Robust standard errors are in the parentheses, adjusting for clustering at the commune level. Weather controls are temperature and rainfall. Individual controls are person's gender, age, education and the size of the household they resided in. All regressions control for commune and year fixed effects. Significance level: \*p<0.1; \*\*p<0.05; \*\*\*p<0.01.

## 4.5 Household Income and Expenditures

Table 6 reports the estimated impact of salinization on household income and consumption. In column 1 of the table, one S.D. increase in SI is estimated to reduce the total income of a household by about 1.8%. The effect is marginally statistically significant at the 10% level. With regards to household consumption, higher salinity intrusion is associated with lower spending on less-essential expenditure categories. In columns 2 and 3 of table 6, one S.D. increase in SI is estimated to reduce household spending on non-food goods by about 6% and to reduce spending on food for festivals by about 3.1%. Both estimates are statistically significant at the 5% level. In terms of magnitude, the estimated effect of salinization on household less-essential consumption is substantially larger than the estimated effect on income.

**Table 6: Estimated Impact on Household Income and Expenditures.**

	Dependent variable:				
	Log Total	Log Expenditures			
	Income	Non-Food Goods	Festive Food	Health	Education
	OLS (1)	OLS (2)	OLS (3)	Poisson (4)	Poisson (5)
SI	-0.018* (0.010)	-0.060*** (0.006)	-0.031*** (0.006)	0.018 (0.011)	0.249*** (0.027)
Observations	2,367	2,367	2,367	2,367	2,367
R <sup>2</sup>	0.382	0.392	0.309		
Controls	✓	✓	✓	✓	✓
Commune & Year FE	✓	✓	✓	✓	✓

NOTES—Robust standard errors are in the parentheses, adjusting for clustering at the commune level. Weather controls are temperature and precipitation measured for the commune. Household controls are household size, household head's age and years of education. All regressions control for commune- and year fixed effects. Significance level: \* p<0.1; \*\* p<0.05; \*\*\* p<0.01.

Estimated effects of salinization on household spending on health and education are reported in columns 4 and 5 of table 6. Because the expenditure data on these two categories include many zeros, estimates from Poisson MLE is reported. For these two outcome variables, OLS estimations with the outcome variables being standardized and with adding one to the outcome observations equaling zero are used as robustness test. In column 4, higher SI is estimated to increase expenditures on medical goods and services but the estimate is not precise. The result holds with alternative OLS estimations. In column 5, salinization is estimated to induce more spending on education. The estimate is statistically significant at the 1% level and

is large in magnitude with one S.D. increase in SI estimated to increase education spending by roughly 24.9%. The result holds with alternative OLS estimations with the estimate's magnitude smaller for estimation with standardized outcome variable (one S.D. increase in SI estimated to increase education spending by roughly 15.7%). Given that MKD is one of the regions in Vietnam with more modest investment and performances in standard education, this result provides an interesting aspect of the impact entailed by salinization for the region. Furthermore, because education expenses include both spending on schooling for children and spending on training activities for adults, the result could also signal increased investment of farmers on acquiring new skills to adapt to salinization. We note that further tests are required for conclusion.

## 4.6 Adaptation Smoothing Mechanisms

In response to salinity intrusion, for outside-agriculture adaptation such as taking up off-farm work and migration and within-agriculture adaptation such as crop switching or diversification, we hypothesize that distance to urban centers, the availability and development of local credit market, non-agricultural sectors and agricultural technologies provide mechanisms that help farmers smooth their adaptation process. In the following, we present the results for two mechanisms which have been tested so far.

### Distance to Urban Centers

To test whether being located near a large city further induces labor to leave agricultural sector in response to salinization, we estimate the equation below:

$$Y_{ict} = \alpha + \beta SI_{c\bar{t}} + \beta_1 SI_{c\bar{t}} \times InvDistCity_c + \delta T_{c\bar{t}} + \gamma P_{c\bar{t}} + \eta \mathbf{X}_{ict} + \lambda_c + \theta_t + \epsilon_{ict}. \quad (4)$$

$Y_{ict}$  in the estimated equation are outcomes on labor supply. The other variables are similar to those included in the main estimation equation discussed in section 3.  $InvDistCity_c$  is the inverted distance from commune  $c$  to its closest major city, which is a municipality or class 1-2 provincial city. Our estimate of interest is  $\hat{\beta}_1$ . If being closer to large cities increases the (negative) salinity-elasticity of labor supply in agriculture,  $\hat{\beta}_1$  is expected to be negative for the indicator outcome variable *Working in Agriculture as Primary Job*. If being closer to large cities increases the probability of finding additional jobs,  $\hat{\beta}_1$  is expected to be positive for the indicator outcome variable *Working a Secondary Job*.

Table 7 reports the results estimated for equation 4. For outcome variable *Working in Agriculture as Primary Job* in panel A of the table - in column 1 for individuals holding agricultural land, the estimate  $\hat{\beta}_1$  is positive and statistically significant. In contrast to the stated hypothesis, being closer to large cities in this case induces labor to stay more in agriculture. It is noted here

that communes located closer to larger cities could be those located more inland and thus are less affected by salinization. In column 2 for the sample of individuals without agricultural land, the estimate for  $\hat{\beta}_1$  is negative and statistically significant, in line with the stated hypothesis. In panel B of table 7, results for outcome variable *Working a Secondary Job* are reported. For both samples, the estimates for  $\hat{\beta}_1$  are however not statistically significant.

**Table 7: Smoothing Mechanisms - Migration.**

<b>Panel A</b>	Dependent variable: Working in Agriculture as Primary Job Yes/No Full sample: All Individuals	
	Sample: Landholding	Sample: Landless
	LPM	LPM
	(1)	(2)
SI	-0.018* (0.011)	0.0004 (0.006)
SI x InvDistCity	0.074*** (0.023)	-0.025*** (0.009)
Observations	9,836	3,757
R <sup>2</sup>	0.168	0.217
Controls	✓	✓
Commune & Year FE	✓	✓
<b>Panel B</b>	Dependent variable: Working a Secondary Job Yes/No Full sample: Individuals Working In Agriculture as Primary Job	
	Sample: Landholding	Sample: Landless
	LPM	LPM
	(1)	(2)
SI	0.013** (0.005)	-0.407 (0.925)
SI x InvDistCity	-0.019 (0.015)	0.507 (1.413)
Observations	3,904	353
R <sup>2</sup>	0.173	0.352
Controls	✓	✓
Commune & Year FE	✓	✓

NOTES—Robust standard errors are in the parentheses, adjusting for clustering at the commune level. Weather controls are temperature and rainfall. Individual controls are person's gender, age, education and the size of the household they resided in. All regressions control for commune and year fixed effects. Significance level: \*p<0.1; \*\*p<0.05; \*\*\*p<0.01.

### Local Financial Development

To test for the role of local financial market development in smoothing adaptation to salinization and reducing income losses, we estimate the following equation:

$$Y_{ict} = \alpha + \beta_1 SI_{c\bar{t}} + \beta_2 FinFirm_{d,t-2} + \beta_3 SI_{c\bar{t}} \times FinFirm_{d,t-2} + \delta T_{c\bar{t}} + \gamma P_{c\bar{t}} + \eta X_{ict} + \lambda_c + \theta_t + \epsilon_{ict}. \quad (5)$$

$Y_{ict}$  in the estimated equation are two outcomes *Total Revenue* measuring household revenue from all crops and aquaculture and *Total Income* measuring household income from production, wages and other sources. The other variables are similar to those included in the main estimation equation discussed in section 3.  $FinFirm_{d,t-2}$  characterizes the level of development of the financial market and is the number of financial-service firms per 10,000 people in district  $d$  at time  $t - 2$ .  $\hat{\beta}_3$  is the estimate of interest and is expected to be positive if financial firms increase farmers' access to credit and thus help them with the adaptation to salinity shocks and with mediating income losses.

**Table 8: Smoothing Mechanisms - Credit Access.**

	Dependent variable:	
	Log Total Agricultural Revenue	Log Total Income
	OLS (1)	OLS (2)
SI	-0.048 (0.050)	-0.049** (0.021)
FinFirm	0.112 (0.106)	0.006 (0.056)
SI x FinFirm	0.040 (0.064)	0.039** (0.019)
Observations	1,805	1,805
R <sup>2</sup>	0.303	0.389
Controls	✓	✓
Commune & Year FE	✓	✓

NOTES—Robust standard errors are in the parentheses, adjusting for clustering at the commune level. Weather controls are temperature and precipitation measured for the commune. Household controls are household size, household head's age and years of education. All regressions control for commune- and year fixed effects. Significance level: \*p<0.1; \*\*p<0.05; \*\*\*p<0.01.



Table 8 reports the results estimated for equation 5. The estimates for the interaction term coefficient  $\hat{\beta}_3$  are positive for both outcome variables. However only the estimate for household total income is statistically significant. The results provide suggestive evidence that a more developed local credit market helps ease the farmers' income losses caused by higher salinity intrusion.

## 5 Discussion

We study the socio-economic impact caused by saltwater intrusion in an agricultural coastal delta and the adjustments of farmer households in response. Our study area is the Vietnamese Mekong delta, a highly productive agricultural region, especially for rice – which is however a salt-sensitive crop. Our goals are to delineate and understand how the shock affects the agricultural economy of MKD and, furthermore, transforms it through different adjusting and adapting channels. While migration is mentioned in the literature, we also look for other adjustments within agricultural sector and outside agricultural sector. Adverse impacts of salinity shocks are verified in our results for the production of rice in MKD. We also find evidence of salinization reducing agricultural land, labor supply in agriculture and farmer households' income and consumption. Furthermore, our results point to the within-agricultural adjustment of salt-resistant crop production and the role of diversification or crop switch in sustaining farmers' income and food security against salinization shocks. We also test for different mechanisms for smoothing adaptation, for which we find mixed evidence on labor migration for off-farm work in urban centers and suggestive evidence on the role of credit market development in easing farmers' income losses. We further hypothesize that technological progress and human development play the crucial roles in enabling adaptation to salinization and will continue our research in this direction.

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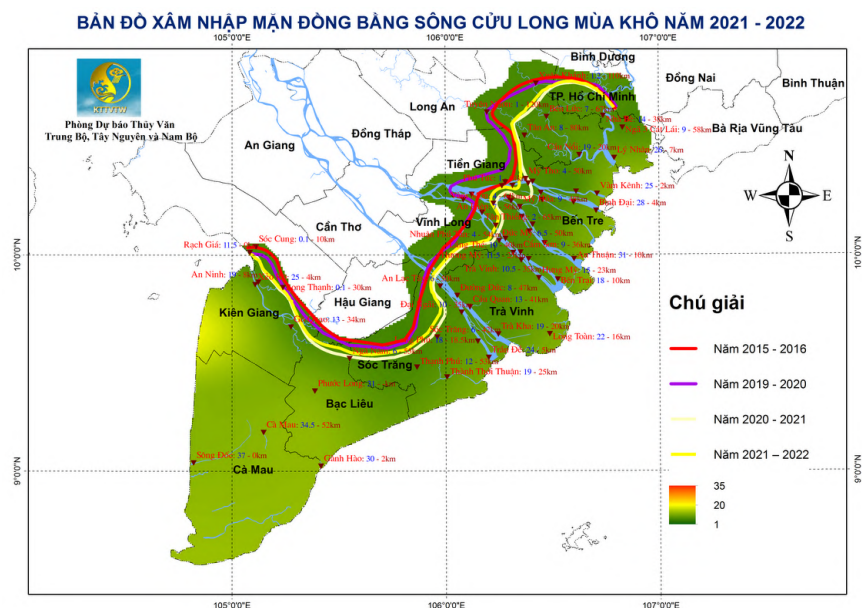
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## Appendix A. Validity of the Constructed Salinity Index

### Reported Salinity Border



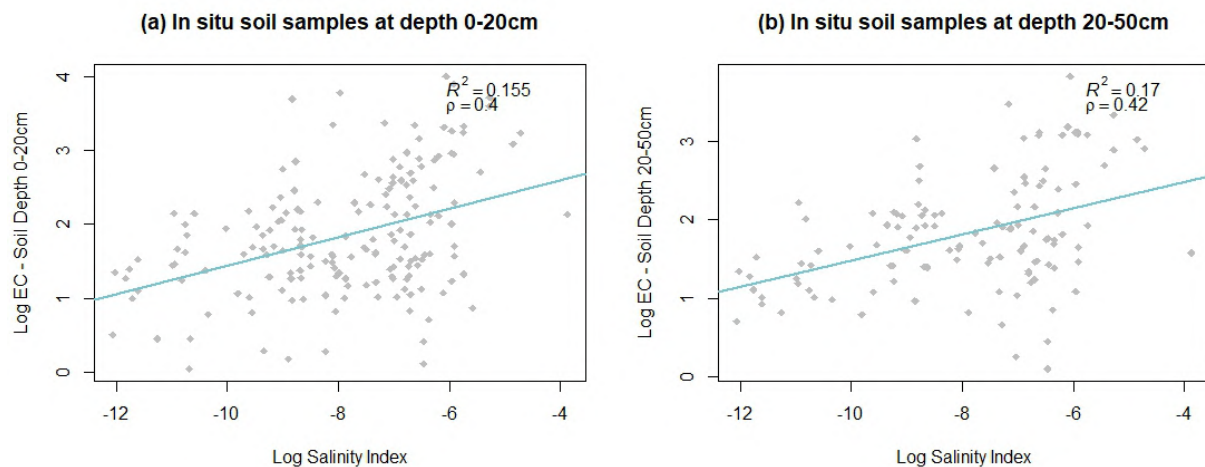
**Figure 7:** Salinity border reported by Vietnam Meteorological and Hydrological Department. Colored lines are mapped extents of saltwater intrusion in years 2015-2016 (red), 2019-2020 (purple). Retrieved from source.

### Correlation between SI and In Situ Salinity

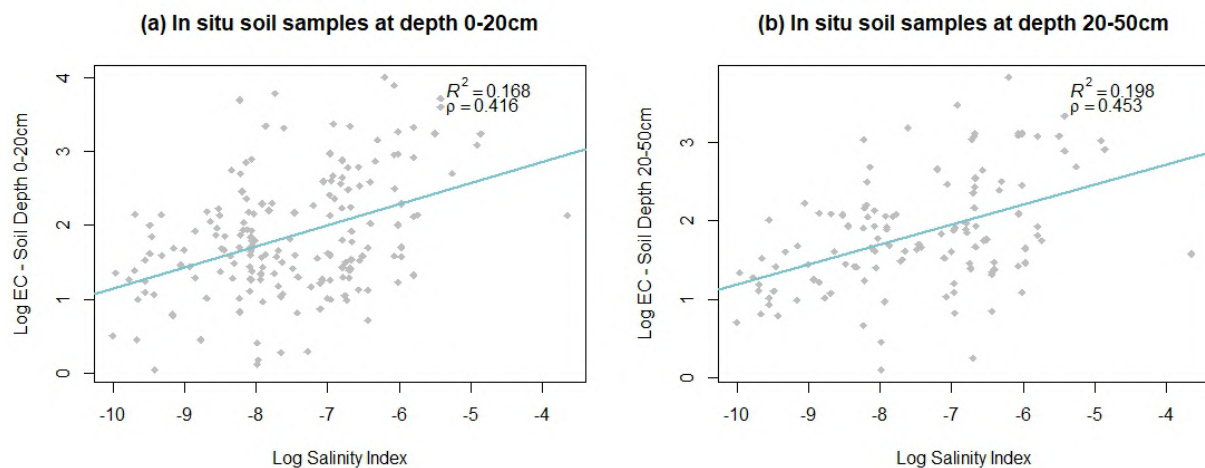
In situ data of soil samples were collected in different locations in Ben Tre, Tra Vinh, Soc Trang, Bac Lieu in April 2016. The data is provided by Soil Sciences Department - Can Tho University. Saturated electrical conductivity (EC) is the chosen measure of soil salinity. SI is the constructed salinity index for the commune where the sample is located and is measured for April 2016, March 2016 and average for November 2015 - April 2016. Table 9 reports the Pearson correlation coefficients between EC measure of in situ data and constructed SI. Figures 8, 9 and 10 plot in situ data against SI and their fitted regression lines.

**Table 9:** Pearson correlation coefficients between SI and in situ data.

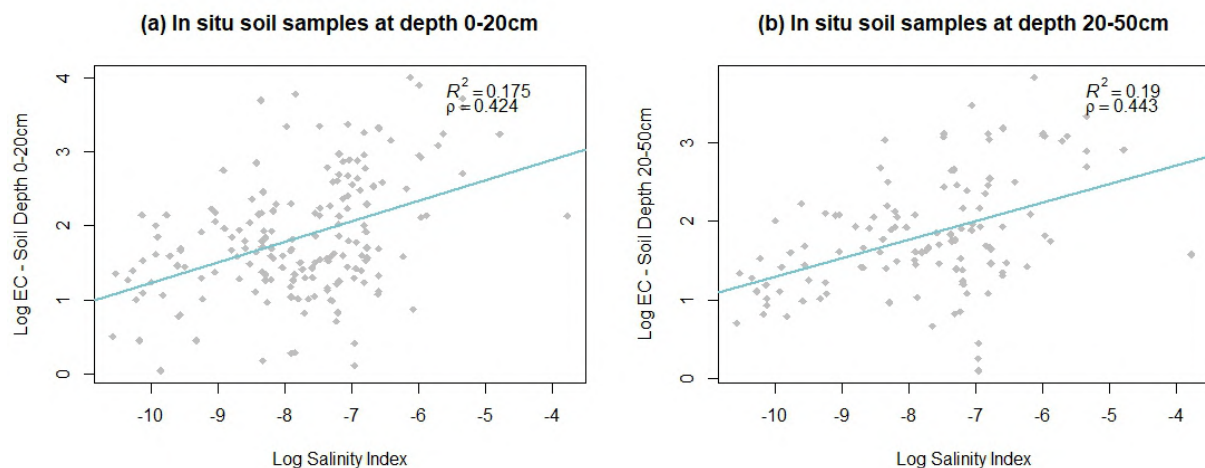
Correlation N = 184	Soil: depth 0-20cm, Log EC	Soil: depth 20-50cm, Log EC
Log SI: April 16	0.400	0.420
Log SI: March 16	0.416	0.453
Log SI: November 15-April 16	0.424	0.443



**Figure 8:** Soil Samples Collected in April 2016 and SI Measured for April 2016.



**Figure 9:** Soil Samples Collected in April 2016 and SI Measured for March 2016.



**Figure 10:** Soil Samples Collected in April 2016 and Averaged SI from November 2015 to April 2016.

## Appendix B. Results of Alternative Estimations

**Table 10: Alternative Estimations for Revenue Share Variables.**

<b>Panel A</b>	Sample: All Agricultural Producers				
	Dependent variable: Revenue Share				
	Rice	Aquaculture	Industrial	Fruits	Other Grains
	Poisson	Poisson	Poisson	Poisson	Poisson
	(1)	(2)	(3)	(4)	(5)
SI	-0.098*** (0.023)	-0.142** (0.067)	0.137*** (0.022)	-0.002 (0.009)	0.034 (0.047)
Observations	2,367	2,367	2,367	2,367	2,367
<b>Panel B</b>	Samples: Producers for Individual Crop or Aquaculture				
	Dependent variable: Revenue Share				
	Rice	Aquaculture	Industrial	Fruits	Other Grains
	OLS	OLS	OLS	OLS	OLS
	(1)	(2)	(3)	(4)	(5)
SI	-0.058*** (0.010)	-0.342* (0.180)	0.022** (0.009)	0.005 (0.005)	-0.015 (0.023)
Observations	1,175	726	1,163	1,237	602

NOTES—Robust standard errors are in the parentheses, adjusting for clustering at the commune level. Weather controls are temperature and precipitation measured for the commune. Household controls are household size, household head's age and years of education. All regressions control for commune- and year fixed effects. Significance level: \*  $p < 0.1$ ; \*\*  $p < 0.05$ ; \*\*\*  $p < 0.01$ .



**Table 11: Alternative Estimations for Revenue and Land Binary Variables.**

<b>Panel A</b>	Dependent variable: Producer Yes/No				
	Rice	Aquaculture	Industrial	Fruits	Other Grains
	Probit	Probit	Probit	Probit	Probit
	(1)	(2)	(3)	(4)	(5)
SI	-0.012** (0.005)	-0.019** (0.009)	0.015** (0.007)	-0.007*** (0.003)	0.060*** (0.023)
Observations	2,367	2,367	2,367	2,367	2,367
<b>Panel B</b>	Dependent variable: Agricultural Land Use Yes/No				
	Rice	Aquaculture	Industrial	Fruits	Other Grains
	Probit	Probit	Probit	Probit	Probit
	(1)	(2)	(3)	(4)	(5)
SI	-0.014*** (0.005)	-0.018 (0.020)	0.019*** (0.003)	-0.004 (0.005)	0.170*** (0.038)
Observations	2,367	2,367	2,367	2,367	2,367

NOTES—Robust standard errors are in the parentheses, adjusting for clustering at the commune level. Weather controls are temperature and precipitation measured for the commune. Individual controls are gender, age, years of education and household size. All regressions control for commune- and year fixed effects. Significance level: \*p<0.1; \*\*p<0.05; \*\*\*p<0.01.