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ARTICLE

Does Adaptation to Saltwater Intrusion Improve Household Income in the Mekong Delta, Vietnam?

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ABSTRACT

Saltwater intrusion poses a substantial threat to agricultural industry. Employing an instrument variable approach, this study used a survey of 469 households affected by saltwater intrusion in the selected provinces in Mekong Delta, Vietnam to investigate the impact of adaptation methods to saltwater intrusion on household income. The findings reveal that adopting agricultural transformation, applying technology in crop cultivation and aquaculture, and implementing multiple adaptation methods can improve household income. Meanwhile, no significant effect is observed from job change. The results are robust when incorporating the alternative measurement of household income, say net income. The study also shows that heterogeneous effects exist when considering different sectors of agricultural industry, say crop cultivation and aquaculture. Given that, the study provides some policy implications for the local government and farmers to alleviate the adverse impacts of saltwater intrusion and improve their livelihoods, contributing to the sustainable development of Vietnam's agricultural industry.

Keywords: Adaptation Methods; Household Income; Mekong Delta; Saltwater Intrusion; Vietnam

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1. Introduction

Climate change has significant adverse effects on agriculture and food security in many countries worldwide, regardless of their level of development[1]. Unlike other industries, the agricultural sector is more likely fragile as its productivity is heavily reliant on climatic conditions. Changes in temperature, rainfall patterns, rising sea levels, increased flooding, or prolonged droughts and other extreme weather events could cause various problems such as soil degradation, water scarcity, saltwater intrusion, biodiversity loss, ultimately reducing agricultural production and threatening the sustainability of national food systems[2–4].

No exception, Vietnam's agriculture industry is facing numerous challenges posed by climate change, with saltwater intrusion emerging as the most critical issue, particularly in the coastal areas of the Mekong River Delta. Recognized as an agriculture hotspot in Vietnam, the Mekong River Delta accounts for approximately 55% of the nation's rice production and more than 90% of its rice exports, strengthening Vietnam's position as one of the world's leading rice exporters[5, 6]. Apart from rice, this fertile area is the ideal place for fruits cultivation and aquaculture. According to[7], the Mekong River Delta produces nearly 671.7 thousand tons of shrimp, 1.41 million tons of pangasius fish, and 4.3 million tons of fruit, making up 83.51%, 98%, and 60% of the national output, respectively. Therefore, this region plays an important role in ensuring national food security while contributing significantly to Vietnam's GDP growth. However, the saltwater intrusion in the Mekong River Delta has become increasingly severe over the last decade. Notably, in 2016, saltwater intrusion extended more than 90 kilometers inland from the coast, marking the highest recorded level of saltwater intrusion[8]. This extreme event devastated eleven out of thirteen provinces in the region, destroying around 210,000 hectares of agricultural land, whereas 250,000 households, along with schools, clinics, hotels, and production facilities suffered from freshwater shortages[9]. The Center of Environment Engineering anticipated that by 2030, 45% of the agricultural land in the Mekong River Delta would be damaged, with coastal provinces such as Tien Giang, Tra Vinh, Soc Trang, Bac Lieu, Ca Mau, and Ben Tre bearing the brunt of the impact[10]. Moreover, by 2025, climate change is projected to diminish agriculture productivity by 3.4% to 6.7% compared to the severe saltwater intrusion event in 1998[11].

According to[12], 80% of the population of the Mekong Delta is in some way involved in rice production. In other words, the livelihoods of millions of people in the region are closely tied to agricultural activities. As the adverse effects of saltwater intrusion continue to intensify, it has become increasingly urgent to explore whether different adaptation strategies could mitigate this challenge and improve the livelihoods of farmers. While a large body part of existing literature has explored various aspects of saltwater intrusion in the Vietnamese Mekong Delta such as its causes[13–19], its effects on agricultural production and farmers' adaptive responses[6, 20–24], no research has comprehensively examined the relationship between different adaptation strategies and their impact on household income. Filling this gap, our research analyzes how three adaptation methods including job change, agricultural transformation and technology application affect household incomes, thereby providing policy recommendations to assist farmers in applying effective adaptation methods that not only help mitigate the detrimental influences of saltwater intrusion but also boost their income, ultimately fostering long-term sustainability in the Mekong Delta.

The remaining parts of this paper are structured as follows. Section 2 presents literature review. Section 3 describes methodology and data. Section 4 discusses empirical results. And section 5 concludes the paper.

2. Literature Review

In recent years, the number of works on saltwater intrusion in the Vietnamese Mekong Delta has gradually increased, mainly focusing on social-economic aspects such as its impact on agriculture production or farmers' adaptation to saltwater intrusion. For example, ref.[21] utilized a database collected from 214 farmers in three villages in Soc Trang province to examine how saltwater intrusion affects rice production. The empirical findings revealed significant reductions in rice yields, with

annual productivity losses ranging from 2.5 to 4.05 tons per hectare. Expanding the scope of research, ref.[24] investigated 390 rice and fish farming households in An Giang, Can Tho and Soc Trang provinces and found that saltwater intrusion not only reduces agricultural productivity but also has a negative impact on household income, degrades natural resources and exacerbates environmental degradation. Notably, among agriculture activities, fish farming was found to be the most vulnerable to saltwater intrusion, resulting in greater losses in household income and production capacity than rice farming or integrated rice-and-fish farming households. Meanwhile, ref.[25] provided strong evidence that rice yields during the winter-spring season are at a larger risk of decline than during the summer-autumn cropping season while analyzing the Standardized Precipitation Index (SPI) and the maximum and minimum values of annual average salinity from 1980 to 2019. More recently, ref.[23] explored the effects of saltwater intrusion on rice production in Mekong Delta employing farm level panel data in 2014 and 2016. They stated that the damage magnitude of households in severely affected regions is higher compared to those in less affected areas, with total revenue and net revenue declining by approximately 4969.8 thousand VND per ha and 4679.3 thousand VND per ha, respectively. Research by[26] strengthened this outcome, highlighting the adverse influences of saltwater intrusion on paddy yields in salinity-prone and coastal districts. Drawing on a dataset of 344 rural households, ref.[27] explored the causal relationship between saline intrusion and poverty in the Mekong Delta. Their findings showed that saltwater intrusion significantly reduces rural household income, increasing the likelihood of households falling into lower-income brackets. Notably, the impact is more severe for poorer households than for non-poor households. Moreover, the authors also highlighted that saltwater intrusion also has a negative impact on households with low education and farming.

Considering the second stream of research, ref.[22] emphasized that cultivating salt-tolerant rice varieties and employing suitable agro-chemical practices could enable farmers in regions experiencing salinity levels of up to 4% to sustain rice production while maintaining their income. However, when salinity levels exceed 4%, transitioning from traditional rice farming to a rice-shrimp rotational system becomes a viable adaptation strategy to enhance farmers' livelihoods. Applying binary logit model to determine factors affecting changes in farming systems in Kien Giang and Soc Trang provinces, ref.[28] stated that the educational level of household heads is the key driver in adopting new farming systems in these areas. In contrast, the distance from fields to rivers and the salinity level negatively influenced changes in farming practices. Moreover, factors such as labor shortages, poor water quality, topography, limited access to combine harvesters, inadequate transportation infrastructure, dryers, and household savings were identified as significant obstacles to adaptation in the Vietnamese Mekong Delta[29]. Ref.[20] employed MOTA (Motivation-Ability) technique to examine farmers' adaptive capacities in the Tra Vinh province across three distinct saline environments, namely seawater areas, brackish water areas, and freshwater areas. The authors discovered that while farmers in these regions possess a high awareness of saltwater intrusion, their motivation for adapting to saltwater intrusion remains relatively low. In addition, the adaptive capacities of these farmers are moderate, with the lowest capacities identified as their educational level and engagement in non-agricultural organizations. Ref.[6] found similar outcomes while highlighting that rice farming households' preference for constructing dykes as an effective strategy to mitigate the impact of saltwater intrusion.

In summary, while the volume of studies on saltwater intrusion in the Vietnamese Mekong Delta continues to grow, no research has investigated the impact of various adaptation strategies on household income. This study aims to address this gap by exploring the relationship between different adaptive strategies and household income in this fertile region, in turn, providing policy recommendations to assist farmers in adopting effective adaptation measures that not only mitigate the effects of saltwater intrusion but also boost their income, contributing to the sustainable development of the Mekong Delta.

3. Methodology and Data

3.1. Data

Data collection

The data used in this study were collected from a household-level survey conducted in the Mekong Delta region during 2023 and 2024. The survey was based on three sources: (1) a literature review, (2) expert consultancy, and (3) the actual situation of saltwater intrusion and adaptive measures in the region. The literature review helped classify household income measurements, adaptation methods to saltwater intrusion, and other factors affecting both household income and adaptation to saltwater intrusion. Expert consultancy provided suggestions and criteria for designing the survey, including the questionnaire, which was administered to provincial locations in the Mekong Delta region and to households affected by saltwater intrusion. The actual situation provided the basis for narrowing the study's aim and scope. Based on these sources, we selected three provinces for the survey: Ca Mau, Kien Giang, and Ben Tre. These provinces have been heavily affected by saltwater intrusion, particularly in 2016, 2018, and 2022 [30, 31]. While saltwater intrusion affects all sectors of the community, we focused on households involved in crop cultivation and aquaculture, as they are the most vulnerable to the impacts of climate change and saltwater intrusion [23, 32, 33].

Based on the severity of saltwater intrusion and the economic and social characteristics of each province, 75 households in Kien Giang, 249 households in Ben Tre, and 145 households in Ca Mau were selected to participate in the survey, totaling 469 households. Of these, 247 households were engaged in crop cultivation, while 222 households were involved in aquaculture.

Adaptation methods

The issue of saltwater intrusion has persisted for many years, and households have been using various adaptation methods over time. In this study, we focus on the adaptation methods used since 2016. This is because since then saltwater intrusion has become a major challenge among the impacts of climate change on households in the region. Two criteria were applied to select adaptation methods for study: (1) the methods must be in use at the time of the survey, and (2) they must have been implemented for at least two years. These conditions ensure that the adaptation methods are specifically in response to saltwater intrusion and have a measurable impact on household income. Given that three original adaptation methods were identified for further analysis, including job change (*jobchange*), agricultural transformation (*transformation*) and technology application (*technology*). The adaptation method of job change refers to households switching from farming jobs in crop cultivation and aquaculture to other types of employment. This is considered the most extreme response caused by saltwater intrusion. Households are categorized under agricultural transformation if they adopt new farming models for crop cultivation and aquaculture. Households applying any type of technology to farming practices are classified under technology adaptation. All three indicators of adaptation methods are binary variables, in which they take a value of one if households apply the respective adaptation method, otherwise they take a value of zero. Finally, we created a fractional probability indicator of adaptation methods, say *multi*. This variable takes a value of one, two, or three if households apply one, two, or three of the adaptation methods, respectively; if no adaptation methods are applied, the value is zero. Households applying more adaptation methods are considered to have greater resilience to saltwater intrusion, which is associated with relatively higher income.

Given that a summary of descriptive statistics of the data used for analysis in this paper are depicted in **Table 1**.

The figures in **Table 1** show that the average monthly income of households affected by saltwater intrusion is around 14.442 million Vietnam Dong (VND), with the highest income at 265 million VND and the lowest at 0.1 million VND. This suggests a significant income gap among households in the region. A similar pattern is observed when considering households' net income, where the average is 5.038 million VND, and the highest and lowest values are 135 million VND and -77 million VND, respectively.

For adaptation methods, an average of 5.8% of households affected by saltwater intrusion changed

Table 1. Summary of descriptive statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
income	469	14.442	20.362	0.1	265
netincome	469	5.038	12.258	−77	135
training	469	0.343	0.475	0	1
jobchange	469	0.058	0.233	0	1
transformation	469	0.130	0.337	0	1
technology	469	0.446	0.498	0	1
multi	469	0.023	0.091	0	3
edu	469	1.915	1.396	1	5
gender	469	0.744	0.437	0	1
poverty	469	0.072	0.260	0	1
members	469	3.917	1.413	1	12

Source: Authors' calculation from the survey.

their occupation, 13% modified their farming model, and 44.6% applied technical assistance for crop cultivation and aquaculture. Only 2.3% of households used more than one method. These figures suggest that a large number of farmers are relying on traditional (non-adaptative) methods to cope with saltwater intrusion, and more comprehensive adaptation strategies are not yet widely adopted.

With respect to household characteristics, the average household size is four members, and more than 74.4% of households are headed by females, while only 25.6% are headed by males. In terms of education, the data indicates that the average education level of household heads is relatively low, with more than 52.87% of households having only a certificate of secondary education. This could be a barrier for farmers in adopting and implementing new technologies and techniques in crop cultivation and aquaculture. Regarding poverty rate, the average poverty rate of the surveyed households is approximately 7.2%, which is significantly higher than the rates of 1.52% for the Mekong Delta region and 2.93% for Vietnam in 2024. This suggests that households affected by saltwater intrusion in the region are more vulnerable compared to other households in both the region and the country as a whole.

3.2. Empirical Strategy

It is important to note that the magnitude of saltwater intrusion may affect both income level and the likelihood of using adaptation methods, but it is not included in the model. In addition, data used in this paper were collected from households affected by saltwater intrusion and surveyed in the selected provinces rather than the whole Mekong Delta region, the individual characteristics of the provinces and households may not be fully captured in the model. As a result, the issues of endogeneity may arise in various forms. The ordinary least squares (OLS) estimates are biased and inconsistent. Therefore, in the study, we employ instrument variable method to quantify whether adaptation methods to saltwater intrusion improve household income. We note that F-test, Durbin-Wu-Hausman test, and Sargan-Hansen test are performed to check for endogeneity and evaluate the appropriateness of IV estimation.

The empirical specification is expressed as follows:

$$income_{ij} = \alpha_0 + \alpha_1 Z_{ij} + \alpha_2 X_{ij} + \theta_{i,j} + \epsilon_{i,j}, \qquad (1)$$

where, *i* and *j* denote household *i* and province *j* in the Mekong delta region in Vietnam. Variable *income*, expressed in Vietnam Dong (VND), represents the income of households affected by saltwater intrusion in the provinces of the Mekong delta region in Vietnam. Z is vector of adaptation methods, including job change (*jobchange*), agricultural transformation (*transformation*), technology adaptation (*technology*), and multiple adaptation method (*multi*). X is vector of households' characteristics, including the education level of household heads (*edu*), the gender of household heads (*gender*), the poverty status (*poverty*), and the total members of households (*members*). θ represents individual fixed effects. And ϵ is error terms.

As mentioned in the previous section, the majority of household heads have received a relatively low level of education. It is believed that training plays a crucial role in enhancing their ability to implement adaptation methods for saltwater intrusion. Training not only provides farmers with knowledge of these adaptation techniques but also increases their likelihood of applying them effectively. It enhances understanding, strengthens technical and decision-making skills, and encourages collaborative approaches to adaptation. Together, these elements contribute to more effective responses to saltwater intrusion and enhance the resilience of households facing the impacts of saltwater intrusion [34–36]. Therefore, participating in training programs associated with saltwater intrusion (*training*) is used as an instrument variable in the first stage regression. Variable *training* takes a value of one if households have participated in training programs organized by either local or national authorities, or both agencies. The second instrumental variable is the local people's evaluation of the effectiveness of the irrigation infrastructure system (*infrastructure*). A well-functioning irrigation infrastructure system could reduce the negative consequences of saltwater intrusion, resulting in a lower probability of applying adaptation methods [16, 36–38]. We use a five-point scale method to measure the local people's evaluation of the effectiveness of the irrigation infrastructure system, where *infrastructure* is evaluated as very effective - 5, effective - 4, moderate - 3, ineffective - 2 and very ineffective - 1. Given that the first-stage regression takes a form as follows:

$$Z_{ij} = \alpha_0 + \alpha_2 training_{ij} + \alpha_2 infrastructure_{ij} + \alpha_2 X_{ij} + \theta_{i,j} + _{i,j}, \quad (2)$$

where *training* and *infrastructure* are the two instrumental variables, and other notations remain as indicated in Equation (1).

4. Empirical Results

Using IV estimation, we first estimate the impact of adaptation methods to saltwater intrusion on household income in the Mekong delta region. The baseline results are reported in **Table 2**.

To check the goodness of fit of the IV approach, we first employ the Durbin-Wu-Hausman test to determine whether endogeneity is potentially present in the model, where the null hypothesis is that the regressor is exogenous, and the alternative hypothesis is that the regressor is endogenous [39]. Given the estimated results for the Durbin-Wu-Hausman test in **Table 2**, we reject the null hypothesis and accept the alternative hypothesis, indicating that the IV estimation should be used instead of OLS estimation. Next, we perform an F-statistic test to check for weak instruments. As suggested by [40], if the F-statistic value is lower than the critical threshold of 10, the instruments are considered weak. As reported in **Table 2**, all F-statistic values for models 1, 2, 3, and 4 are greater than 10. Thus, the instruments used in the paper, say *training* and *infrastructure* are strong predictors of the endogenous variable, confirming the appropriateness of the IV estimation. Finally, the Sargan-Hansen test is used to identify the validity of the instruments, checking whether the instruments are uncorrelated with the error terms [32]. The null hypothesis of the Sargan-Hansen test is that the instruments are uncorrelated with the error terms, while the alternative hypothesis is that they are correlated with the error terms. The results in **Table 2** show that we cannot reject the null hypothesis. As a result, the instruments used in this paper are valid.

The results from **Table 2** show that the estimated coefficients for *transformation*, *technology* and *multi* are positive and statistically significant, suggesting that agricultural transformation, applying technology in crop cultivation and aquaculture and applying multiple adaptation methods contribute to the income of households affected by saltwater intrusion. These methods enable farmers to partially mitigate the negative effects of saltwater intrusion on crop cultivation and aquaculture, diversify their income sources, and create new opportunities, all of which can lead to an increase in household income. The findings are in line with those of [24, 30, 41, 42]. Using data from 300 rice-producing households in An Giang and Tra Vinh in 2016 and employing endogenous switching regression, ref. [41] shows that the rice productivity of farmers adopting adaptation measures is higher than that of those not adopting adaptation measures. Considering the Mekong Delta region and using fixed-effect regressions, ref. [42] indicates that households able

Table 2. Baseline results: Income.

Variables	(1)	(2)	(3)	(4)
jobchange	122.826			
	(105.743)			
transformation		47.613***		
		(16.204)		
technology			10.917***	
			(3.063)	
multi				2.414**
				(1.127)
edu	1.919	0.707	1.520	1.343
	(1.474)	(1.097)	(0.936)	(0.899)
gender	−3.965	−8.009***	−3.349*	−4.421**
	(3.230)	(2.759)	(2.004)	(2.009)
poverty	−6.133	−5.317*	−7.504***	−7.250***
	(4.611)	(2.741)	(2.147)	(1.971)
members	−0.467	1.205*	−0.063	0.289
	(1.349)	(0.678)	(0.577)	(0.510)
Constant	8.560	8.479**	11.337***	8.671**
	(6.807)	(4.212)	(3.773)	(3.816)
First stage regression	jobchange	transformation	technology	multi
training	Yes	Yes	Yes	Yes
infrastructure	Yes	Yes	Yes	Yes
F-statistic	10.673	10.477	130.901	289.765
Sargan-Hansen test	2.901	2.079	3.926	6.306
Durbin-Wu-Hausman test	8.105***	13.605***	13.528***	6.232***
Individual fixed effect	Yes	Yes	Yes	Yes
Observations	469	469	469	469
R-squared	0.012	0.011	0.020	0.033

Robust standard errors in parentheses; *** p < 0.01, ** p < 0.05, * p < 0.1.
Source: Authors' estimation.

to diversify their crop cultivation can reduce the vulnerability of rice farming households to drought and saltwater intrusion. Similarly, ref.[30] finds that all adaptations to saltwater intrusion significantly contribute to farmers' livelihoods and improve the revenues of rice farming households in the central coastal region of Vietnam. Considering adaptation pathways of agricultural systems in the Mekong and Red River deltas in Vietnam, ref.[43] show that adaptation methods should continue to change to resist the challenges of saltwater intrusion, suggesting that applying multiple adaptation methods should reduce the negative effects of saltwater intrusion. The findings of[43] are in line with a conclusion of[24] when analyzing impact of adoption options on the 390 rice- and fish-farming households in selected provinces in Mekong Delta region.

It is worth noting that the estimated coefficient for the *jobchange* variable is positive but statistically insignificant. This suggests that there is no empirical evidence to conclude that changing to a new job contributes to the income of households affected by saltwater intrusion in the Mekong Delta region. This finding is interesting but not entirely surprising. Most households in the region heavily rely on crop cultivation and aquaculture, so switching to a new job is likely to have a significant impact on their livelihood. However, this transition would require more time to assess its effects on income since a new job may require additional training, experience, adjustment to a new environment, responsibilities, and skill requirements[44, 45]. Empirically, ref.[46] stated that the income of migrants caused by the impacts of the intensifying drought and saltwater intrusion in the

Mekong Delta region is relatively low. Our findings suggest the need for targeted policies focused on the development of sustainable agriculture and comprehensive adaptation methods to mitigate rural out-migration in response to the impacts of saltwater intrusion.

For household characteristics, the estimated coefficients for the education level are positive but statistically insignificant, indicating that there is no evidence to conclude that education impacts household income. This could be because most household heads have relatively low levels of education, which may not be sufficient to improve the productivity of their farming productivity. Except for the *jobchange* variable, the coefficients for the *gender* and *poverty* variables are negative and statistically significant, indicating that the income of female-headed households and households in poverty are lower compared to that of male-headed households and non-poor households, respectively. These findings are quite common in literature on agricultural sectors [24].

Alternative household income: Net income

It is straightforward to show that the absolute values of household income may not fully reflect the real household income affected by saltwater intrusion, especially when households have applied different adaptation methods to saltwater intrusion. This is because households may face a significant financial burden to combat saltwater intrusion. To better capture the meaningful impacts of adaptation methods on household income, we create a new income indicator, called *net-income*. The *netincome* indicator is calculated by subtracting all expenses incurred to combat saltwater intrusion from the household income. To reduce variations among the incomes and expenses of households, the income and expense of households are weighed by the differences between the largest income and expense and the smallest income and expense, respectively. Then, the net income indicator is calculated as follows:

$$netincome_{i,j} = \frac{income_{i,j}}{\text{Max}(income_j) - \text{Min}(income_j)} - \frac{expense_{i,j}}{\text{Max}(expense_j) - \text{Min}(expense_j)} \quad (3)$$

where *netincome* is the average monthly net income of households, *income* and *expense* are in turn the average monthly income and monthly expenses of households. *Max* and *Min* denote the maximum and minimum values of the average monthly income and expense, respectively. The estimated results using IV estimation with the net income indicator are presented in **Table 3**. It is important to note that all tests to assess the appropriateness of IV estimation, including the F-statistic, Sargan-Hansen test, and Durbin-Wu-Hausman test, have been performed and are reported in **Table 3**. The results from these tests confirm that the IV estimation is appropriate.

The estimated results in **Table 3** show that the estimated coefficients for *transformation*, *technology*, and *multi* variables using the net income indicator are positive and statistically significant, but the magnitudes of those coefficients are relatively lower compared to those when using the absolute household income level. These findings indicate that an effective irrigation infrastructure and participation in training programs on saltwater intrusion can reduce the negative effects of saltwater intrusion, thereby lowering the probability of applying adaptation methods. As a result, the income effects of adaptation methods are smaller when using the income indicator [16, 26, 47]. Similarly, there is no empirical evidence to conclude whether changing to a new job affects the net income of households in the Mekong Delta region. The results with the net income indicator not only confirm the robustness of our baseline findings but also indicate that the households' vulnerability to saltwater intrusion is generally mitigated when adaptation methods are implemented.

Crop Cultivation vs. aquaculture

Traditional crops such as rice and vegetables are highly sensitive to saltwater intrusion. As the level of saltwater intrusion increases, it impairs plants' ability to absorb water and nutrients, leading to significant reduction in crop yields [48, 49]. In contrast, aquaculture systems are directly influenced by the salinity of water, and the impact of saltwater intrusion on aquaculture largely depends on the species being farmed and their tolerance to saline conditions. The income of households engaged in crop cultivation and aquaculture can differ due to several factors. These include the biological responses of crops and aquaculture species to environmental conditions, investment requirements, market dynamics, risks, and adaptive capacities. Aquaculture often provides more frequent, higher-value, and potentially more resilient income opportunities, especially

Table 3. Estimated results: Net income.

Variables	(1)	(2)	(3)	(4)
jobchange	65.916			
	(60.229)			
transformation		20.187**		
		(9.376)		
technology			5.048**	
			(2.318)	
multi				1.444*
				(0.820)
edu	1.426	0.873	1.216**	1.102**
	(0.874)	(0.574)	(0.598)	(0.562)
gender	−3.677**	−5.461***	−3.438***	−3.912***
	(1.811)	(1.594)	(1.181)	(1.204)
poverty	−4.322	−4.148	−5.069**	−4.896**
	(3.296)	(2.523)	(2.467)	(2.450)
members	−0.233	0.572	0.017	0.167
	(0.730)	(0.396)	(0.341)	(0.315)
	(5.231)	(2.387)	(2.017)	(1.608)
Constant	−1.263	−1.045	0.188	−1.335
	(3.843)	(2.474)	(2.131)	(2.287)
First stage regression	jobchange	transformation	technology	multi
training	Yes	Yes	Yes	Yes
infrastructure	Yes	Yes	Yes	Yes
F-statistic	10.673	10.477	130.901	289.765
Sargan-Hansen test	0.735	0.613	0.809	2.169
Durbin-Wu-Hausman test	3.741***	7.818***	3.633***	3.954***
Individual fixed effect	Yes	Yes	Yes	Yes
Observations	469	469	469	469
R-squared	0.011	0.019	0.086	0.099

Robust standard errors in parentheses; *** p < 0.01, ** p < 0.05, * p < 0.1.
Source: Authors' estimation.

for those able to adapt to the challenges posed by saltwater intrusion. On the other hand, crop cultivation is more vulnerable to environmental changes like saltwater intrusion, leading to more variable income due to seasonal fluctuations, market prices, and crop yields [47, 48]. Given these differences, it is reasonable to believe that the effects of adaptation methods to saltwater intrusion may vary between households engaged in crop cultivation and those in aquaculture. Therefore, we divided total sample into two groups of crop cultivation and aquaculture to figure out whether the heterogeneous effects are raised among different groups of households. The estimated results for the two subgroups, crop cultivation and aquaculture, based on IV regression are reported in **Table 4**.

Similarly, we replace the absolute household income (*income*) with the household net income (*net-income*) to examine the heterogeneous effects on the two groups of households, crop cultivation and aquaculture. The estimated results with the IV regression are depicted in **Table 5**. It is important to note that the F-statistic, Sargan-Hansen test, and Durbin-Wu-Hausman test are performed to check the appropriateness of the IV estimation under the two subgroups of sample with both income and net income indicators.

The estimated results in **Tables 4** and **5** reveal some interesting outcomes. First, there is no evidence to conclude that changing to a new job has an income effect, even when estimating for the two sub-groups of farmers affected by saltwater intrusion. Second, with respect to *transformation*, *technology* and *multi*, the findings for crop cultivation, using both income and net in-

Table 4. Crop Cultivation vs. Aquaculture: Income.

	Crop Cultivation				Aquaculture			
VARIABLES	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
jobchange	397.860				−53.340			
	(981.498)				(35.503)			
transformation		30.135*				−47.657**		
		(16.240)				(22.603)		
technology			7.761***				−11.704	
			(2.682)				(10.328)	
multi				2.917**				−2.541
				(1.220)				(2.049)
edu	7.983	1.955***	1.976***	1.843***	0.318	−0.319	2.446	1.798
	(14.089)	(0.676)	(0.636)	(0.608)	(3.492)	(2.941)	(2.527)	(2.385)
gender	9.358	−4.098*	−1.498	−1.909	−8.533	−10.241**	−5.399	−7.092*
	(32.897)	(2.127)	(1.324)	(1.353)	(5.351)	(5.018)	(4.929)	(4.256)
poverty	−10.319	−4.865**	−5.544***	−5.368***	−5.495	−7.440	−10.749**	−9.624**
	(20.909)	(2.323)	(1.855)	(1.668)	(4.738)	(5.397)	(4.752)	(4.395)
members	1.212	1.069*	0.912*	0.949**	−1.132	1.074	−0.962	−0.425
	(2.588)	(0.559)	(0.473)	(0.471)	(1.276)	(1.157)	(0.977)	(0.845)
Constant	−13.259	4.208	3.379	1.125	20.063**	12.933*	17.736**	14.861*
	(45.977)	(2.817)	(2.334)	(2.608)	(9.107)	(7.471)	(7.435)	(7.653)
First stage regression	jobchange	transformation	technology	multi	jobchange	transformation	technology	multi
training	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
infrastructure	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
F-statistic	10.778	15.529	202.114	301.017	13.088	15.380	14.846	36.859
Sargan-Hansen test	0.135	2.006	0.007	1.649	2.395	0.112	5.026	5.083
Durbin-Wu-Hausman test	3.848***	4.329***	2.252***	0.073***	9..795***	5.659***	2.794***	5.984***
Individual fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	247	247	247	247	222	222	222	222
R-squared	0.013	0.034	0.163	0.190	0.035	0.041	0.005	0.061

Robust standard errors in parentheses; *** p < 0.01, ** p < 0.05, * p < 0.1.
Source: Authors' estimation.

come indicators, are consistent with the baseline results. These confirm the sensitivity of crop cultivation to saltwater intrusion. Notably, households engaging in crop cultivation who apply adaptation methods are able to reduce the negative consequences of saltwater intrusion, thereby enhancing their income. This supports extensive literature on the effects of adaptation to saltwater intrusion for crop cultivation in the Mekong Delta region in general and selected provinces in the region in specific such as [33, 41, 50, 51]. Third, the estimated coefficients for *transformation*, *technology* and *multi* under the two sub-groups are statistically significant, and show show negative signs, indicating that adaptation methods to saltwater intrusion significantly reduce the income of aquaculture households. This is interesting but somewhat explainable. Aquaculture typically provides high economic value, whereas the reverse is true for crop cultivation. Additionally, aquaculture requires significant investments for any adaptation methods. As a result, the mitigating effects of applying adaptation methods to saltwater intrusion may not be sufficient to offset the heavy burden of investment costs and the losses directly caused by saltwater intrusion.

The findings on the heterogenous effects of adaptation methods to saltwater intrusion on different groups of households, crop cultivation and aquaculture, can arrive at some policy implications for both government authorities and households. First, the launch of programs and strategies to address saltwater intrusion should be tailored to specific sectors rather than applying a one-size-fits-all approach. Second, it is essential to help farmers in crop cultivation adopt adaptation methods, as this is empirically believed to strengthen resilience and enhance the income of households affected by saltwater intrusion. Third, adaptation methods for saltwater intrusion in the aquaculture sector need to be carefully evaluated and implemented with caution. In this regard, government authorities should provide both financial and technical support packages, while households must invest in acquiring the necessary technology, skills, and management capabilities.

5. Conclusions

Utilizing a dataset of 469 households across three selected provinces in the Mekong Delta, this study investigates the relationship between adaptation strategies, job change, agricultural transformation, technology application and multiple adaptations, and household income. The empirical findings revealed that adopting

Table 5. Crop Cultivation vs. Aquaculture: Net income.

	Crop Cultivation				Aquaculture			
VARIABLES	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
jobchange	387.510				−6.438			
	(972.338)				(10.636)			
transformation		27.397**				−14.351**		
		(12.838)				(9.502)		
technology			5.859**				−9.240*	
			(2.317)				(5.268)	
multi				2.521***				−1.695**
				(0.950)				(0.858)
edu	7.306	1.444**	1.482**	1.354**	1.034	0.622	0.469	0.958
	(13.933)	(0.632)	(0.598)	(0.559)	(1.343)	(1.354)	(1.199)	(1.274)
gender	8.590	−4.391**	−2.132*	−2.413*	−5.640**	−6.070**	−7.251***	−5.896**
	(32.262)	(1.870)	(1.214)	(1.244)	(2.330)	(2.534)	(2.592)	(2.306)
poverty	−6.435	−1.213	−1.942	−1.712	−9.356	−8.694	−7.856	−8.765
	(20.404)	(1.754)	(1.291)	(1.140)	(5.810)	(5.818)	(6.048)	(5.903)
members	0.847	0.711	0.600*	0.609*	−0.238	−0.198	0.135	−0.295
	(2.525)	(0.466)	(0.360)	(0.357)	(0.532)	(0.516)	(0.560)	(0.470)
Constant	−21.256	−4.292	−5.033**	−6.990***	5.251	5.164	5.309	7.268*
	(45.240)	(2.891)	(2.236)	(2.383)	(3.726)	(3.655)	(3.738)	(3.878)
F-statistic	10.778	15.529	202.114	301.017	13.088	15.380	14.846	36.859
Sargan-Hansen test	0.026	0.193	1.798	0.011	1.530	3.116	0.601	0.707
Durbin-Wu-Hausman test	6.679***	11.085***	4.287***	1.225***	0.215***	0.634***	3.495***	0.566***
Individual fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	247	247	247	247	222	222	222	222
R-squared	0.012	0.052	0.128	0.157	0.114	0.094	0.031	0.126

Robust standard errors in parentheses; *** p < 0.01, ** p < 0.05, * p < 0.1.
Source: Authors' estimation.

agricultural transformation models, applying technology in crop cultivation and aquaculture, and using multiple adaptation strategies could enhance the income of households impacted by saltwater intrusion. In contrast, changing to a new job shows no discernible effect on household income, indicating that shifting occupations may not effectively mitigate the economic challenges faced by households in this region. Regarding household characteristics, the incomes of female-headed households and poor households are relatively lower than that of male-headed and non-poor households, whereas the level of education appears to have no significant impact on household income affected by saltwater intrusion in the region. These outcomes remain consistent even when we use net income as an alternative measure to run regressions.

In this study, we further divided the total sample into two subsamples, crop cultivation households and aquaculture households, to check whether heterogeneous effects exist among different household groups. We found that changing to a new job had no visible impact on income for either group of households. For crop cultivation households, the estimated coefficients for other adaptation methods, including *transformation, technology* and *multi* were positive and statistically significant, indicating that these methods effectively increase their income. Meanwhile, negative effects were observed for aquaculture households, suggesting a reduction in household income. This outcome can be attributed to the significant investments required for adaptation measures in aquaculture. As a result, substantial financial burdens coupled with direct losses caused by saltwater intrusion may outweigh the benefits of these adaptation methods, ultimately making them insufficient to improve household income.

To effectively address the challenges posed by saltwater intrusion and improve household income in the Mekong Delta, a coordinated effort between the government and households is essential. First, the government should implement targeted policies designed with the

specific characteristics and needs of different types of agriculture activities, thereby ensuring the effectiveness and feasibility of adaptation strategies while enabling farmers to respond to saltwater intrusion with appropriate solutions that align with their unique circumstances. In addition, financial support mechanisms such as subsidies, low-interest loans, and grant programs are crucial to alleviating the financial burden on farmers as they transition to adaptive methods. By this way, farmers could access to and adopt advanced technologies and sustainable farming practices, coping with increasing salinity levels while maintaining productivity. Moreover, the government should prioritize the organization of training workshops and outreach programs to improve farmers' technical expertise and management capabilities. Simultaneously, investment in infrastructure including building and maintaining essential infrastructure such as salinity barriers, drainage systems, and water reservoirs is crucial to control and mitigate salinity levels across agricultural zones. Finally, fostering public-private partnerships is key to driving innovation and supporting the development of climate-resilient farming practices. Collaborating with private stakeholders can stimulate R&D activities, and dissemination of cost-effective technologies, particularly for the aquaculture sector, where adaptation methods often require significant investment.

Overall, the study has achieved its research objectives, offering valuable insights into the impact of adaptation measures on household income in response to saltwater intrusion in the Mekong Delta. However, due to data limitation, the study was focused on selected provinces in the region. Consequently, the findings may not be directly applicable to households in other provinces in the Mekong Delta. Moreover, the data used for this research were collected over a short time frame (2023 and 2024), which does not capture the long-term variability and trends in saltwater intrusion. Therefore, expanding the scope and utilizing longitudinal data are necessary for future research to provide a more comprehensive understanding of saltwater intrusion.

Author Contributions

All authors contribute equally to all parts of the manuscript, including conceptualization, methodology, validation, formal analysis, writing, reviewing and editing.

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Institutional Review Board Statement

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Not applicable.

Data Availability Statement

The data presented in this study are available on request from the corresponding author.

Conflicts of Interest

The authors declare no conflict of interest.

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