Examine the Agriculture, Poverty, and Climate Change

Nexus in Vietnam

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Abstract

Vietnam is likely to be among the hardest hit countries by climate change, which may threaten the recent progress it has made in accelerating agricultural growth and poverty reduction. To examine how agriculture and the rural poor may be affected by a changing climate, this paper measures Vietnamese farmers' adaptation behavior in terms of adjustments to the production portfolio and input usage. Specifically, the paper estimates a rice yield function based on household-level crop production, long-term climate measurements and recent weather shocks. The results suggest that rice production will suffer from climate change. However, Vietnamese farmers are likely to respond to changes in rainfall and temperature by adjusting input usage. While this will help maintaining productivity levels, expanding irrigation and agricultural intensification will be key components of climate change adaptation strategies at farm and national level. Localized policy packages aiming at increasing yield by focusing on vulnerable groups (ethnic-minority and/or the poor) can help achieve multiple development goals of poverty reduction, food security and climate change adaptation.

Keywords: Climate change, poverty, Vietnam, rice, control function, weak instruments, multiple endogenous variables, Heckman

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1. Introduction

Vietnam is among the countries that will be worst affected by the impacts of climate change (Dasgupta et al. 2007). Climate change can have serious implications for economic growth and human development, especially in the agricultural sector, due to its direct exposure to and dependence on weather and other natural conditions (Tubileeo and Rosenzweig 2008). Studies for the Southeast Asian region show that climate change could lower agricultural productivity by 15–26 percent in Thailand, 2–15 percent in Vietnam, 12–23 percent in the Philippines, and 6–18 percent in Indonesia (Zhai and Zhuang 2009). Nguyen, Vu, and Nguyen (2008) found that the Mekong River Delta and the coastal areas in the north of the central region are most vulnerable to the impact of global warming in Vietnam and they estimate that the average temperature will increase by 2.5 degrees Celsius by 2070, and sea levels are expected to rise up to 33 centimeters by 2050. According to Dasgupta et al.'s (2007) estimation, about 20–30 percent of the Mekong River Delta will be affected by 2100, and some areas will be salinated.

Agriculture in general and paddy rice specifically have played an important role in food security, poverty reduction, rural employment generation, and foreign exchange earnings in Vietnam. Paddy rice accounts for more than three-quarters of the country's total annual harvested agricultural area and employs about two-thirds of the rural labor force, thus making a significant contribution to rural livelihoods (Vu and Glewwe 2009; Nguyen, Yu and Breisinger 2009 and 2010). Rice cultivation is a major source of income (in many cases the major or only source) for more than three-fourths of poor households and for about 48 percent of nonpoor households. Rice production has grown steadily over the past two decades, mainly driven by yield improvement, and hence transformed the country from a net rice importer to the second-largest rice exporter in the world (FAO 2011).

Increase in temperature and erratic rainfall can directly affect the agriculture and food supply through their effects on crops. The changing climate is likely to be especially damaging for rice cultivation given its sensitivity to changes in temperature and water conditions. Hydroclimatic disasters such as typhoons, floods, and droughts, which could become more severe and frequent as the climate changes, have decreased agricultural production substantially in recent years. Zhu and Trinh (2010) estimated that rice yield in Vietnam could decline by 4.2 – 12.5 percent by 2030 due to climate change. The impact is especially alarming in the poor regions (Central Highland and northern Vietnam), highlighting the enlarged gaps in food supply in these regions. Although the impact of climate change is relatively moderate in the major rice-producing region of the Mekong River Delta, they estimated average rice yield will drop by 1–8 percent by 2030.

Even without climate change, the rice sector in Vietnam is facing severe challenges. Land under rice cultivation has been decreasing and is expected to decrease further in the future: the total rice growing area declined by 6 percent in 2000–2007, mostly due to rapid industrialization and urbanization. According to the Resolution on ensuring National Food Security of Vietnam (GOV, 2009), the total area under rice production is projected to drop by nearly 10 percent by 2030. While current rice yields in Vietnam are still high compared to those in other Southeast Asian countries, yield levels have been stagnating in recent years (FAO 2011). Declining agricultural productivity, together with the volatility associated with climate change, could compound the risk of food insecurity in Vietnam and the rest of the world. Given limited scope of arable land expansion, productivity-led growth is the only feasible option to improve rice production in the long run. Increasing rice productivity will ensure long-term food security, help the country maintain a stable source of export revenues, and support rural employment and continued poverty reduction.

In light of these complex challenges of rice production, climate change and poverty reduction, this paper measures Vietnamese farmers' adaptation behavior in terms of adjustments to the production portfolio and input usage. Specifically, the paper gives answers to the following research questions: (1) What is the impact of climate change on rice yield? (2) How does the poverty status of households affect farmers' ability to adjusting production portfolio and input usage? (3) How does rice yield respond to input use in the river deltas?

By answering these questions, the paper adds value to the existing literature in several ways. First, it assesses the impact of climate change and weather shocks on rice production and productivity in Vietnam, adding evidence for understanding long-term food security in the developing country context. The results corroborate other studies on the negative impact of global warming and the positive effect of modern inputs on rice yield in the region. Second, it examines farmers' adaptation behavior under external weather shocks to see how producer cope with climate change by adjusting usage of productive inputs. Third, this paper links the agriculture and climate change challenges to rural poverty, which remains high in many countries, including Vietnam. Fourth, it addresses common methodological problems in estimation in innovative and systematic ways, including sample selection, endogeneity and heterogeneity. Despite the difficulties in estimating structural models, appropriate econometric techniques can be applied to a combination of economic models to produce credible and relevant results. Finally, the econometric techniques presented in this paper, the control function approach embedded in sample selection, can be applied in other economic investigations of joint demand for endogenous inputs and a production function, while accommodating the nonlinear effects of unobservable factors and endogenous inputs.

The paper is organized as follows. Section 2 presents the methodology for estimating the yield function focusing on sample selection with endogenous inputs. Section 3 describes data used in this paper. Section 4 presents the empirical results of changes in rice yield associated with both biophysical and socioeconomic conditions, demonstrating the impacts of climate change on rice production and possible policy interventions for adaptation. Section 5 concludes by providing policy options derived from this study.

2. Household Rice Production Model

2.1 Yield function

In order to understand how rice farmers behave when facing a changing climate and possible external weather shock under diverse agroecological conditions, we first examine how short- and long-term climate pattern affects the decision to employ inputs and then how climate affects rice yield. A structural model with a linear functional form is chosen to represent the production technology of Vietnamese farmers (Sadoulet and de Janvry 2003):

$$Y = \alpha Z + u \tag{1}$$

where rice yield Y is a function of factors Z, including labor and modern inputs (fertilizer and irrigation) per unit of land. Z also includes other fixed and quasi-fixed inputs that are exogenous (including climate); $\alpha$is a vector of coefficients to be estimated. Y is log transformed, and so are the Z variables that are continuous. Some of the Z variables are not in log form because they are dichotomous. There are some additional econometric issues that arise in the estimation of this structural model, including endogeneity and sample selection bias.

2.2. Econometric considerations

The decision of input usage like irrigation, fertilizer and hired labor may be endogenous in household production decision, producing inconsistent parameter estimates (Doraszelski and Jaumandreu 2009). The control function approach is used to handle endogeneity in the use of irrigation (Appendix). It offers some distinct advantages over standard 2SLS for models that are nonlinear in parameters, including improved efficiency and precision (Wooldridge 2008). In addition, Felipe, Hasan, and McCombie (2008) suggested that the endogeneity bias may occur if the inputs are measured in terms of value, due to poor approximation to an account identity. We run a separate model using fertilizer consumption quantity to examine price-induced endogeneity.

The control function approach provides a straightforward two-step procedure to control for endogeneity of explanatory variables. The first step is to estimate a reduced form equation of endogenous explanatory variables using some exogenous variables as instrumental variables. In the second step, the generalized residuals obtained from the reduced form are used as an additional explanatory variable in the structural model regression of rice yield in Equation (1). The estimates of yield function are control function estimates, because the inclusion of the residuals from reduced form equation "controls" for the endogeneity of inputs in the structural equation.

The problem of sample selection bias arises when some rural households choose not to grow rice and hence are not included in the estimation of rice yield. This self-selection in samples can further complicate the problem of identifying the effect of an endogenous variable because rice yield may or may not be observed for some households. Heckman (1979) demonstrates that an OLS regression of using the selected sample generally leads to inconsistent estimation of coefficients. He proposed a technique to adjust bias from sample selection and produces consistent and asymptotically normal results.

2.3 Model for estimation

Following Wooldridge (2002), a sample selection model is chosen for this study, with one or more of the explanatory variables being endogenous (correlated with the error term). The model includes multiple equations. The first equation is the structural equation of interest, the rice yield function. The second equation is the demand function of endogenous input, which is the linear projection of the potentially endogenous variables on all the exogenous variables. The control function approach (Wooldridge 2007) is used to deal with the bias due to nonlinear interactions of the inputs into rice production with unobservable variables specific to input usage. The third equation is the sample selection equation for households reporting rice production.

$$y_1 = z_1\delta_1 + \sum_j \alpha_j y_{2j} + u_1, \text{ j=1,2,…,J} \quad (2)$$

$$y_{2j} = z\delta_{2j} + v_{2j} \quad (3)$$

$$y_3 = 1(z\delta_3 + v_3 > 0) \quad (4)$$

where y_1, y_{2j}, y_3 represent rice yield, endogenous input(s) of rice yield, and an indicator function for selection of the observation into the sample, respectively. z_1 is a vector of exogenous covariates; z is a vector of exogenous covariates includes z_1 variables (also in the rice yield equation) and a vector z_2 of instruments that affects each of the endogenous inputs y_{2j} but have no direct influence on rice yield y_1. Vector z_2 is also called excluded instruments because they are not included in the structural equation. $\delta_1, \delta_{2j}, \delta_3, \alpha_j$ are vectors of parameters to be estimated, and u_1, v_{2j}, v_3 are disturbance terms with arbitrary correlation.

Equation (4) captures the fact that not all rural households growing rice as some can be specialized in other crops. Since non-rice crop yields are excluded from Equation (2) and (3), Equation (4) helps correct biases in the estimated parameters resulting from any non-randomness of the selected sample. The Heckman (1979) sample selection technique is used to correct bias of any non-randomness of a selected sample with the inverse of the Mills ratio.

A three step procedure is applied to obtain consistent estimators of the sample selection model with endogenous explanatory variables:

1. Use control function technique to obtain generalized residuals for endogenous variable $\widehat{GR_j}$.
2. Use the Heckman technique to obtain the probit estimates of the inverse of the Mills ratios, $\widehat{\lambda_3} = \lambda(z\widehat{\delta_3}) = \phi(z\widehat{\delta_3})/\Phi(z\widehat{\delta_3})$, where $\widehat{\delta_3}$ is estimated from selection Equation (4) using all observations.
3. Plug $\widehat{\lambda_3}$ in rice yield Equation (2) as one of the exogenous regressors to adjust the parameters using the selected subsample for which we observe both y_1 and y_{2j}. Generalized residuals $\widehat{GR_j}$ are also included to control for endogeneity. The new equation for estimation is

$$y_1 = z_1\delta_1 + \sum_j \alpha_j y_{2j} + \sum_j \eta_j \widehat{GR_j} + \gamma\widehat{\lambda_3} + e, \text{ j=1,2,…,J} \quad (5)$$

where η is a vector of parameters associated with the general residuals from endogenous variable regression Equation (3).

The terms $\widehat{GR}_J$ and $\widehat{\lambda_3}$ are the control function variables because they control for the effects of unobservable factors that would otherwise contaminate the estimates of structural parameters of yield. $\widehat{GR}_J$ serves as a control for unobservable variables that are correlated with y_{2j}, thus allowing these endogenous inputs to be treated as if they were exogenous covariates during estimation. The inverse of the Mills ratio $\widehat{\lambda_3}$ controls for the effects of sample non-randomness of structural parameters.

Step 2 and 3 can be combined in one step by using maximum likelihood. Wooldridge (2002) suggests that maximum likelihood approach is more efficient that the procedure described above if error terms in Equation (2) and (4) are jointly normal. The results from maximum likelihood estimation do not require adjustment for standard errors.

The usual t and F statistics can be used to test whether the estimated coefficients on the controls for unobservables are statistically significant. There are several cases in test:

1. If η and γ are both insignificant, the parameters of the yield function can be consistently estimated with OLS using a selected sample. That is, endogeneity and sample selection are not empirically discernible, despite a strong theoretical case for their existence.
2. If only η is statistically significant, the instrumental variable method is a special case of the control function approach and the latter is the preferred estimation method. The structural parameters can be consistently estimated by applying 2SLS on the selected sample but the standard errors of the 2SLS need to be adjusted for standard error (Wooldridge 2002).
3. If only γ is statistically significant, the Heckman approach is applied to account for sample selectivity bias while ignoring endogeneity does not result in biased estimates.

To accommodate nonlinear interactions of unobservable factors with the observed regressors specified in the structural function of yield, Equation (5) can be further extended as

$$y_1 = z_1\delta_1 + \sum_j \alpha_j y_{2j} + \sum_j \eta_j \widehat{GR}_J + \sum_j \tau_j(\widehat{GR}_J \times y_{2j}) + \gamma\widehat{\lambda_3} + e, \text{ j=1,2,…,J} \quad (6)$$

where $(\widehat{GR}_j \times y_{2j})$ is the interaction of the endogenous input j with its residual, and τ is a vector of additional parameters to be estimated. The interaction term controls for the effects of possibly neglected nonlinear interactions of unobservable variables with yield inputs.

Additionally, interaction terms between poverty status and inputs are introduced to quantify the effect of poverty on the household's ability to increase yield and mitigate the negative impact of adverse weather. Hence, the structural model is not linear in inputs because the model includes two groups of interaction terms: interaction of an endogenous input with its residual $\widehat{GR}_j \times y_{2j}$ and interaction of poverty status and inputs.

3. Data on agriculture, climate and poverty in Vietnam

Vietnam has relatively complicated terrain, characterized by numerous mountains, many rivers, and a long and meandering coastline. About 28 percent of the total land area of the country is agricultural land, and plains cover about 25 percent of the country's total land area. The country is divided into eight agroecological zones based on its climate and biophysical environment (Appendix Figure 1). The northern part of the country is mostly mountainous, with the South China Sea on the south and plains in the middle. This region includes the North West (NW), North East (NE), and Red River Delta (RRD) agroecological zones. The Red River Delta has low elevation with extensive rice and vegetable fields. The central part of Vietnam is sloping and narrow. There are small plains along the coastline and narrow and deep valleys between sloping mountainsides. This part includes the North Central Coast (NCC), South Central Coast (SCC), and Central Highlands (CHL) agroecological zones. The NCC and CHL zones are mostly mountainous. The southern part has much more even and flat topography. The South East (SE) zone includes regions with low to medium elevation, and the Mekong Delta River (MRD) zone is a vast flat area with low elevation. Some parts of this delta have elevations below sea level; therefore, about a million hectares are covered by flood water for two to four months every year.

Vietnam's General Statistics Office (GSO) conducts the Vietnam Household Living Standards Surveys (VHLSS) biennially, and this study uses the surveys conducted in 2004 and 2006. Both surveys include information on household crop production and village-level information on access to community and social services (e.g., transportation, electricity, markets, schools, and health facilities) and weather shocks (drought, flood, and typhoon). The variables used in the yield function estimation include inputs and outputs of rice production, together with quasi-fixed inputs and supply shifters. The common factors typically used in empirical production analysis include irrigation, research investment, extension services, access to capital and credit, agroclimatic conditions, policy and rural infrastructure (irrigation, electricity and transportation). In this paper the variables are selected based on production theory and previous studies on the determinants of productivity and government investment as summarized by Sadoulet and de Janvry (2003); Fan, Yu and Saurkar (2008) and Fan, Hong and Long (2003).

The diverse agroecological conditions are reflected in the rainfall and temperature records of the 25 weather stations in the country. Long term climate pattern is represented by monthly average rainfall and temperature from 1979 to 2007. We combine long-term climate records from the weather stations with household surveys from VHLSS 2004 and 2006. Descriptive statistics of the variables are summarized in Table 1.

Despite the country's rapid economic transformation, rice still dominates in Vietnamese crop cultivation, accounting for more than three-quarters of the annual crop harvested area. The majority of the producers in the rice-based farming system of Vietnam are smallholders who typically operate on a small plot of paddy field (0.7 hectare in 2004 and 1.4 hectares in 2006). This suggests that focusing on increasing farm productivity offers the single most important pathway of income generation. Average rice yield is stagnant at 4.7-4.8 ton per hectare, which is consistent with national trend reported by Nguyen, Yu, and Breisinger (2009 and 2010). The majority of agricultural labor working in paddy fields is family labor as hired labor accounts for only 4.2 percent of total labor used for rice production. Adoption of modern inputs is high in Vietnam compared to many developing countries, where 97 percent of rice producers opt to use chemical fertilizers and more than 70 percent of households irrigate their rice fields. On average, a household consumed 324 kilograms of chemical fertilizer per hectare in 2006, mainly nitrogen and phosphate fertilizers. Market participation is not very high, and the majority of the rice harvest is still consumed within the household. Only about a quarter of harvested rice enters commercial channels, which underscores the importance of rice in rural Vietnamese households' nutritional status and food security. Although the share of rice sold on the market is not very high, about 44 percent of Vietnamese households were net sellers in 2006 (Vu and Glewwe 2008). Furthermore, about 14–20 percent of households become specialized in rice cultivation by focusing exclusively on rice in their annual crop fields.

Less than one-quarter of rice-farming households are headed by a member of an ethnic minority. More than one-third of rice-growing households are classified as poor, much higher than national average. Overall, access to infrastructure and public services improved marginally between the two survey rounds. At the commune level, the share of annual cropland under irrigation increased marginally in two years while electricity is universally available. The average distance to the nearest transportation and market increased slightly but farmers also experienced a small improvement in access to technical support from agricultural extension agencies. More than one-fifth of rice-producing communes in the sample are defined as poor by the government. We introduce two irrigation variables due to the nature of irrigation spending. Usually government is responsible for the construction and maintenance of irrigation infrastructure (canals and dams), and this part is captured by the share of irrigated annual crop area at the commune level. However, farmers must pay a fee to irrigate their plots, and this part is captured by the household-level private irrigation expenditure variable.

This descriptive analysis leads to a number of hypotheses. Based on agronomic and economic theory, higher rice yields are observed under intensified production process characterized by higher input usage (labor, fertilizer, and household irrigation). The quality of the labor force is reflected by household head literacy, and a literate farmer should be more able to adopt new technology and produce more efficiently. Ethnic-minority households are more reliant on rice than their ethnic-majority counterparts for livelihood, but they tend to have persistent disadvantages to escape poverty and they are expected to be less productive (ADB 2006). For instance, rice yields are usually compromised among the poor and ethnic minorities due to physical and financial constraints.

Previous research by Fan, Hong and Long (2004) suggests that investment in road yields high returns in every zone in Vietnam, while education investment produces larger impacts in the South East and delta zones. Access to transportation and markets increases productivity by increasing the availability of inputs, reducing input prices due to lower transport costs, and increasing income due to greater opportunities for sales or higher prices. Because infrastructure access is measured as the distance to infrastructure and social services, the expected signs of these variables are negative. We expect the availability of crop extension services to increase rice productivity, and the coefficient of the distance to an agricultural extension agent should be negative as well. Other infrastructure variables such as electricity availability are supposed to boost yield through machinery usage. The poverty status of a commune should be associated with its productivity level and we expect the coefficients of being a poor commune to be negative.

Agriculture is sensitive to short-term changes in weather that affect the production of crops. Low level of rainfall and high temperature cause drought, whereas intense rainfall over a short period of time may cause floods. Both the situations induce negative effects in the agriculture. Climate change may cause weather pattern changes, affecting the frequency and intensity of typhoons. High temperatures are a constraint to rice production and can cause a significant yield reduction. Studies on the impact of climate change on crop yield generally report a negative response when temperatures exceed the optimal level for biological process (Rosenzweig and Hillel 1995).

4. Discussion of results

The explanatory variables from VHLSS and climate records are classified into five groups for their effects on rice yield, endogenous input and selection equations: inputs for rice production, household characteristics, commune characteristics, climate factors and control variables. Table 2 summarizes the variables used in the analysis. The first group is inputs used directly for rice production at household level, including family and hired labor, fertilizer, irrigation, machine rental, chemical, market participation (share of sale in total harvest) and the importance of rice in crop production (share of rice area). Household characteristics include household head age, gender, educational grade, marital status, ethnical group, literacy, and household size and poverty status. The third group is commune characteristics, which describes commune infrastructure such as irrigation and electricity coverage, distance to market and transportation, access to agricultural extension. Dummy variables are used to capture commune poverty status, remoteness and whether having ongoing government infrastructure program. The fourth group includes both short- and long-term climatic factors. Long-term climate pattern is captured by averages and variations of rainfall and temperature over the period of 1979-2007, while short-term weather variables are proxied by external shocks such as flood, drought and typhoon over the last 3 years. The bottom panel of Table 2 lists the last group of control variables. They represent unobserved factors that in theory could affect rice yield in complex ways. They are included only in the rice yield equation to ensure consistently estimation of parameters in structural equation.

In order to properly interpret the estimated parameters of the model in Equation (2)-(4), it is important that the endogenous inputs and sample selection equations are identified. Since there are three endogenous inputs in Equation (2), identification requires at least four (three for endogenous input demand functions and one for sample selection function) exclusion restrictions because there are four equations that need to be solved simultaneously. All the four instruments should be excluded from the yield function (Wooldridge 2002), and the data fully satisfies this requirement.

As emphasized by Wooldridge (2002), all exogenous variables should appear in the selection equation, and all should be listed as instruments in estimating Equation (5) to avoid any exclusion restrictions.

4.1 Endogenous input demand

The estimation results of demand for endogenous inputs are summarized in the first 3 columns of Table 3. In general, input usage is positively correlated with other inputs (chemical and equipment rental), market participation (rice sale), reliance on rice for income (share of rice in total crop land), household wealth (per capita income) and commune infrastructure (irrigation coverage and access to market and transportation). The effect of household labor force is mixed, suggesting that it is a substitute input for hired labor but a complementary input for fertilizer. Additional factors contributing to fertilizer use includes education (grade and literate), small household size and access to electricity. Electricity powered machinery can substitute for irrigation. Households with better access to agricultural extension stations or located in a better-off community generally have high demand for hired labor. Demand for fertilizer and irrigation is depressed in households headed by an ethnic minority and/or in poor communes.

Regarding climate factors, warm and humid weather with less predictable climate pattern generate higher demand for irrigation in rice production. Hired labor use is higher in areas with low rainfall and low variation of temperature. Coefficients of weather events reveal rice farmers' coping strategy when faced with adverse weather. Spending for irrigation increases in areas of higher flood occurrence over the past 3 years but decreases with typhoon occurrence. It suggests although producers choose to invest less in areas prone to typhoon, they try to take advantage of high nutrient contents in soil from sediment in the medium term by increasing irrigation use to mitigate the adverse impact of drought. Similarly, demand for hired labor is low in areas prone to droughts in the medium term, but producers spend considerably more to hire extra labor to fight drought in current growing season. Farmers also choose to hire less labor for rice production if the area experienced flood in recent months. Overall, producers' behavior follows the rational assumption: allocate inputs according to medium term weather pattern while adjust input level in current season to minimize loss when faced with external weather shocks.

4.2 Sample selection

The set of factors that affects demand for inputs into rice yield also influences selection of rural households into the estimation sample. The last column of Table 3 presents estimation results of a probit model of rice producing in a household survey. As in the case of endogenous inputs, a household is more likely to grow rice if it has more labor and household members, spends more in chemical and machine rental, actively participates in markets, reports higher income, is headed by an ethnic minority and located in communes with low access to transportation. Producers in remote communes or low access to electricity tend to include rice in their production portfolio. Temperature plays an important role in a household's decision of growing rice: an environment characterized by warm and dependable temperature is more favorable for rice production and hence more likely to result in rice production. Past flood and drought discourage producers from growing rice, and rice growers choose to modify input levels based on recent weather shocks.

4.3 Rice yield

Table 4 presents several approaches to analyze the determinants of rice yield in Vietnam. OLS and 2SLS estimates are summarized in column (1) and (2), respectively, under the assumptions that (1) the unobservable effects are not correlated with excluded instruments or the correlation is linear and (2) the estimation sample is randomly selected from the population of interest (rice farmers in this case). Column (3)-(5) presents the maximum likelihood Heckman estimates, controlling for sample selection bias and heterogeneity of the rice yield. Heckman estimation drops the assumptions in 2SLS of column (2) and replaces them with two alternative assumptions: (3) the sample on which rice yield is estimated is not random and (4) the interaction between unobservable effects and the covariates of rice yield is not linear. Therefore, the generated regressor (the inverse of the Mills ratio) in selected sample is introduced into the structural function of rice yield through the Heckman procedure to correct sample selection bias. In addition, new generated regressors of interaction terms between input and its residual are included in the regression through control functions to account for correlations of unobservable factors and rice yield (column (4)). In order to measure the impact of poverty on producers' input use, we also introduced interaction between household poverty status and endogenous variables in column (5).

The results in Table 4 show that coefficients of hired labor, fertilizer and irrigation in 2SLS estimation are considerably larger in magnitude than that of OLS, suggesting a downward bias in OLS if endogeneity is ignored. A comparison of 2SLS results in column (2) with Heckman in column (3) shows that accounting for sample selection bias further increases the estimated coefficients of endogenous inputs while reducing standard error slightly.

Irrigation expansion and agricultural intensification have played a key role in the rapid growth of agricultural production and in coping with climate variability (Kirby and Mainuddin 2009). Yield elasticities with respect to inputs are all statistically significant and of the expected sign. Intensification in the production process increases rice yields, as yield elasticities with respect to home and hired labor are about 0.05. A one percent increase in fertilizer spending in the field can increase paddy yield by 0.13-0.16 percent and a one percent increase in irrigation spending can lead to a 0.06 percent increase in yield. Higher rice yield is generally observed among households with a diversified production and not overwhelmingly concentrated on rice. Households who participate in market senjoy a small yield advantage.

Most ethnic minorities live in the mountainous and poor regions of the north and central highlands, dependent on agricultural incomes. Increased rice production can help rural ethnic-minority households to boost income, escape poverty, and improve their food security (Nguyen 2006). The coefficients of household poverty status are positive and significant in column (3) and (4), but household poverty status becomes statistically insignificant after interactions terms between poverty and control variables are introduced, suggesting the existence of possible correlations between household characteristics and other unobservable factors. Although many of the coefficients on commune characteristics are statistically significant in OLS, they are not in 2SLS, indicating that OLS results could be misleading due to inconsistency and bias. Most of the coefficients on demographics and commune characteristics are quite similar between 2SLS and Heckman estimation, perhaps due to the exogeneity of these variables. Examined with input demand function, we conclude that investment in rural infrastructure improves yields directly and indirectly through the positive link between infrastructure and endogenous inputs.

Climate change is shown to have an impact on rice production, which is consistent with other studies (Zhai and Zhuang 2009; Zhu and Trinh 2010). On average, if temperature increases by 1 degree average yield could be 0.02 percent lower, which translates into a yield loss of 1 kg per hectare, or 19 thousand tons at the country level. Input demand function has demonstrated that large variations in weather patterns discourage farmers to invest and can reduce productivity. Table 4 concurs this finding and reports positive correlation between high and reliable precipitation and crop yield. Although past weather events could affect farmers' demand for inputs, their direct impacts on rice yield are mostly insignificant except for floods. As we suspected, higher yield is reported in areas with high occurrence of flood, probably because rice yield is usually higher in fertile river deltas and coastal area with extensive water ways, which is also more likely to experience floods.

The coefficients on residuals are statistically significant for endogenous inputs in column (3), implying that they are all endogenous in the rice yield equation and that the inclusion of these residual terms in the structural equation is necessary to obtain consistent estimators. The interaction between endogenous inputs and their residuals are introduced to capture potential non-linear correlations between rice yield inputs and unobservable factors (column (4)-(5)). The nonlinearity of unobservable effects and endogenous inputs holds because the estimated coefficients of interaction terms in column (4) are all statistically significant. The interaction of fertilizer and its residual is the main source of heterogeneity in rice yield. That is, farmers applying fertilizer are more likely to adopt new technology or use other inputs to boost yield.

The three way interaction between endogenous input, its residual and poverty status in the rice yield equation highlights the different impact of inputs on yield (column (5)). As presented in Figure 1, the upward trend suggests the positive contribution of input intensification in yield improvement for both poor and non-poor households. What's more, rice yield increases faster in non-poor households than in poor households if hired labor use increases by the same amount, resulting in a larger yield gap as hired labor expense increases. For example, if household spending in hired labor increases from 20 to 50 thousand Dong per hectare (from -4 to

-3 in log term in x-axis), average rice yield is predicted to increase from 6.0 to 6.3 ton per hectare (1.78 to 1.83 in log term in y-axis) for non-poor households, a 5.2 percent improvement. For poor households, predicted rice yield increases by 4.8 percent from 5.7 to 5.9 tons per hectare (1.73 to 1.78 in log term in y-axis). This elasticity of rice yield with respect to hired labor can also be interpreted as the responsiveness of rice yield to hired labor. In other words, poor households face more physical, knowledge and credit constraints which prevent them from increasing yield through new technology adoption or input intensification. This leads to lower productivity progress than their better-off counterparts as illustrated in Figure 1.

The response line of rice yield to household irrigation expense for the poor households crosses with that of non-poor households. While non-poor households report higher average rice yield at very low irrigation use, poor households begin to catch up as irrigation expense reaches higher levels and may even surpass non-poor households when irrigation use is at very high range. At sample mean of about 50 Dong per hectare of irrigation expense (-3 in log term), predicted rice yield is 6.3 ton per hectare for non-poor households, which is 5.7 percent higher than poor households average. Again, the graph shows that average yield of poor households is less responsive to irrigation intensity than their non-poor counterparts in most cases (poor households usually spend less on inputs). Moreover, the yield gain of poor households grows when irrigation application increases.

Fertilizer response gives a similar story that average rice yield grows as fertilizer expenditure increases. In most cases, the predicted yield for the poor falls below that of the non-poor although we find poor households enjoying a small yield advantage at low levels of fertilizer spending. However, the yield gap between poor and non-poor households is smaller when compared with irrigation. This is not surprising given the high adoption rate of chemical fertilizer in the country. In the case of commune irrigation coverage, it is clear that rich households benefit more from existing irrigation facilities in the neighborhood as average yield is higher than that of poor households.

The coefficient on the inverse of the Mills ratio is insignificant even after accounting for heterogeneity of rice yield through inclusion of interaction terms of the residuals and endogenous inputs in the structural equation (column (3)-(5)). It suggests that the structural error term is uncorrelated with the error of sample selection equation because Wald test yields p-value=0.99.

It means that the unobservable factors that are associated with selection of rice producer into estimation sample are separable from unobservables that are correlated with rice yield.

4.4 Discussion of instruments

In Table 3, the joint F and χ^2 tests show that the entire set of instruments z is valid for both input demand and sample selection equations. This discussion will focus on the validity of excluded instruments z_2 (Table 3).

An instrument should satisfy three properties: relevance, strength and exogeneity. First, an instrument is relevant if its effect on a potentially endogenous explanatory variable is statistically significant. Second, an instrument is strong if its coefficient is “large”. Finally, the instrument is exogenous if it is unrelated with the structural error term in Equation (2). An instrumental variable that meets all these criteria is defined as a valid instrument. If the endogenous variable is strongly correlated with the included exogenous variable z_1 but only weakly correlated with the excluded instrument z_2, the usual 2SLS estimators are biased toward the OLS estimator and the inference based on the standard errors may suffer from severe size distortion (Angrist and Pischke 2009).

The F statistic and the partial R^2 provide important information about the validity and relevance of instruments in the case of a single endogenous variable (Shea 1997). The F statistic in input demand equations and χ^2 statistic in selection equation test for the joint significance of excluded instruments. If the F/χ^2 statistic is not significant, the excluded instruments have no significant explanatory power for endogenous demand and sample selection after controlling for the effect of exogenous variables. Stock, Wright and Yogo (2002) suggest that simply looking at the p-value of an F statistic is not sufficient and the F statistic should exceed 10 for inference to be reliable. The F statistic on excluded instruments ranges 21-168 for endogenous inputs and 48 for selection (Table 3), all with p-values = 0.00, suggesting the validity of instruments for individual endogenous variables. In addition, the partial R^2 statistic measures the correlation between endogenous variable and the excluded instruments after partialling out the effect of exogenous variables, showing the predictive power of the instruments in endogenous inputs and sample selection (Table 3).

In the case of multiple endogenous variables, it is necessary to test the assumption that the excluded instruments are uncorrelated with the structural error term. The diagnostic tests

(Table 4 2SLS) indicate that the inputs into yield function are endogenous (regression-based test of exogeneity statistic is 42.52 with associated p-value = 0.00), which implies that the OLS estimates are not reliable for inference due to inconsistency. What's more, there is a need to detect weak instruments (Stock and Yofo 2005) using the Cragg-Donald minimum eigenvalue statistic. In this paper, there are 4 endogenous regressors (including the sample selection variable) and 31 instruments, and the Cragg-Donald statistic of 3 endogenous regressors and 8 excluded instruments is 12.15. From Table 1 of Stock and Yofo (2005) the critical value of 2SLS relative bias (the bias of the 2SLS estimator relative to the bias of the OLS estimator) at 5% is 15.18 and at 10% is 9.01. It suggests that if we are willing to tolerate a 10 percent relative bias, we can reject the null hypothesis test of weak instruments and conclude that our instruments are not weak.

4.5 Sensitivity analysis

To examine the robustness of this analysis, the Heckman model with endogenous inputs is applied under difference assumptions.

First, the endogeneity bias may occur if the inputs are measured in terms of value, due to poor approximation to an account identity (Felipe, Hasan, and McCombie 2008). Fertilizer quantity, available only in 2006, is used to substitute fertilizer value in the estimation. Appendix Table 1 compares the estimated results of fertilizer demand and yield equation based on fertilizer expense and quantity in 2006. The coefficients are slightly smaller for fertilizer quantity than that of fertilizer expense, but are quite similar in other coefficients. F-test statistic for fertilizer quantity is far above 10 with p-value=0.000 and partial R^2 value increases considerably, suggesting that the excluded variables are valid with improved predictive power. The eigenvalue statistic falls between 10 and 20 percent critical value (based on Stock and Yofo's (2005) tabulation), indicating that fertilizer quantity is a weaker instrument compared with fertilizer value. The results show that studies based on input value alone could have a risk of overestimating fertilizer response, although the bias contamination does not spread to other parameter estimation. Figure 2 compares yield elasticities under different definition of fertilizer and demonstrates some common trends: yield responses positively to intensified input use, and poor households generally report lower productivity and benefit less from commune irrigation infrastructure. Poor households start with a yield advantage but average yield rises at a faster pace among non-poor households.

Second, the yield response to inputs could vary by agroecological zones. Additionally household poverty status could affect how producers respond to climate change through input adjustment. The deltas are the major producer of rice. If ranked by output share in 2006, Mekong River Delta and Red River Delta contribute 38.5 and 18 percent of total rice production in Vietnam, respectively. We will assess the difference between deltas and other regions under difference biophysical conditions. The comparison of coefficients for deltas and other agroecological zones are shown in Appendix Table 2 and yield response by household poverty status is illustrated in Figure 3. Similarly to the stories in Figure 1 and 2, there is, in generally, an upward trend between input use and rice yield, and average yield of poor households are low. However, the yield response line can be quite different between major and minor rice producing zones. For example, rice production can be highly labor intensive. The response lines of hired labor in non-delta zones (the right figure) are steeper than that of delta zone, suggesting that the predicted yield gain should be greater in non-delta zones if hired labor cost increases by the same amount. On the other hand, in delta with lower poverty incidence, yield gap is larger than that of non-delta zones. Given the substantial regional variations in crop production, localized policy packages targeting poverty reduction in the deltas are more effective in promoting adaptation to climate change and achieving food security.

Third, to investigate the potential impact of outlier in this estimation, we also run the same model specification excluding the extreme values of yield at both ends (the largest and smallest 5 values of rice yield, together 0.11 percent of the sample is dropped). The coefficients are quite similar in many cases, which implies that the model specification is robust to extreme values.

The estimated coefficients on the inverse of the Mills ratio are statistically significant at 1 percent level in the second and third sensitivity tests, namely sample breakdown by agroecological zones or excluding extreme values (Appendix Table 2 and 3). This finding justifies the model specification of Heckman with control function approach because it corrects for sample selectivity bias, even though we did not find statistical evidence in the full sample. We can obtain the difference between average rice yield and average crop yield (including other cereals and tubers) in the general population, but it is very helpful in this study of rice yield response.

5. Conclusions and discussion

This paper has integrated rice yield responses with an assessment of potential impacts of climate change and poverty on agricultural systems. By combining both socioeconomic and environmental factors in the analysis of rice production, this study takes a holistic approach to the issues of agricultural productivity, rural poverty and climate change.

We find that climate change affects rice production directly and indirectly. Changing natural endowment of soil and climate condition plays an important role in both producers' decision of growing rice and in determining rice yields. Climate can also impact crop yield indirectly by affecting the intensity of inputs (irrigation, labor and fertilizer) as farmers opt to increase input use in an environment with favorable biophysical conditions. In addition, we find that farmers follows rational assumption as they allocate inputs according to medium term of 3 years weather patterns while adjust input level in current season to minimize loss when faced with external weather shocks. Take temperature as an example, we confirm a negative correlation between rice yield and long-term average temperature. High temperature can also be a constraint to rice production in an indirect way because farmers are forced to spend more on irrigation, discouraging fertilizer and other input use.

Although rice production may be reduced because of climate change, the empirical results show that proper agronomical practice and investment in rural infrastructure and human capital can mitigate the negative impact of climate change and help farmers adapt. We notice that instead of directly affecting crop yield, improvement in rural infrastructure can contribute to yield growth indirectly through facilitating intensification. Experiences in other developing countries also indicate that investment in rural infrastructure could enhance both labor productivity and efficiency (Fan, Yu, and Saurkar 2008).

We found a general pattern of positive response to input intensification. However, the results of this analysis highlight the heterogeneity in yield response, which differs starkly across different agroecological conditions and poverty status. Additional irrigation canals may not help boost rice yield in the deltas, while in other regions rice farmers are eager to take advantage of additional irrigation facilities in their communes. The poor generally report lower crop yield because challenging geographic conditions, insufficient road connection and lack of market access may prevent the poor from benefiting from commune irrigation and social services. These results support the argument that the promotion of modern technology and infrastructure probably is an effective instrument to promote productivity and climate change resilience. However, there is no one-size-fit-all solution. Future policies need to be tailored to local conditions to produce high returns to the investment and effective mitigation of climate change.

The result has important implications in policy design to incorporate climate change in poverty reduction and development among ethnic minorities. It suggests that policies addressing any one of the issues need also take the others into consideration because policies to answer one development goal may contribute to achieve others. In short, different goals can be complementary and the formulation of development plans should be viewed in a broader context. Evidence in this paper suggests that policies aiming at increase yield by helping vulnerable groups (ethnic-minority and/or the poor) or focusing on areas with great potential can also contribute to poverty reduction and climate change adaptation. The results have confirmed Swinkels and Turk's conclusion (2006) that development among ethnic minorities through increased agricultural production and productivity is essential to raise incomes and thus reduce both regional and ethnic differences in poverty and welfare.

There are other adaptation options not captured in this study, including investment in agricultural research and development (R&D). The recent stagnation in rice productivity underscores the urgent need for substantial investment in agricultural R&D to reinvigorate agricultural productivity growth, which is known to be the most important source of income and output growth in a land constrained country (Minot, Baulch, and Epprecht 2006; Nin Pratt, Yu, and Fan 2009). Past experience has indicated that government investment in agricultural R&D has the highest impact in agricultural production and poverty reduction, far above education, road, and irrigation. In Vietnam, the economic return is estimated to be 12.22 Dongs for every one Dong used for agricultural R&D (Fan, Hong, and Long 2004). In preparation for future climate change, it is important to invest in agricultural R&D in order to supply farmers with higher input responsive, high-yield, drought- and flood-tolerant crop varieties and highly efficient production practices that are more resilient in adverse soil and weather conditions.

Despite the application of the control function approach, the effects of unobservable factors in the rice yield equation might not have been fully captured. The problem caused by unobservables in the estimation of structural equations using regression can be partly addressed by experimental methods if it is incorporated in the design and analysis (Glewwe et al. 2004).

Appendix. Control function approach

Parameter estimates could be inconsistent if the independent variables are correlated with unobservable factors affecting adoption behavior. We address the potential endogeneity problem by using the control function (CF) approach (Rivers and Vnong 1988). In the standard case where endogenous explanatory variables are linear in parameters, the CF approach leads to the usual 2SLS estimator. But there are differences for models nonlinear in endogenous variables even if they are linear in parameters. The CF approach offers some distinct advantages for models that are nonlinear in parameters because the CF estimator tackles the endogeneity by adding an additional variable to the regression, generating more precise and efficient estimator than the IV estimator (Wooldridge 2008).

The CF approach provides a straightforward two-step procedure to test and control for endogeneity of explanatory variables in modern technology access and demand (Wooldridge 2008). Let y_1 denote the response variable Y^* in Equation (1), y_2 the endogenous explanatory variable (a scalar), and z the vector of exogenous variables including X and M in Equation (1) with unity as its first element. Consider the model

$$y_1 = z_1\delta_1 + a_1 y_2 + u_1, \quad (2)$$

where z_1 is a strict sub-vector of z that also includes a constant, δ_1 and a_1 are parameters to be estimated. The exogeneity of z is given by the orthogonality (zero covariance) conditions

$$E(z'u_1) = 0. \quad (3)$$

The first step in the CF approach is to estimate a reduced form equation of endogenous explanatory variable. Just as in 2SLS, the reduced form of y_2 – that is, the linear projection of y_2 onto the exogenous variables – plays a critical role. Write the reduced form with an error term as

$$y_2 = z\pi_2 + v_2 \quad (4)$$

$$E(z'v_2) = 0,$$

where π_2 are parameters to be estimated. Endogeneity of y_2 arises if and only if u_1 is correlated with v_2. Write the linear projection of u_1 on v_2, in error form, as

$$u_1 = \rho_1 v_2 + e_1, \quad (5)$$

where $\rho_1 = E(v_2 u_1)/E(v_2^2)$ is the population regression coefficient. By definition, $E(v_2 e_1) = 0$ and $E(z'e_1) = 0$ because u_1 and v_2 are both uncorrelated with z.

In the second step, the residuals obtained from the reduced form are used as an additional explanatory variable in the structural model regression of the regression model. Plugging u_1 in Equation (5) into Equation (2) gives

$$y_1 = z_1\delta_1 + a_1 y_2 + \rho_1 v_2 + e_1, \quad (6)$$

where we now view v_2 as an explanatory variable in the equation. As just noted, e_1 is uncorrelated with v_2 and z. Plus, y_2 is a linear function of z and v_2, and so e_1 is also uncorrelated with y_2. This suggests an OLS regression of y_1 on z_1, y_2, and v_2 provides consistent estimates of δ_1 and a_1 (as well as ρ_1), because OLS consistently estimates the parameters in any equation where the error term is uncorrelated with the right hand side variables. However, v_2 is not observable. We can rewrite $v_2 = y_2 - z\pi_2$ and consistently estimate π_2 by OLS and replace v_2 with $\hat{v}_2$, the OLS residuals from the first-stage regression of y_2 on z. Simple substitution gives

$$y_1 = z_1\delta_1 + a_1 y_2 + \rho_1 \hat{v}_2 + \text{error}, \quad (7)$$

where $\text{error}_i = e_{i1} + \rho_1 z_i(\hat{\pi}_2 - \pi_2)$ for each observation i, which depends on the sampling error in $\hat{\pi}_2$ unless $\rho_1 = 0$.

The OLS estimates from Equation (7) are control function estimates, because the inclusion of the residuals $\hat{v}_2$ "controls" for the endogeneity of y_2 in the original equation (although it does so with sampling error because $\hat{\pi}_2 \neq \pi_2$). The OLS estimators are consistent for δ_1, a_1, and ρ_1, and they are identical to the 2SLS estimates of Equation (7) using z as the vector of instruments (Standard errors from Equation (7) must adjust for the generated regressor). We can test endogeneity $H0{:}\ \rho_1 = 0$, as the usual t statistic is asymptotically valid under homoskedasticity ($\text{Var}(u_1|z, y_2) = \sigma_1^2$ under $H0$; or use the heteroskedasticity-robust version (which does not account for the first-stage estimation of π_2).

If the coefficient on the generalized residual is significantly different from zero in the structural model, the explanatory variable of interest, y_2, is endogenous in a farmer's decision to use irrigation. Using the reduced form residual can control for endogeneity of y_2 and produces consistent estimates in the yield equation.

When the function is not linear in the endogenous variable, the CF estimator solves the endogeneity by adding general residual from reduction form regression to the structural regression. The CF estimates are no longer the same as 2SLS estimates, generating more precise estimator than traditional IV estimator (Wooldridge 2008). In addition, the CF approach is likely more efficient than a direct IV approach, but it is less robust due to the orthogonality conditions.

References

ADB (Asian Development Bank). 2006. Vie: Poverty assessment. Strategy and program assessment. Manila, the Philippines: ADB.

Angrist, J. D., and J.-S. Pischke. 2009. Mostly Harmless Econometrics: An Empiricist's Companion. Princeton, NJ: Princeton University Press.

Dasgupta, S., B. Laplante, C. Meisner, D. Wheeler, and J. Yan. 2007. The impact of sea level rise on developing countries: A comparative analysis. World Bank Policy Research Working Paper WPS4136. Washington, D.C.: World Bank.

Doraszelski, U., and J. Jaumandreu. 2009. R&D and productivity: Estimating endogenous productivity. Mimeo. Cambridge, Mass., U.S.A.: Harvard University.

Fan, S., P. L. Huong, and T. Q. Long. 2003. Government spending and poverty reduction in Vietnam. Report prepared for the World Bank.

Fan, S, B. Yu, and A. Saurkar. 2008. Public spending in developing countries: Trends, composition and changes. In Public expenditure, growth and poverty in developing countries: Issues, methods and findings, ed. S. Fan. Baltimore: John Hopkins Publications.

FAO (Food and Agriculture Organization of the United Nations). 2011. FAOSTAT. <http://faostat.fao.org/site/291/default.aspx>. Accessed March 2010. Rome: FAO.

Felipe, J., R. Hasan, and J. S. L. McCombie. 2008. Correcting for biases when estimating production functions: An illusion of the laws of algebra? Cambridge Journal of Economics 32 (3): 441–459.

Glewwe, P., M. Lremer, S. Moulin, E. Zitzetize. 2004. Retrospective vs. prospective analysis of school inputs: The case of flip charts in Kenay. Journal of Development Economics 74: 251-268.

GSO (General Statistics Office of Vietnam). Various years. Statistical yearbook of Vietnam. Hanoi: GSO.

GOV (Government of Vietnam). 2009. Resolution No. 63/NQ-CP dated December 23, 2009 on ensuring national food security, Hanoi, Vietnam

Kirby, M., and M. Mainuddin. 2009. Water and agricultural productivity in the lower Mekong basin: Trends and future prospects. Water International 34 (1): 134–143.

Minot, N., B. Baulch, and M. Epprecht. 2006. Poverty and inequality in Vietnam: Spatial patterns and geographic determinants. Research Report 148. Washington, D.C.: International Food Policy Research Institute.

Nin Pratt, A., B. Yu, and S. Fan. 2009. Comparisons of agricultural productivity growth in China and India. Journal of Productivity Analysis. <http://www.springerlink.com/content/x977174pmh931162/>.

Nguyen, T. 2006. Poverty, poverty reduction and poverty dynamics in Vietnam. Background paper for the Chronic Poverty Report 2008–09. Manchester, U.K.: Chronic Poverty Research Centre.

Nguyen, H. M., B. Yu, and C. Breisinger. 2010. The future of food security in Vietnam under policy and sector development changes. Vietnam Economic Management Review 4 & 5 (1).

Nguyen, H. N., K. T. Vu, and X. N. Nguyen. 2008. Flooding in Mekong River Delta, Vietnam. Human Development Report 2007/2008. Hanoi: United Nations Development Programme.

Rosenzweig, C and D. Hillel. 1995. Potential impact of climate change on agriculture and food supply. Consequence 1(2).

Rivers, D. and Q.H. Vuong. 1988. Limited information estimators and exogeneity tests for simultaneous probit models. Journal of Econometrics 39: 347-366.

Sadoulet, E., and A. de Janvry. 2003. Quantitative development policy analysis. Baltimore: Johns Hopkins University Press.

Shea, J. 1997. Instrument relevance in multivariate linear models: A simple measure. Review of Economics and Statistics 79: 348–352.

Stock, J. H., J. H. Wright, and M. Yogo. 2002. A survey of weak instruments and weak identification in generalized method of moments. Journal of Business and Economic Statistics 20: 518–529.

Stock, J. H., and M. Yogo. 2005. Testing for weak instruments in linear IV regression. In Identification and Inference for Econometric Models: Essays in Honor of Thomas Rothenberg, ed. D. W. K. Andrews and J. H. Stock, 80–108. New York: Cambridge University Press.

Swinkels, R., and C. Turk. 2006. Explaining ethnic minority poverty in Vietnam: A summary of recent trends and current challenges. Background paper for Vietnam Country Economic Memorandum (CEM)/Ministry of Planning and Investment (MPI) meeting on ethnic minority poverty.

Tubiello, F. N. and C. Rosenzweig. 2008. Developing climate change impact metrics for agriculture. The integrated Assessment of Journal 8(1): 165-84.

Vu, L., and P. Glewwe. 2008. Impacts of rising food prices on poverty and welfare in Vietnam. Working Paper Series No. 13. Hanoi, Vietnam: Development and Policies Research Center (DEPOCEN).

Wooldridge, J.M. 2002. Introductory Econometrics: A Modern Approach. Cincinnati, Ohio: The South-Western College Publishing. Thomson Learning.

Wooldridge, J.M. 2007. What’s New in Econometrics? Lecture Notes. National Bureau of Economic Research.

Wooldridge, J. M. 2008. Applied Microeconometrics. Workshop Notes. Madison, Wisconsin.

Zhai, F., and J. Zhuang. 2009. Agricultural impact of climate change: A general equilibrium analysis with special reference to Southeast Asia. Asian Development Bank Institute Working Paper Series 131. Manila, the Philippines: Asian Development Bank.

Zhu, T., and M. V. Trinh. 2010. Climate change impacts on agriculture in Vietnam. In Proceedings of the International Conference on Agricultural Risk and Food Security, June 11–12, 2010, Beijing.

Table 1. Descriptive statistics of VHLSS 2004 and 2006

Variable	2004 Mean	2004 Std. Dev.	2006 Mean	2006 Std. Dev.
Household crop production				
Total area (ha)	1.0	1.2	1.7	2.5
Rice area (ha)	0.7	1.0	1.4	2.5
Share of rice in crop area (%)	73.7	25.8	81.3	21.9
Types of crops (max=4)	2.8	1.0	2.2	0.8
Share of hired labor use (%)	72.3	44.8	71.4	45.2
Share of fertilizer use (%)	49.6	50.0	47.4	49.9
Share of irrigation use (%)	97.1	16.7	97.2	16.4
Inputs for rice production				
Output (ton)	3.4	5.4	6.7	13.3
Yield (ton/ha)	4.7	1.3	4.8	1.2
Labor (man day/ha)	749.5	657.5	486.7	504.3
Share of hired labor in rice labor (%)	4.2	10.2	4.2	10.8
Share of rice using fertilizer (%)	96.5	18.3	96.9	17.4
Fertilizer cost (000 Dong/ha)	1.3	0.7	1.0	0.6
Nitrogen fertilizer (kg/ha)			98.3	82.9
Phosphate fertilizer (kg/ha)			84.2	125.0
Potassium fertilizer (kg/ha)			33.8	47.4
NPK fertilizer (kg/ha)			96.5	139.6
Total fertilizer (kg/ha)			323.8	224.2
Share of rice area under irrigation (%)	72.1	44.9	71.3	45.2
Irrigation cost (000 Dong/ha)	0.3	0.3	0.2	0.2
Share of rice harvest that is sold (%)	24.9	29.6	25.8	30.5
Share of hh. growing only rice (%)	13.5	34.2	20.3	40.2
Household characteristics				
Household size (person)	4.6	1.7	4.5	1.7
Share of male head (%)	83.5	37.1	83.2	37.4
Head age (year)	47.9	13.5	48.0	13.0
Head grade (year)	7.0	3.0	7.0	3.0
Share of married head (%)	85.6	35.1	86.3	34.4
Share of minority head (%)	23.3	42.3	23.7	42.6
Share of poor households (%)	49.3	50.0	38.0	48.5
Commune characteristics				
Share of irrigated crop land (%)	69.7	33.6	71.2	33.1
Share of electricity access (%)	97.4	16.0	98.5	12.0
Distance to bus stop (km)	3.0	5.6	3.2	7.7
Distance to market (km)	3.7	9.6	3.8	10.4
Distance to extension station (km)	0.7	1.1	0.8	1.2
Share of being poor (%)	0.0	0.1	0.0	0.5
Share of being remote (%)	11.1	11.1	10.9	10.7
Share of infrastructure program (%)	22.5	41.7	20.8	40.6

Climate factor				
Average annual precipitation (mm)	1757.3	203.4	1755.1	201.1
Variability of annual precipitation (mm)	292.0	68.0	293.0	67.6
Average annual temperature (degree)	23.9	2.0	23.9	2.0
Variability of annual temperature (degree)	0.4	0.1	0.4	0.1
Number of flood events over the past 3 years (time)	0.3	0.6	0.3	0.6
Number of flood events in this year (time)	0.1	0.2	0.0	0.2
Number of typhoons over the past 3 years (time)	0.2	0.4	0.3	0.6
Number of typhoons in this years (time)	0.1	0.2	0.0	0.2
Number of droughts over the past 3 years (time)	0.2	0.5	0.2	0.5
Number of droughts in this years (time)	0.0	0.2	0.0	0.2

Source: Authors’ calculation based on VHLSS 2004 and 2006.

Table 2. Factors to determine rice yield, endogenous input demand and sample selection equations

	Yield	Endogenous input demand			Sample
		Irrigation	Fertilizer	Hired labor	selection
Inputs for rice production (per hectare)					
family labor	X	X	X	X	X
hired labor	X	X	X	X	X
fertilizer expense	X	X	X	X	X
irrigation expense	X	X	X	X	X
machine rent expense		X	X	X	X
chemical expense		X	X	X	X
share of sale in total harvest	X	X	X	X	X
share of rice in total crop area	X	X	X	X	X
Household characteristics					
male	X	X	X	X	X
age	X	X	X	X	X
grade	X	X	X	X	X
marital status	X	X	X	X	X
being minority	X	X	X	X	X
being a poor household	X	X	X	X	X
per capita household income		X	X	X	X
literacy		X	X	X	X
household size		X	X	X	X
Commune characteristics					
share of irrigated annual crop land	X	X	X	X	X
having power supply	X	X	X	X	X
distance to nearest market	X	X	X	X	X
distance to nearest extension	X	X	X	X	X
distance to nearest stop		X	X	X	X
being a poor commune	X	X	X	X	X
being a remote commune		X	X	X	X
having infrastructure program		X	X	X	X
year dummy	X	X	X	X	X
Climate factor					
average precipitation	X	X	X	X	X
average temperature	X	X	X	X	X
variation of precipitation	X	X	X	X	X
variation of temperature	X	X	X	X	X
flood over the past 3 years	X	X	X	X	X
typhoon over the past 3 years	X	X	X	X	X
drought over the past 3 years	X	X	X	X	X
flood over the past year	X	X	X	X	X
typhoon over the past year	X	X	X	X	X
drought over the past year	X	X	X	X	X
Control variables					

hired labor residual	X
fertilizer residual	X
irrigation residual	X
inverse of the Mills ratio	X
interact terms	X

Table 3. Estimation results for endogenous input functions and sample selection function

	Endogenous input			Sample
	Hired labor	Fertilizer	Irrigation	selection
Inputs for rice production				
family labor	-0.47	0.06	-0.01	0.46
	(0.03)***	(0.01)***	(0.02)	(0.04)***
chemical	0.09	0.21	0.11	0.13
	(0.03)***	(0.02)***	(0.02)***	(0.00)***
rent	0.07	0.02	0.09	0.14
	(0.02)***	(0.01)***	(0.01)***	(0.00)***
share of sale in total rice harvest	0.06	0.01	0.03	0.05
	(0.01)***	(0.00)***	(0.01)***	(0.00)***
share of rice in total crop area	0.89	-0.18	0.46	
	(0.14)***	(0.07)***	(0.08)***	
Household characteristics				
male	0.14	0.00	-0.09	0.04
	(0.15)	(0.04)	(0.07)	(0.03)
age	0.02	0.00	0.00	-0.00
	(0.00)***	(0.00)***	(0.00)	(0.00)***
grade	0.02	0.02	0.01	-0.01
	(0.02)	(0.01)***	(0.01)	(0.00)*
marital status	0.01	0.07	-0.08	0.01
	(0.13)	(0.03)**	(0.05)	(0.03)
being minority	0.00	-0.22	-1.10	0.44
	(0.19)	(0.06)***	(0.14)***	(0.04)***
being a poor household	-0.13	-0.01	0.00	-0.02
	(0.12)	(0.03)	(0.05)	(0.02)
per capita household income	0.99	0.07	0.12	0.11
	(0.11)***	(0.03)***	(0.05)**	(0.03)***
household size	-0.06	-0.06	0.05	0.07
	(0.13)	(0.04)*	(0.06)	(0.03)**
literate	0.27	0.40	-0.11	-0.02
	(0.19)	(0.10)***	(0.09)	(0.04)
Commune characteristics				
share of irrigated annual crop land	-0.01	0.03	0.07	-0.00
	(0.02)	(0.01)***	(0.01)***	(0.00)
having power supply	-1.14	1.54	-0.43	-0.55
	(0.52)**	(0.32)***	(0.26)	(0.07)***
distance to nearest market	-0.03	-0.01	-0.03	-0.00
	(0.02)*	(0.00)***	(0.01)***	(0.00)
distance to nearest extension	-0.05	-0.01	-0.00	-0.00
	(0.02)**	(0.01)	(0.01)	(0.01)
distance to nearest transportation	-0.20	-0.33	-0.66	0.23
	(0.20)	(0.07)***	(0.14)***	(0.05)***
being a poor commune	0.43	-0.12	-0.44	0.07
	(0.18)**	(0.06)*	(0.12)***	(0.05)
being a remote commune	-0.00	-0.01	-0.01	-0.01

	(0.01)	(0.00)	(0.01)	(0.00)*
having infrastructure program	-0.16	0.02	-0.10	0.01
	(0.12)	(0.03)	(0.06)*	(0.02)
Climate factor				
average precipitation	-0.03	0.00	0.01	0.00
	(0.01)***	(0.00)	(0.01)**	(0.00)
average temperature	0.00	0.05	0.21	0.04
	(0.08)	(0.03)	(0.05)***	(0.02)**
variation of precipitation	0.01	-0.00	0.01	-0.00
	(0.00)***	(0.00)***	(0.00)***	(0.00)
variation of temperature	-1.22	0.14	1.03	-0.10
	(0.14)***	(0.04)***	(0.08)***	(0.03)***
drought over the past 3 years	-0.38	0.02	0.01	0.02
	(0.15)**	(0.06)	(0.08)	(0.03)
flood over the past 3 years	0.03	0.05	0.11	-0.04
	(0.11)	(0.03)*	(0.06)**	(0.02)*
typhoon over the past 3 years	0.14	0.03	-0.15	-0.03
	(0.12)	(0.04)	(0.07)**	(0.03)
drought over the past year	1.16	0.12	0.04	-0.14
	(0.40)***	(0.13)	(0.21)	(0.07)*
flood over the past year	-0.56	-0.08	-0.18	0.02
	(0.25)**	(0.08)	(0.13)	(0.05)
typhoon over the past year	-0.30	0.09	0.13	0.10
	(0.27)	(0.09)	(0.17)	(0.06)*
Constant	-1.73	-3.61	-16.29	-2.60
	(3.13)	(1.08)***	(1.80)***	(0.73)***
Observations	9124	9124	9124	25579
R^2/Pseudo R^2	0.28	0.41	0.51	0.44
F/χ^2 test for all instruments=0	126.77	19.34	144.07	4543
p-value of F/χ^2 test for all instruments=0	0	0	0	0
Partial R^2on excluded instruments	0.03	0.15	0.06	0.08
F test for excluded instruments=0	20.97	168.34	53.43	48.45
p-value of F/χ^2 test for excluded instruments=0	0.00	0.00	0.00	0.00

Source: Authors' estimation based on VHLSS 2004 and 2006.

Note: Endogenous inputs are estimated using OLS and sample selection equation is estimated using MLE probit model, assuming possible correlation within commune. Variable rice land share is dropped due to perfect predictability in selection equation. All continuous variables are expressed in logarithm terms. Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

Table 4. Estimation results of rice yield function

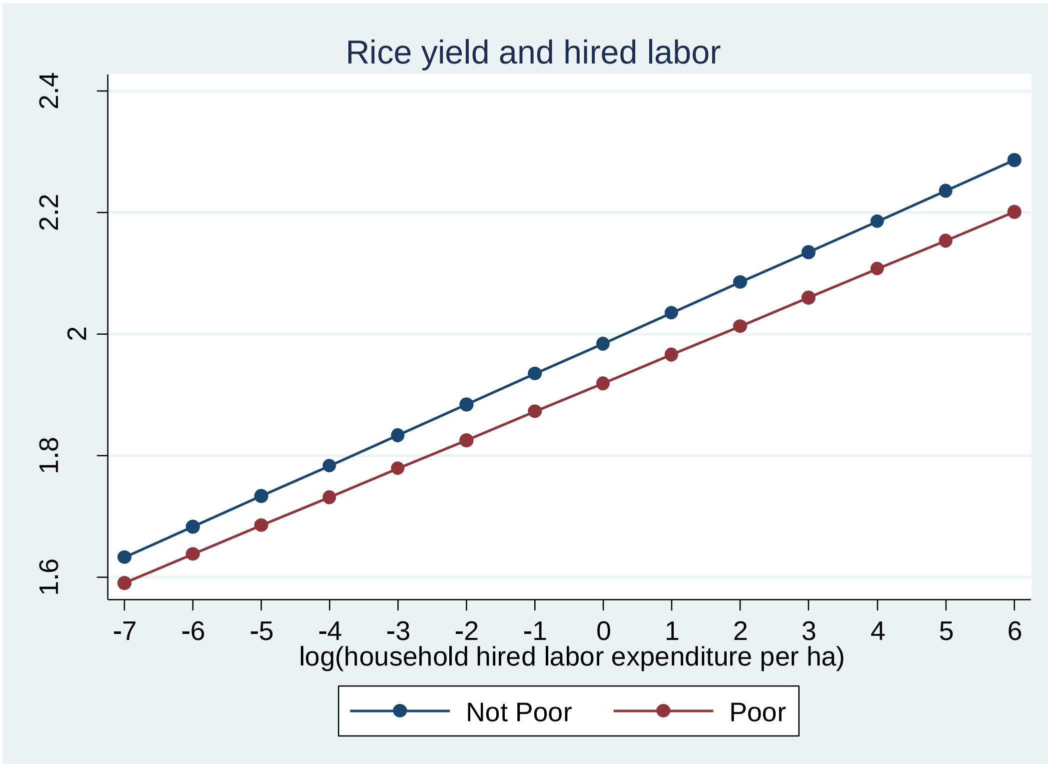
	OLS	2SLS	Heckman		
Dep. var. = Rice yield	(1)	(2)	(3)	(4)	(5)
Inputs for rice production					
family labor	0.013	0.035	0.048	0.045	0.044
	(0.00)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***
hired labor	0.005	0.050	0.053	0.054	0.055
	(0.00)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***
fertilizer	0.099	0.127	0.128	0.152	0.161
	(0.01)***	(0.02)***	(0.02)***	(0.02)***	(0.02)***
irrigation	0.031	0.046	0.069	0.067	0.063
	(0.00)***	(0.02)***	(0.02)***	(0.02)***	(0.02)***
share of rice in total crop land	-0.046	-0.092	-0.104	-0.098	-0.094
	(0.01)***	(0.02)***	(0.02)***	(0.02)***	(0.02)***
share of sale in total rice harvest	0.007	0.003	0.003	0.003	0.003
	(0.00)***	(0.00)***	(0.00)***	(0.00)***	(0.00)***
Household characteristics					
male	0.011	0.011	0.014	0.012	0.012
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
age	0.000	-0.001	-0.002	-0.001	-0.001
	(0.00)	(0.00)***	(0.00)***	(0.00)***	(0.00)***
grade	0.004	-0.000	-0.001	0.000	0.000
	(0.00)***	(0.00)	(0.00)	(0.00)	(0.00)
marital status	-0.014	-0.012	-0.010	-0.009	-0.009
	(0.01)*	(0.01)	(0.01)	(0.01)	(0.01)
being minority	-0.024	0.031	0.065	0.058	0.059
	(0.01)*	(0.03)	(0.03)**	(0.03)*	(0.03)*
being a poor household	-0.021	0.015	0.017	0.017	0.020
	(0.01)***	(0.01)	(0.01)**	(0.01)**	(0.03)
Commune characteristics					
share of irrigated annual crop land	0.006	0.004	0.002	0.004	0.002
	(0.00)***	(0.00)**	(0.00)	(0.00)*	(0.00)
having power supply	0.061	0.052	0.049	0.038	0.048
	(0.05)	(0.07)	(0.06)	(0.06)	(0.06)
distance to nearest market	-0.003	-0.001	0.000	-0.000	-0.000
	(0.00)***	(0.00)	(0.00)	(0.00)	(0.00)
distance to nearest extension	0.000	0.003	0.003	0.002	0.002
	(0.00)	(0.00)	(0.00)*	(0.00)	(0.00)
being a poor commune	-0.064	-0.022	0.004	-0.008	-0.007
	(0.01)***	(0.02)	(0.02)	(0.02)	(0.02)
Climate factor					
average precipitation	0.000	0.002	0.002	0.002	0.002
	(0.00)	(0.00)*	(0.00)**	(0.00)***	(0.00)***
average temperature	-0.015	-0.021	-0.025	-0.019	-0.020
	(0.01)**	(0.01)**	(0.01)***	(0.01)***	(0.01)***
variation of precipitation	-0.000	-0.001	-0.001	-0.001	-0.001
	(0.00)	(0.00)**	(0.00)***	(0.00)***	(0.00)***
variation of temperature	-0.002	0.043	0.021	0.040	0.039

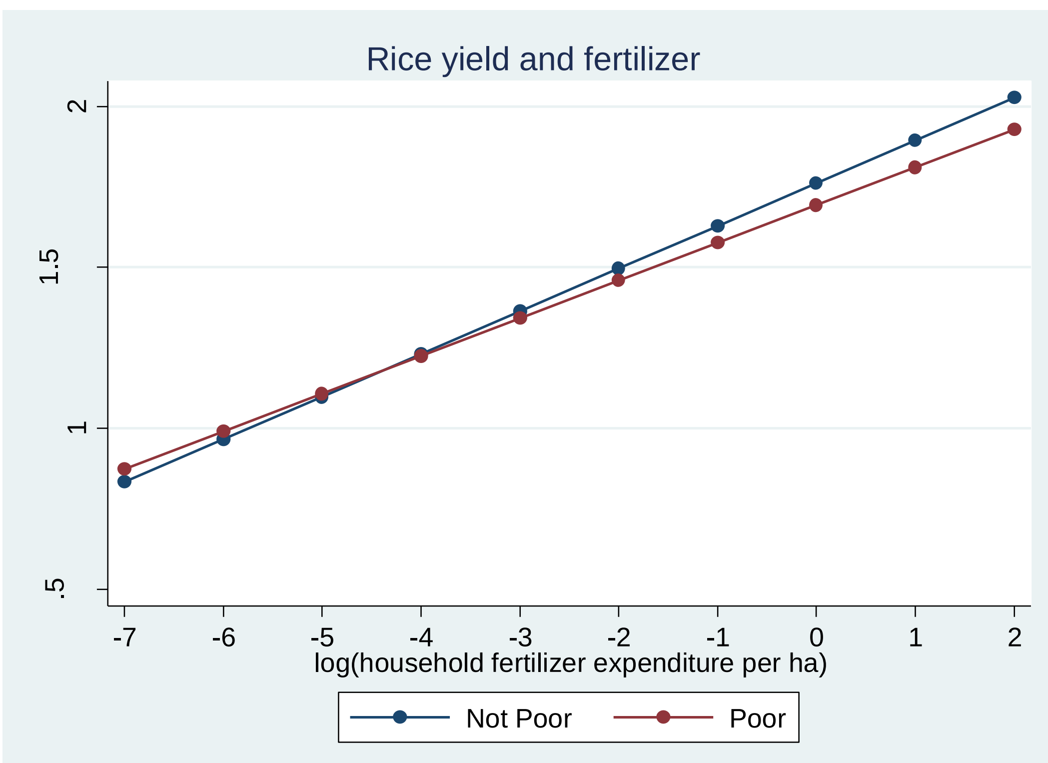
	(0.01)	(0.03)	(0.03)	(0.03)	(0.03)
drought over the past 3 years	-0.023	-0.004	-0.003	0.002	0.002
	(0.01)**	(0.01)	(0.01)	(0.01)	(0.01)
flood over the past 3 years	0.022	0.017	0.013	0.015	0.015
	(0.01)***	(0.01)**	(0.01)**	(0.01)**	(0.01)**
typhoon over the past 3 years	0.008	0.004	0.007	0.007	0.006
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
drought over the past year	0.072	0.010	0.003	0.006	0.006
	(0.02)***	(0.03)	(0.02)	(0.02)	(0.02)
flood over the past year	-0.031	0.001	0.008	0.004	0.006
	(0.02)*	(0.02)	(0.02)	(0.02)	(0.02)
typhoon over the past year	0.022	0.027	0.026	0.027	0.026
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Predicted/pseudo residuals					
hired labor residual			-0.049	-0.051	-0.054
			(0.01)***	(0.01)***	(0.01)***
fertilizer residual			-0.039	-0.001	-0.029
			(0.02)**	(0.02)	(0.02)
irrigation residual			-0.040	-0.016	-0.016
			(0.02)*	(0.02)	(0.02)
inverse of the Mills ratio			0.037	0.021	0.021
			(0.02)	(0.02)	(0.02)
Residual interactions					
irrigation X its residual				0.005	0.005
				(0.00)***	(0.00)***
fertilizer X its residual				0.016	0.016
				(0.00)***	(0.00)***
hired labor X its residual				-0.001	-0.001
				(0.00)*	(0.00)
poor X hired labor					-0.003
					(0.00)
poor X hired labor residual					0.007
					(0.00)*
poor X hired labor X hired labor residual					0.000
					(0.00)
poor X fertilizer					-0.014
					(0.02)
poor X fertilizer residual					0.048
					(0.02)***
poor X fertilizer X fert. residual					0.001
					(0.00)
poor X hh irrigation					0.010
					(0.01)
poor X hh irrigation residual					-0.000
					(0.01)
poor X hh irr. X irr. residual					0.002
					(0.00)
poor X commune irrigation					0.002
					(0.00)

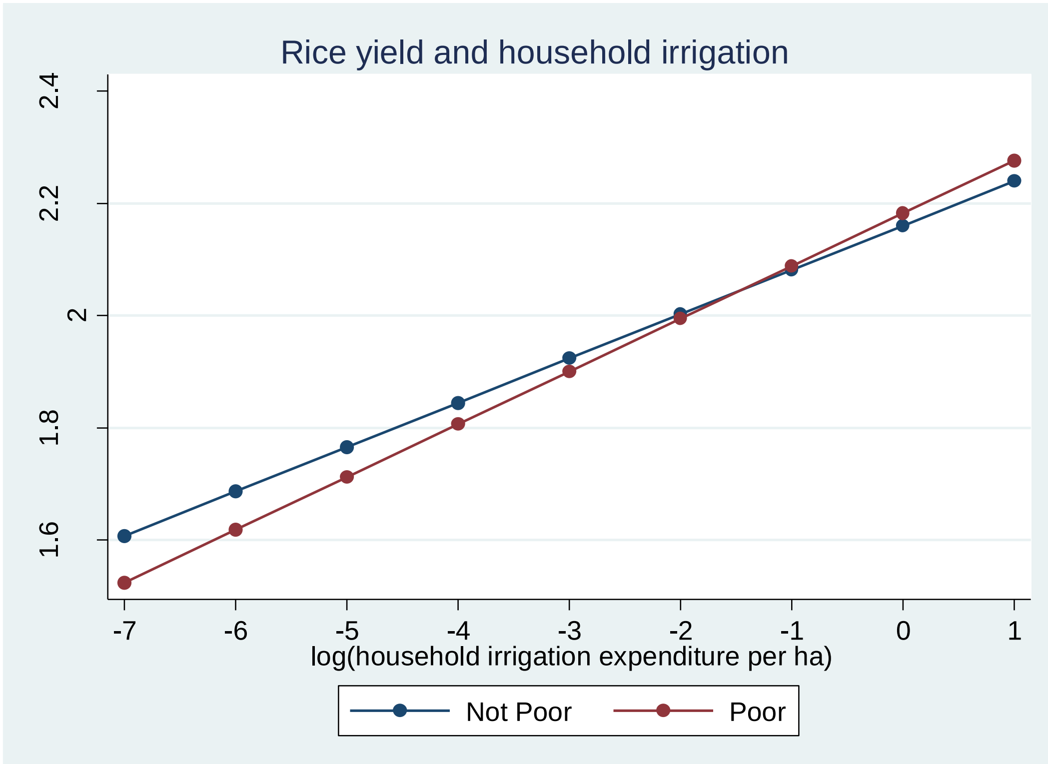
Constant	2.046	2.149	2.393	2.102	2.114
	(0.24)***	(0.41)***	(0.39)***	(0.38)***	(0.38)***
Observations	9124	9124	25579	25579	25579
R^2/Log likelihood	0.46	0.12	-9339	-9175	-9147
P-value of F/χ^2 test for joint coefficients=0	0.00	0.00	0.00	0.00	0.00
Eigenvalue test of weak instruments		12.15			
F statistic of endogeneity of instruments		42.52			
P-value of endogeneity of instruments		0.00			
rho (correlation of yield residual with sample selection residual)			0.000	0.000	0.000
			(0.01)	(0.01)	(0.01)
sigma (sigma of rice yield)			0.244	0.239	0.239
			(0.01)	(0.01)	(0.01)
p-value of Wald test of indep. eqns. (rho = 0)			0.999	0.999	0.999

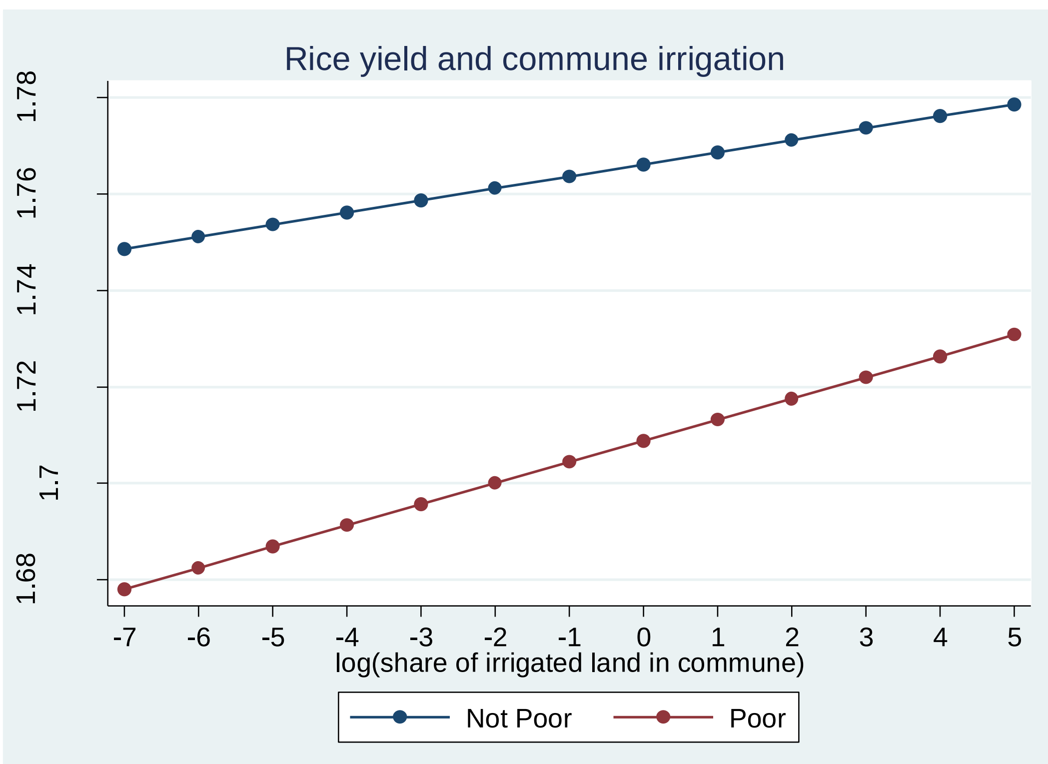
Source: Authors' calculation based on VHLSS 2004 and 2006.
Note: Assume possible correlation within commune. All continuous variables are expressed in logarithm terms. Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

Figure 1. Elasticity of rice yield to inputs



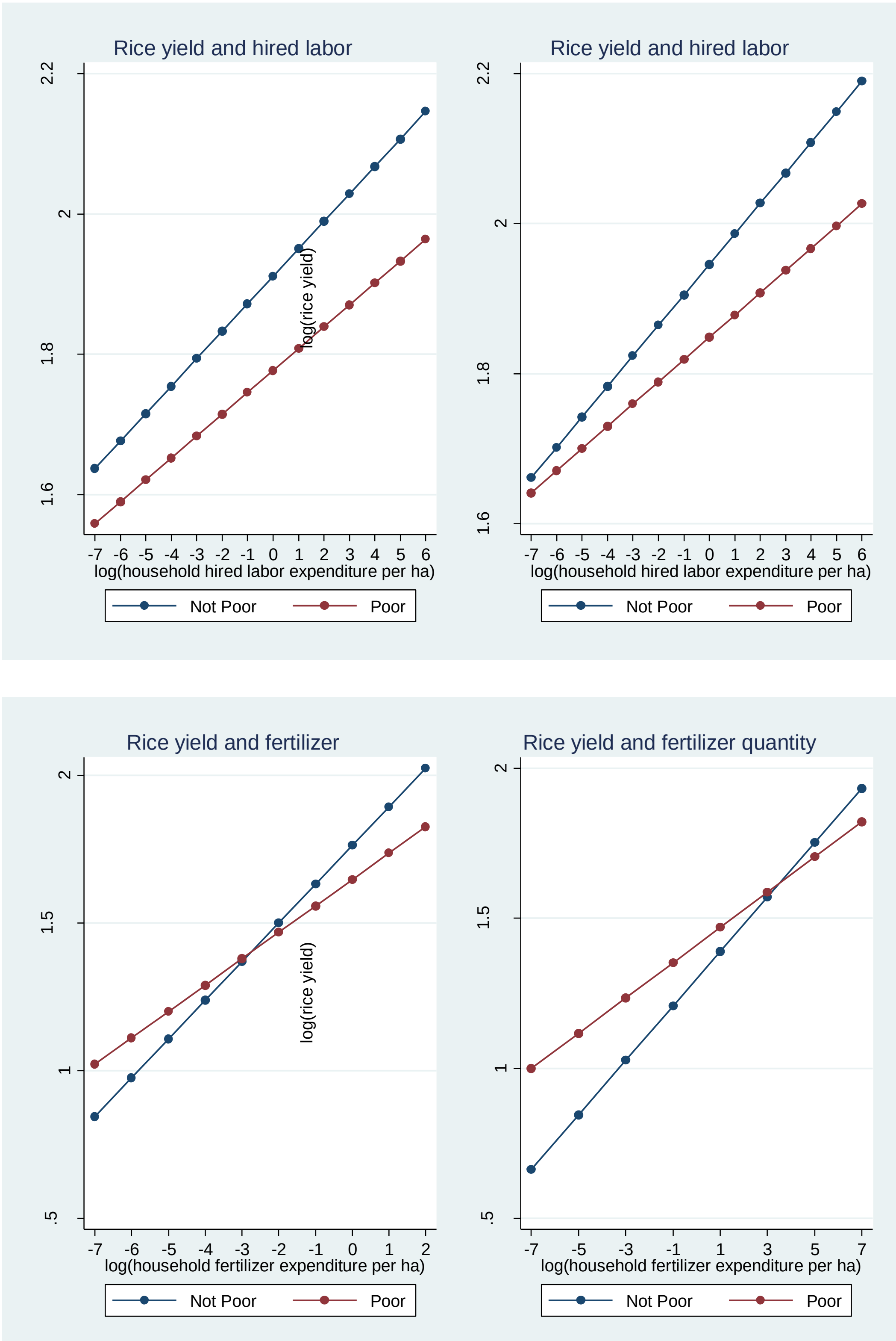


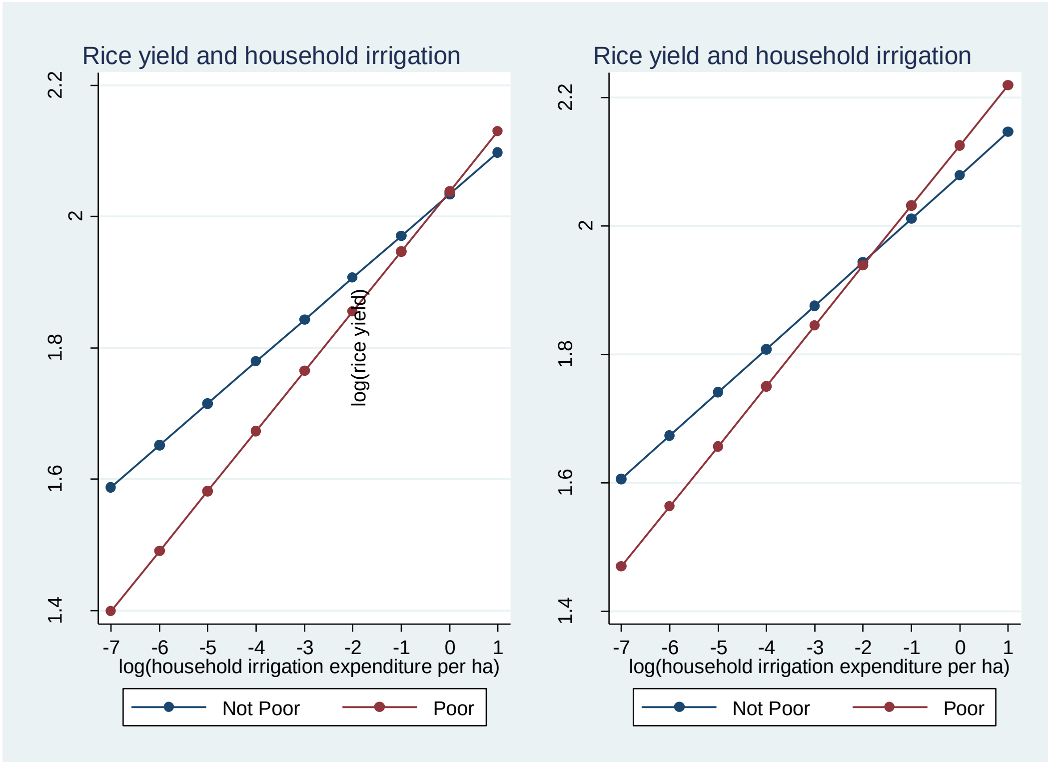


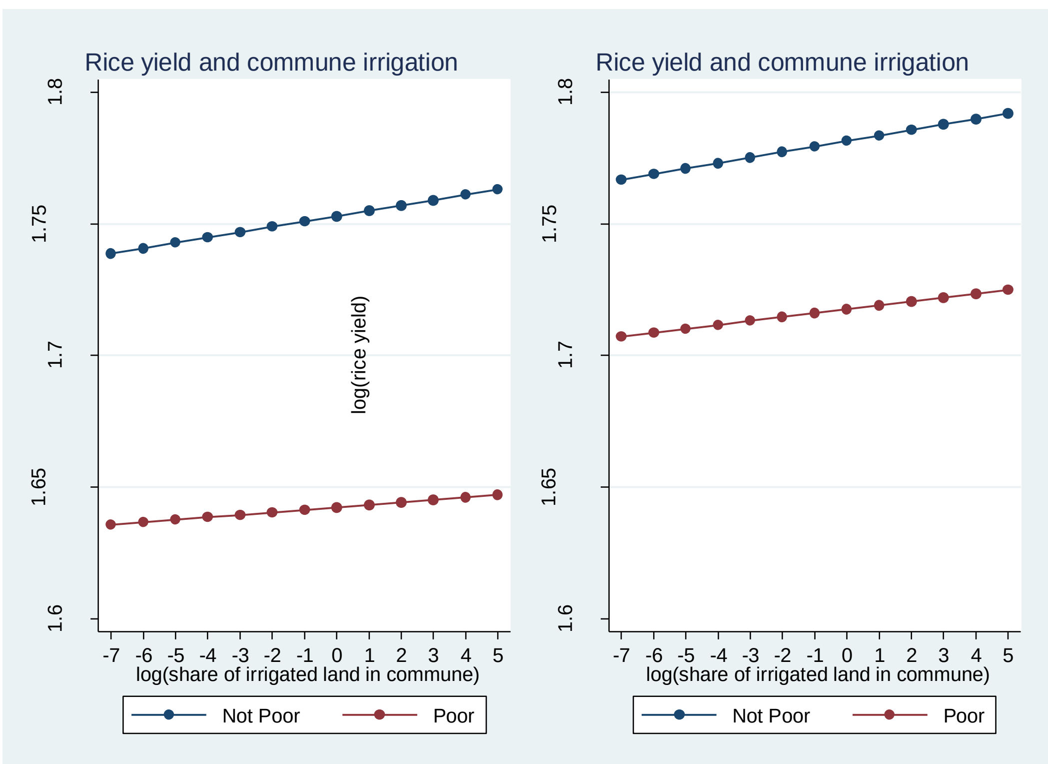


Source: Author's estimation using VHLSS 2004 and 2006.

Figure 2. Elasticities of rice yield to inputs, left figure based on fertilizer value and right figure on fertilizer quantity

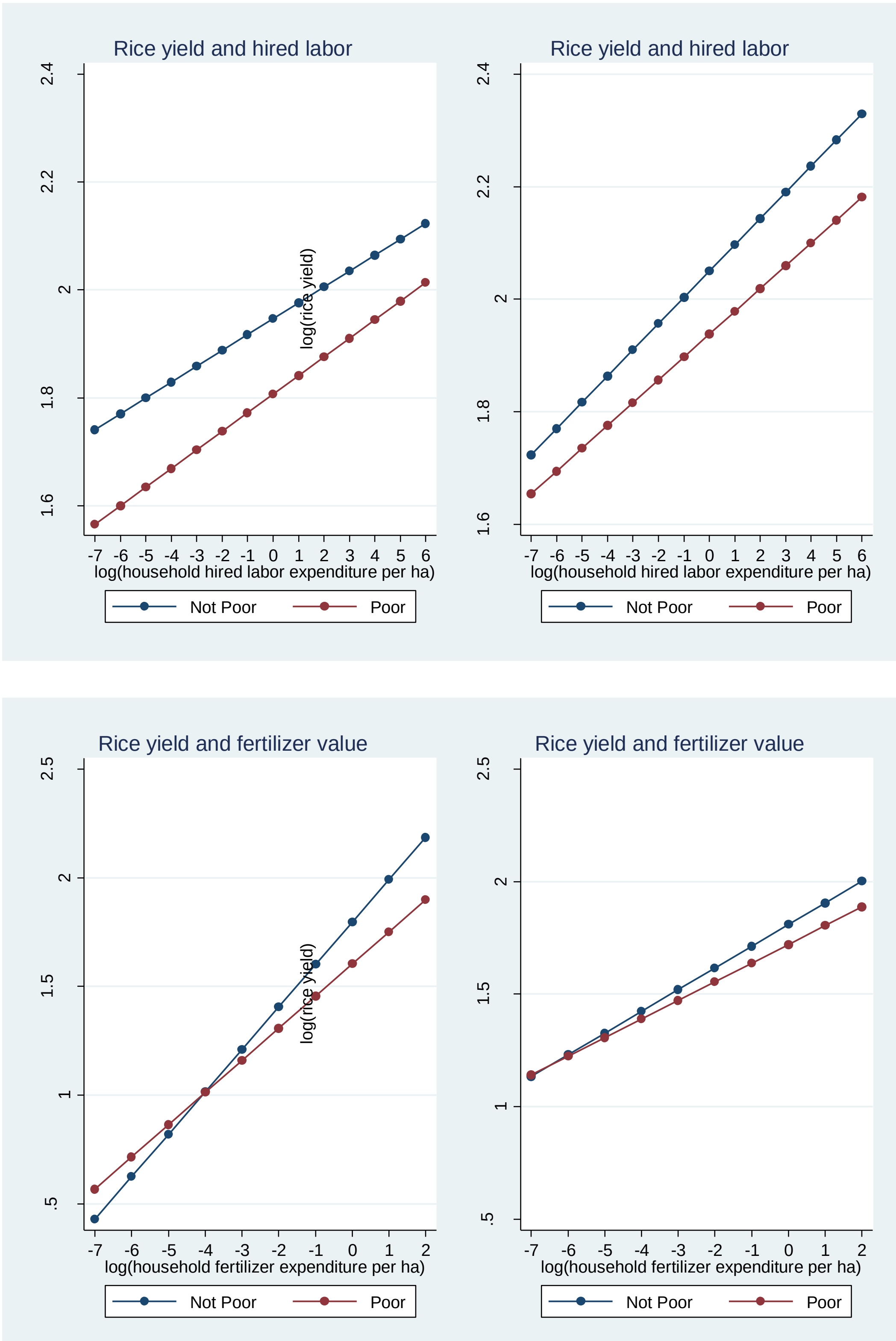


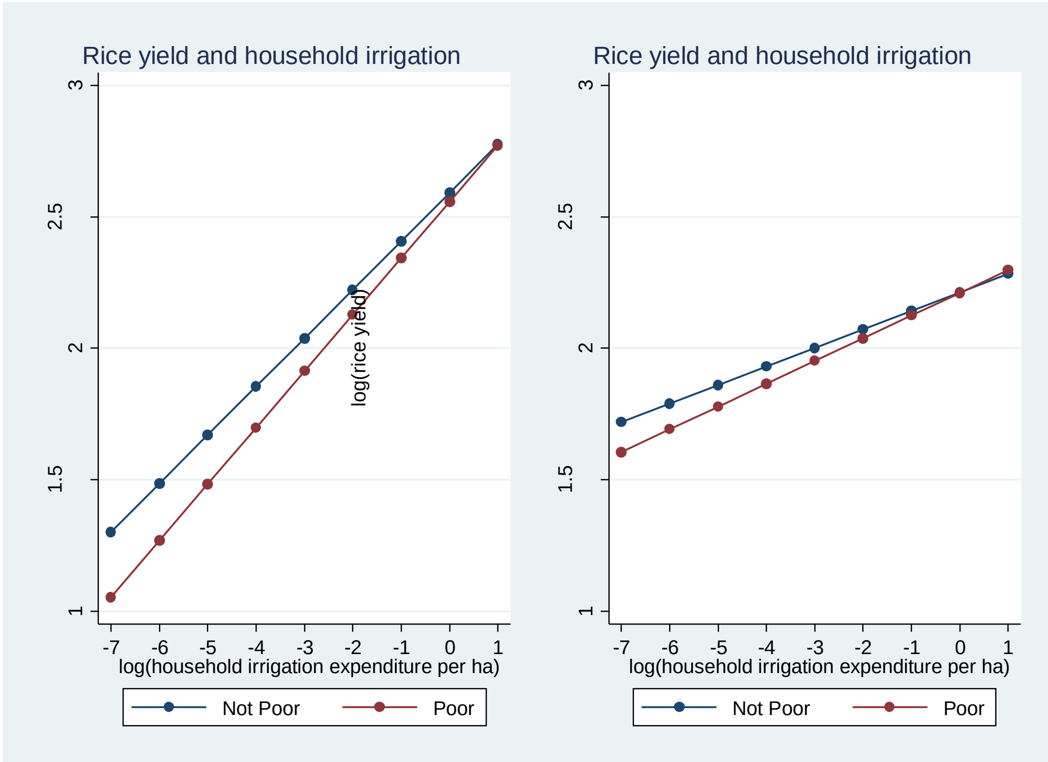


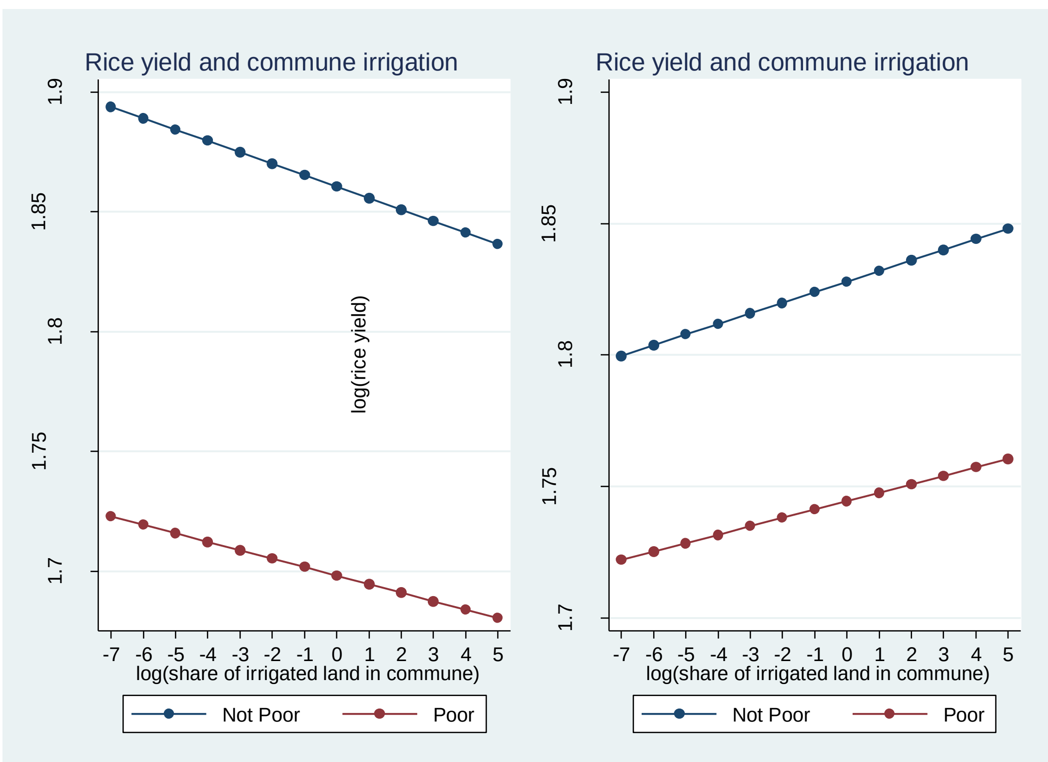


Source: Authors' estimation based on VHLSS 2006.
Note: The graphs are based on the model with three-way interactions.

Figure 3. Elasticity of rice yield to inputs, left figure based on delta zones and right figure on other agroecological zones







Source: Authors' estimation based on VHLSS 2004 and 2006.
Note: The graphs are based on the model with three-way interactions.

Appendix Table 1. Comparison of estimation results using fertilizer expense and quantity in 2006

	Fertilizer demand		Heckman basic		Heckman interaction		Heckman pov. inter.	
Dep. var. = Rice yield	expense	quantity	expense	quantity	expense	quantity	expense	quantity
Inputs for rice production								
family labor	0.07	0.09	0.028	0.028	0.027	0.028	0.029	0.030
	(0.01)***	(0.03)***	(0.01)**	(0.01)**	(0.01)**	(0.01)**	(0.01)**	(0.01)**
hired labor			0.039	0.039	0.040	0.040	0.042	0.044
			(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***
fertilizer			0.125	0.074	0.138	0.092	0.149	0.102
			(0.02)***	(0.01)***	(0.02)***	(0.02)***	(0.03)***	(0.02)***
irrigation			0.049	0.044	0.053	0.052	0.055	0.058
			(0.03)*	(0.03)	(0.03)*	(0.03)*	(0.03)**	(0.03)**
share of rice in total crop land			-0.059	-0.068	-0.055	-0.064	-0.055	-0.065
			(0.02)***	(0.02)***	(0.02)***	(0.02)***	(0.02)***	(0.02)***
share of sale in total rice harvest	0.02	0.03	0.001	0.002	0.002	0.002	0.001	0.002
	(0.00)***	(0.01)***	(0.00)	(0.00)	(0.00)	(0.00)*	(0.00)	(0.00)
Household characteristics								
male	0.02	0.06	0.004	0.001	0.002	-0.001	0.005	0.003
	(0.04)	(0.09)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
age	0.00	0.01	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
	(0.00)**	(0.00)***	(0.00)***	(0.00)***	(0.00)**	(0.00)**	(0.00)***	(0.00)***
grade	0.01	0.02	-0.001	-0.001	0.000	-0.000	0.000	-0.000
	(0.01)*	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
marital status	0.06	0.10	-0.022	-0.022	-0.022	-0.022	-0.018	-0.017
	(0.04)	(0.07)	(0.01)**	(0.01)**	(0.01)**	(0.01)**	(0.01)*	(0.01)*
being minority	-0.20	-0.20	0.059	0.043	0.057	0.047	0.077	0.070
	(0.07)***	(0.12)*	(0.05)	(0.05)	(0.04)	(0.05)	(0.04)*	(0.04)*
being a poor household	-0.08	-0.08	0.011	0.009	0.008	0.007	0.084	0.282
	(0.04)*	(0.09)	(0.01)	(0.01)	(0.01)	(0.01)	(0.04)**	(0.12)**
Commune characteristics								
share of irrigated annual crop land	0.03	0.05	0.004	0.004	0.004	0.004	0.002	0.002
	(0.01)***	(0.02)**	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
having power supply	1.91	3.59	0.167	0.141	0.146	0.097	0.229	0.196
	(0.46)***	(0.89)***	(0.09)*	(0.10)	(0.09)	(0.10)	(0.09)**	(0.09)**
distance to nearest market	-0.02	-0.04	-0.001	-0.001	-0.001	-0.001	-0.000	-0.000

	(0.00)***	(0.01)***	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
distance to nearest extension	-0.01	-0.02	0.003	0.002	0.002	0.002	0.002	0.002
	(0.01)	(0.02)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
being a poor commune	-0.17	-0.51	-0.037	-0.048	-0.039	-0.046	-0.024	-0.029
	(0.08)**	(0.17)***	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Climate factor								
average precipitation	-0.00	-0.01	0.002	0.002	0.002	0.002	0.002	0.002
	(0.00)	(0.01)	(0.00)**	(0.00)**	(0.00)**	(0.00)**	(0.00)**	(0.00)**
average temperature	0.01	0.00	-0.006	-0.005	-0.006	-0.005	-0.007	-0.006
	(0.04)	(0.07)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
variation of precipitation	-0.00	-0.00	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
	(0.00)**	(0.00)	(0.00)*	(0.00)*	(0.00)*	(0.00)*	(0.00)**	(0.00)**
variation of temperature	0.05	0.22	0.044	0.038	0.050	0.041	0.037	0.025
	(0.05)	(0.10)**	(0.03)	(0.03)	(0.03)*	(0.03)	(0.03)	(0.03)
drought over the past 3 years	0.01	0.08	-0.017	-0.022	-0.013	-0.016	-0.016	-0.018
	(0.08)	(0.14)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
flood over the past 3 years	0.03	-0.02	0.022	0.027	0.021	0.026	0.018	0.023
	(0.03)	(0.06)	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)**	(0.01)***
typhoon over the past 3 years	0.01	-0.02	-0.015	-0.013	-0.012	-0.012	-0.005	-0.005
	(0.04)	(0.08)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
drought over the past year	0.20	0.47	0.026	0.016	0.029	0.021	0.025	0.018
	(0.14)	(0.26)*	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
flood over the past year	0.07	0.16	-0.035	-0.038	-0.035	-0.035	-0.029	-0.028
	(0.11)	(0.20)	(0.02)	(0.02)	(0.03)	(0.02)	(0.02)	(0.02)
typhoon over the past year	0.15	0.19	0.052	0.058	0.052	0.056	0.034	0.037
	(0.11)	(0.24)	(0.02)**	(0.02)**	(0.02)**	(0.02)**	(0.02)	(0.02)*
Predicted/pseudo residuals								
hired labor residual			-0.036	-0.036	-0.039	-0.039	-0.043	-0.045
			(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***
fertilizer residual			-0.038	-0.030	-0.016	-0.036	-0.051	-0.061
			(0.02)*	(0.01)**	(0.02)	(0.01)***	(0.02)**	(0.02)***
irrigation residual			-0.022	-0.016	-0.007	-0.004	-0.019	-0.018
			(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
inverse of the Mills ratio			0.016	0.010	0.006	0.002	0.028	0.025
			(0.04)	(0.04)	(0.04)	(0.04)	(0.03)	(0.03)

Residual interactions						
irrigation X its residual			0.004	0.005	0.003	0.004
			(0.00)***	(0.00)***	(0.00)*	(0.00)**
fertilizer X its residual			0.009	0.004	0.011	0.005
			(0.00)***	(0.00)***	(0.00)***	(0.00)***
hired labor X its residual			-0.001	-0.001	-0.001	-0.001
			(0.00)***	(0.00)***	(0.00)	(0.00)
poor X hired labor					-0.003	-0.006
					(0.00)	(0.00)
poor X hired labor residual					0.007	0.010
					(0.00)	(0.00)**
poor X hired labor X hired labor residual					-0.001	-0.001
					(0.00)	(0.00)
poor X fertilizer					-0.047	-0.037
					(0.02)*	(0.02)**
poor X fertilizer residual					0.068	0.049
					(0.02)***	(0.02)***
poor X fertilizer X fert. residual					-0.004	-0.002
					(0.00)	(0.00)
poor X hh irrigation					0.023	0.023
					(0.01)**	(0.01)**
poor X hh irrigation residual					-0.006	-0.009
					(0.01)	(0.01)
poor X hh irr. X irr. residual					0.002	0.001
					(0.00)	(0.00)
poor X commune irrigation					-0.001	-0.001
					(0.00)	(0.00)
Excluded instruments						
chemical	0.18	0.30				
	(0.02)***	(0.05)***				
rent	0.03	0.04				
	(0.01)***	(0.01)***				
per capita household income	0.06	0.15				
	(0.04)*	(0.07)**				

household size	-0.09	-0.10						
	(0.04)**	(0.08)						
literate	0.45	0.87						
	(0.12)***	(0.24)***						
distance to nearest transportation	-0.36	-0.41						
	(0.08)***	(0.16)**						
being a remote commune	-0.00	0.00						
	(0.01)	(0.01)						
having infrastructure program	0.01	0.10						
	(0.04)	(0.08)						
Constant	-1.89	0.95	1.691	1.316	1.665	1.230	1.646	1.178
	(1.40)	(2.65)	(0.40)***	(0.43)***	(0.40)***	(0.43)***	(0.37)***	(0.40)***
Observations	4525	4525	11055	11055	11055	11055	11039	11039
R^2/Log likelihood	0.39	0.33	-2880.24	-2897	-2844.74	-2853.83	-2465.14	-2486.14
P-value of F/χ^2 test for joint coefficients=0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Partial R^2 on excluded instruments	0.03	0.08						
Eigenvalue test of weak instruments	7.40	7.29						
P-value of endogeneity of excluded instruments	0.00	0.00						
rho (correlation of yield residual with sample selection residual)			-0.081	-0.084	-0.077	-0.077	-0.026	-0.024
			(0.05)	(0.05)	(0.05)	(0.05)	(0.04)	(0.04)
sigma (sigma of rice yield)			0.239	0.240	0.237	0.237	0.221	0.222
			(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(0.00)
p-value of Wald test of indep. eqns. (rho = 0)			0.105	0.122	0.132	0.153	0.538	0.538

Source: Authors' estimation based on VHLSS 2006.

Note: Assume possible correlation within commune. All continuous variables are expressed in logarithm terms. Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

Appendix Table 2. Comparison of estimation results for delta and non-delta agroecological zones

	2SLS		Heckman basic		Heckman interaction		Heckman pov. inter.	
Dep. var. = Rice yield	delta	non-delta	delta	non-delta	delta	non-delta	delta	non-delta
Inputs for rice production								
family labor	0.020	0.042	0.031	0.087	0.030	0.076	0.021	0.074
	(0.01)**	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***
hired labor	0.032	0.035	0.032	0.049	0.033	0.048	0.032	0.048
	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***
fertilizer	0.236	0.111	0.231	0.119	0.263	0.140	0.205	0.145
	(0.08)***	(0.02)***	(0.05)***	(0.02)***	(0.05)***	(0.02)***	(0.06)***	(0.02)***
irrigation	0.157	0.040	0.211	0.068	0.201	0.066	0.164	0.058
	(0.06)***	(0.02)*	(0.04)***	(0.02)***	(0.04)***	(0.02)***	(0.04)***	(0.02)***
share of rice in total crop land	-0.112	-0.082	-0.133	-0.102	-0.117	-0.093	-0.105	-0.087
	(0.05)**	(0.02)***	(0.03)***	(0.02)***	(0.03)***	(0.02)***	(0.03)***	(0.02)***
share of sale in total rice harvest	0.003	0.003	0.005	0.002	0.005	0.002	0.003	0.002
	(0.00)**	(0.00)**	(0.00)***	(0.00)*	(0.00)***	(0.00)**	(0.00)***	(0.00)**
Household characteristics								
male	0.043	-0.001	0.050	-0.002	0.045	-0.000	0.043	-0.001
	(0.02)**	(0.02)	(0.01)***	(0.01)	(0.01)***	(0.01)	(0.01)***	(0.01)
age	-0.002	-0.000	-0.002	-0.001	-0.002	-0.001	-0.002	-0.001
	(0.00)***	(0.00)	(0.00)***	(0.00)***	(0.00)***	(0.00)	(0.00)***	(0.00)**
grade	-0.002	0.003	-0.001	0.001	-0.001	0.003	-0.001	0.004
	(0.00)	(0.00)*	(0.00)	(0.00)	(0.00)	(0.00)**	(0.00)	(0.00)**
marital status	0.005	-0.014	0.014	-0.015	0.009	-0.012	0.004	-0.013
	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
being minority	-0.068	0.036	-0.059	0.090	-0.052	0.080	-0.064	0.081
	(0.04)	(0.03)	(0.03)*	(0.03)***	(0.03)	(0.03)***	(0.03)**	(0.03)***
being poor	0.032	-0.006	0.037	-0.004	0.035	-0.002	0.106	0.011
	(0.02)*	(0.01)	(0.01)***	(0.01)	(0.01)***	(0.01)	(0.05)**	(0.03)
Commune characteristics								
share of irrigated annual crop land	-0.005	0.007	-0.007	0.004	-0.006	0.005	-0.005	0.004
	(0.00)	(0.00)**	(0.00)***	(0.00)	(0.00)***	(0.00)*	(0.00)**	(0.00)
having power supply	-0.009	0.067	-0.045	0.057	-0.054	0.056	-0.026	0.080
	(0.04)	(0.07)	(0.03)	(0.06)	(0.03)**	(0.06)	(0.03)	(0.06)
distance to nearest market	-0.002	0.001	-0.001	0.003	-0.001	0.002	-0.001	0.002

	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
distance to nearest extension	-0.000	0.003	-0.001	0.004	-0.001	0.002	-0.000	0.002
	(0.00)	(0.00)	(0.00)	(0.00)*	(0.00)	(0.00)	(0.00)	(0.00)
being a poor commune	0.044	-0.046	0.065	0.000	0.057	-0.013	0.042	-0.009
	(0.03)	(0.03)	(0.02)***	(0.03)	(0.02)**	(0.03)	(0.02)*	(0.03)
Climate factor								
average precipitation	0.006	0.001	0.011	0.002	0.009	0.002	0.007	0.002
	(0.00)	(0.00)	(0.00)***	(0.00)	(0.00)***	(0.00)*	(0.00)**	(0.00)*
average temperature	0.000	-0.028	0.000	-0.025	0.000	-0.020	0.000	-0.024
	(0.00)	(0.01)***	(0.00)	(0.01)***	(0.00)	(0.01)**	(0.00)	(0.01)***
variation of precipitation	0.000	0.000	0.000	-0.001	0.000	-0.001	0.000	-0.000
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
variation of temperature	0.000	0.015	0.000	0.004	0.000	0.018	0.000	0.014
	(0.00)	(0.03)	(0.00)	(0.03)	(0.00)	(0.03)	(0.00)	(0.02)
drought over the past 3 years	0.002	-0.005	0.027	0.001	0.020	0.005	-0.011	0.003
	(0.05)	(0.01)	(0.03)	(0.01)	(0.03)	(0.01)	(0.03)	(0.01)
flood over the past 3 years	-0.012	0.022	-0.020	0.020	-0.017	0.021	-0.010	0.016
	(0.01)	(0.01)**	(0.01)**	(0.01)**	(0.01)**	(0.01)**	(0.01)	(0.01)**
typhoon over the past 3 years	-0.012	0.031	-0.007	0.033	-0.005	0.032	0.000	0.031
	(0.02)	(0.01)**	(0.01)	(0.01)***	(0.01)	(0.01)***	(0.01)	(0.01)***
drought over the past year	-0.121	0.032	-0.157	0.011	-0.167	0.019	-0.137	0.012
	(0.11)	(0.03)	(0.07)**	(0.03)	(0.06)**	(0.03)	(0.07)*	(0.03)
flood over the past year	0.043	-0.031	0.044	-0.011	0.045	-0.017	0.051	-0.009
	(0.03)	(0.03)	(0.02)**	(0.02)	(0.02)**	(0.02)	(0.02)**	(0.02)
typhoon over the past year	0.051	0.011	0.068	0.011	0.067	0.010	0.063	-0.000
	(0.05)	(0.03)	(0.04)*	(0.02)	(0.04)*	(0.02)	(0.03)*	(0.02)
Predicted/pseudo residuals								
hired labor residual			-0.029	-0.045	-0.031	-0.044	-0.029	-0.046
			(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***
fertilizer residual			-0.149	-0.028	-0.132	0.019	-0.114	-0.009
			(0.05)***	(0.02)	(0.05)**	(0.02)	(0.06)**	(0.02)
irrigation residual			-0.174	-0.046	-0.139	-0.020	-0.111	-0.021
			(0.04)***	(0.02)**	(0.04)***	(0.02)	(0.04)***	(0.02)
inverse of the Mills ratio			0.055	0.075	0.042	0.053	0.203	0.058
			(0.02)***	(0.02)***	(0.02)**	(0.02)**	(0.02)***	(0.02)***

Residual interactions								
irrigation X its residual					0.006	0.006	0.006	0.005
					(0.00)***	(0.00)***	(0.00)***	(0.00)**
fertilizer X its residual					0.016	0.017	0.014	0.018
					(0.00)***	(0.00)***	(0.01)**	(0.00)***
hired labor X its residual					-0.001	-0.000	-0.000	-0.000
					(0.00)*	(0.00)	(0.00)	(0.00)
poor X hired labor							0.006	-0.005
							(0.01)	(0.00)
poor X hired labor residual							-0.005	0.008
							(0.01)	(0.01)
poor X hired labor X hired labor residual							-0.000	-0.000
							(0.00)	(0.00)
poor X fertilizer							-0.044	-0.018
							(0.04)	(0.02)
poor X fertilizer residual							0.079	0.036
							(0.04)*	(0.02)**
poor X fertilizer X fert. residual							0.005	-0.002
							(0.01)	(0.00)
poor X hh irrigation							0.026	0.011
							(0.01)**	(0.01)
poor X hh irrigation residual							-0.018	0.004
							(0.01)	(0.01)
poor X hh irr. X irr. residual							0.001	0.002
							(0.00)	(0.00)
poor X commune irrigation							0.001	-0.001
							(0.00)	(0.00)
Constant	1.519	2.134	0.938	2.050	1.159	1.830	1.360	1.879
	(0.50)***	(0.45)***	(0.38)**	(0.43)***	(0.36)***	(0.42)***	(0.37)***	(0.37)***
Observations	3836	5288	9207	16372	9207	16372	9199	16341
Log likelihood		0.35	-2134.92	-6380.84	-2081.07	-6259.19	-1702.58	-5900.54
P-value of F/χ^2 test for joint coefficients=0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eigenvalue test of weak instruments	3.09	7.15						
F statistic of endogeneity of instruments	37.71	11.30						

P-value of endogeneity of instruments	0.00	0.00						
rho (correlation of yield residual with sample selection residual)			0.00	0.01	0.00	0.01	-0.81	0.01
			(0.01)	(0.01)	(0.01)	(0.01)	(0.04)	(0.02)
sigma (sigma of rice yield)			0.20	0.26	0.20	0.26	0.21	0.24
			(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
p-value of Wald test of indep. eqns. (rho = 0)			1.00	0.56	1.00	0.45	0.00	0.40

Source: Authors’ estimation based on VHLSS 2004 and 2006.

Note: Assume possible correlation within commune. All continuous variables are expressed in logarithm terms. Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

Appendix Table 3. Comparison of estimation results excluding extreme values

	2SLS		Heckman basic		Heckman interaction		Heckman pov. inter.	
Dep. var. = Rice yield	full sample	excluding extreme values	full sample	excluding extreme values	full sample	excluding extreme values	full sample	excluding extreme values
Inputs for rice production								
family labor	0.035	0.033	0.048	0.050	0.045	0.046	0.044	0.044
	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***
hired labor	0.050	0.050	0.053	0.053	0.054	0.054	0.055	0.055
	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***
fertilizer	0.127	0.126	0.128	0.127	0.152	0.151	0.161	0.161
	(0.02)***	(0.02)***	(0.02)***	(0.02)***	(0.02)***	(0.02)***	(0.02)***	(0.02)***
irrigation	0.046	0.044	0.069	0.074	0.067	0.072	0.063	0.062
	(0.02)***	(0.02)**	(0.02)***	(0.02)***	(0.02)***	(0.02)***	(0.02)***	(0.02)***
share of rice in total crop land	-0.092	-0.087	-0.104	-0.103	-0.098	-0.097	-0.094	-0.090
	(0.02)***	(0.02)***	(0.02)***	(0.02)***	(0.02)***	(0.02)***	(0.02)***	(0.02)***
share of sale in total rice harvest	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.002
	(0.00)***	(0.00)***	(0.00)***	(0.00)***	(0.00)***	(0.00)***	(0.00)***	(0.00)***
Household characteristics								
male	0.011	0.013	0.014	0.017	0.012	0.015	0.012	0.014
	(0.01)	(0.01)	(0.01)	(0.01)*	(0.01)	(0.01)*	(0.01)	(0.01)
age	-0.001	-0.001	-0.002	-0.002	-0.001	-0.001	-0.001	-0.002
	(0.00)***	(0.00)***	(0.00)***	(0.00)***	(0.00)***	(0.00)***	(0.00)***	(0.00)***
grade	-0.000	-0.000	-0.001	-0.001	0.000	-0.000	0.000	0.000
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
marital status	-0.012	-0.013	-0.010	-0.010	-0.009	-0.009	-0.009	-0.010
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
being minority	0.031	0.027	0.065	0.071	0.058	0.064	0.059	0.057
	(0.03)	(0.02)	(0.03)**	(0.03)**	(0.03)*	(0.03)**	(0.03)*	(0.03)**
being poor	0.015	0.017	0.017	0.019	0.017	0.019	0.020	0.040
	(0.01)	(0.01)*	(0.01)**	(0.01)***	(0.01)**	(0.01)***	(0.03)	(0.03)
Commune characteristics								
share of irrigated annual crop land	0.004	0.004	0.002	0.002	0.004	0.003	0.002	0.002
	(0.00)**	(0.00)**	(0.00)	(0.00)	(0.00)*	(0.00)*	(0.00)	(0.00)
having power supply	0.052	0.067	0.049	0.063	0.038	0.054	0.048	0.091

	(0.07)	(0.07)	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)	(0.05)*
distance to nearest market	-0.001	-0.001	0.000	0.000	-0.000	-0.000	-0.000	0.000
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
distance to nearest extension	0.003	0.003	0.003	0.003	0.002	0.002	0.002	0.002
	(0.00)	(0.00)	(0.00)*	(0.00)*	(0.00)	(0.00)	(0.00)	(0.00)
being a poor commune	-0.022	-0.022	0.004	0.012	-0.008	-0.000	-0.007	0.000
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Climate factor								
average precipitation	0.002	0.002	0.002	0.001	0.002	0.002	0.002	0.002
	(0.00)*	(0.00)*	(0.00)**	(0.00)*	(0.00)***	(0.00)***	(0.00)***	(0.00)***
average temperature	-0.021	-0.021	-0.025	-0.026	-0.019	-0.020	-0.020	-0.021
	(0.01)**	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***
variation of precipitation	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
	(0.00)**	(0.00)*	(0.00)***	(0.00)***	(0.00)***	(0.00)***	(0.00)***	(0.00)***
variation of temperature	0.043	0.041	0.021	0.014	0.040	0.032	0.039	0.036
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.02)
drought over the past 3 years	-0.004	-0.001	-0.003	0.000	0.002	0.005	0.002	0.003
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
flood over the past 3 years	0.017	0.013	0.013	0.009	0.015	0.011	0.015	0.009
	(0.01)**	(0.01)*	(0.01)**	(0.01)	(0.01)**	(0.01)*	(0.01)**	(0.01)
typhoon over the past 3 years	0.004	0.006	0.007	0.010	0.007	0.009	0.006	0.011
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
drought over the past year	0.010	0.009	0.003	-0.000	0.006	0.002	0.006	-0.005
	(0.03)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
flood over the past year	0.001	0.005	0.008	0.014	0.004	0.010	0.006	0.015
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
typhoon over the past year	0.027	0.025	0.026	0.024	0.027	0.024	0.026	0.018
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Predicted/pseudo residuals								
hired labor residual			-0.049	-0.050	-0.051	-0.052	-0.054	-0.053
			(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***
fertilizer residual			-0.039	-0.038	-0.001	-0.003	-0.029	-0.035
			(0.02)**	(0.02)**	(0.02)	(0.02)	(0.02)	(0.02)**
irrigation residual			-0.040	-0.046	-0.016	-0.022	-0.016	-0.018
			(0.02)*	(0.02)**	(0.02)	(0.02)	(0.02)	(0.02)

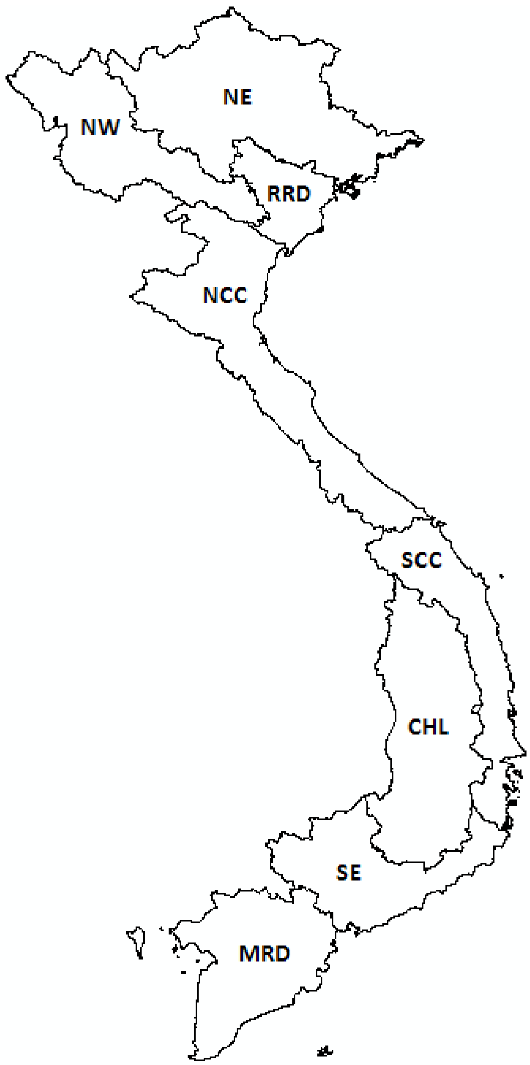
inverse of the Mills ratio			0.037	0.048	0.021	0.032	0.021	0.034
			(0.02)	(0.02)**	(0.02)	(0.02)	(0.02)	(0.02)*
Residual interactions								
irrigation X its residual					0.005	0.005	0.005	0.004
					(0.00)***	(0.00)***	(0.00)***	(0.00)***
fertilizer X its residual					0.016	0.015	0.016	0.016
					(0.00)***	(0.00)***	(0.00)***	(0.00)***
hired labor X its residual					-0.001	-0.001	-0.001	-0.001
					(0.00)*	(0.00)	(0.00)	(0.00)*
poor X hired labor							-0.003	0.002
							(0.00)	(0.00)
poor X hired labor residual							0.007	0.001
							(0.00)*	(0.00)
poor X hired labor X hired labor residual							0.000	0.000
							(0.00)	(0.00)
poor X fertilizer							-0.014	-0.031
							(0.02)	(0.02)*
poor X fertilizer residual							0.048	0.055
							(0.02)***	(0.02)***
poor X fertilizer X fert. residual							0.001	-0.001
							(0.00)	(0.00)
poor X hh irrigation							0.010	0.011
							(0.01)	(0.01)*
poor X hh irrigation residual							-0.000	-0.002
							(0.01)	(0.01)
poor X hh irr. X irr. residual							0.002	0.002
							(0.00)	(0.00)
poor X commune irrigation							0.002	0.002
							(0.00)	(0.00)
Constant	2.149	2.145	2.393	2.458	2.102	2.178	2.114	2.071
	(0.41)***	(0.41)***	(0.39)***	(0.38)***	(0.38)***	(0.37)***	(0.38)***	(0.35)***
Observations	9124	9116	25579	25571	25579	25571	25579	25536
Log likelihood	0.12	0.13	-9338.67	-9074.25	-9174.79	-8920.70	-9147.48	-8437.69
P-value of F/χ^2 test for joint coefficients=0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Eigenvalue test of weak instruments	12.15	12.07						
F statistic of endogeneity of instruments	42.52	42.98						
P-value of endogeneity of instruments	0.00	0.00						
rho (correlation of yield residual with sample selection residual)			0.000	0.000	0.000	0.000	0.000	-0.001
			0.01	0.01	0.01	0.01	0.01	0.01
sigma (sigma of rice yield)			0.244	0.237	0.239	0.234	0.239	0.223
			0.01	0.00	0.01	0.00	0.01	0.00
p-value of Wald test of indep. eqns. (rho = 0)			0.999	0.999	0.999	0.998	0.999	0.900

Source: Authors' estimation based on VHLSS 2004 and 2006.

Note: Assume possible correlation within commune. All continuous variables are expressed in logarithm terms. Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

Appendix Figure 1. Agro-ecological zones of Vietnam



Source: Authors's preparation.