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How Are Farmers Adapting to Climate Change in Vietnam?

Endogeneity and Sample Selection in a Rice Yield Model

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ABSTRACT

Vietnam is likely to be among the countries hardest hit by climate change, threatening its legacy as a champion in leveraging agriculture for development. This paper examines how a changing climate may affect rice production and how Vietnamese farmers are likely to adapt to various climatic conditions using an innovative yield function approach, taking into account sample selection bias and endogeneity of inputs. Model results suggest that although climate change can potentially reduce rice production, farmers will respond mainly by adjusting the production portfolio and levels of input use. However, investments in rural infrastructure and human capital will have to support farmers in the adaptation process if production levels and farm incomes are to be sustained in the future.

Keywords: climate change, Vietnam rice, control function, endogeneity, sample selection

JEL code: C21, D13, Q12

1. INTRODUCTION

Vietnam is among the countries that are likely to be hardest hit by the impacts of climate change (Cruz et al. 2007; Dasgupta et al. 2007; Nguyen 2009; World Bank 2010). Climate change impacts often go beyond changes in rainfall and temperature and affect economic growth and household incomes (Thurlow, Zhu, and Diao 2009; Breisinger et al. 2011). The agricultural sector is particularly vulnerable due to its direct exposure to and dependence on weather and other natural conditions (Howden et al. 2007; Tubiello and Rosenzweig 2008; Nelson et al. 2010). Studies for the Southeast Asian region show that climate change could lower agricultural productivity by 15 to 26 percent in Thailand, 2 to 15 percent in Vietnam, 12 to 23 percent in the Philippines, and 6 to 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 impacts of global warming in Vietnam, and they estimate that the average temperature will increase by 2.5 degrees Celsius by 2070 and that sea levels are expected to rise up to 33 centimeters by 2050. According to Dasgupta et al.'s (2007) estimation, about 20 to 30 percent of the Mekong River Delta may be affected by 2100.

These projections raise serious concerns about agricultural development in Vietnam that has been a key driver of economic transformation by ensuring food security and generating rural incomes and foreign exchange earnings. Within the agricultural sector, paddy rice plays a key role, accounting for more than three-quarters of the country's total annual harvested agricultural area and employing about two-thirds of the rural labor force (Vu and Glewwe 2011; Nguyen, Yu, and Breisinger 2010). Rice cultivation is a major source of income (in many cases the major or only income source) for more than three-fourths of poor households and for about 48 percent of nonpoor households. Moreover, rice production has grown steadily over the past two decades. This growth is mainly explained by improvements in yields, which turned the country from a net rice importer to the second-largest rice exporter in the world (FAO 2011).

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 already decreased agricultural production in Vietnam substantially in recent years. Zhu and Trinh (2010) estimate that rice yields could further decline by 4.2 to 12.5 percent by 2030 due to climate change. The impact is projected to be sizable in the major rice-producing region of the Mekong River Delta and especially alarming in the poorer mountainous regions (Central Highlands and Northern Vietnam), with the average rice yield declining between 1 and 8 percent by 2030.

Even without climate change, the rice sector in Vietnam faces 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 Vietnam's *Resolution on Ensuring National Food Security* (GOV 2009), the total area under rice production is projected to drop by nearly 10 percent by 2030. Although current rice yields in Vietnam are still high compared with 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 bring back the risk of food insecurity in Vietnam and affect food security globally. Given the limited scope of land expansion, productivity-led growth is the only feasible option for improving 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 facing the rice sector, several key questions emerge: (1) What are the potential impacts of climate change on rice yields? (2) How are farmers likely to respond and how do the responses depend on farmers' income levels? And (3) What measures can be taken to support farmers, especially the poor, in adapting to climate change? By attempting to answer 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 climate change 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 producers cope with climate change by adjusting usage of productive inputs with special focus on poor farmers. Third, the paper addresses common methodological problems in the yield function estimation, including sample selection, endogeneity, and heterogeneity. The econometric techniques presented in this paper, particularly the control function approach embedded in sample selection, are innovative and 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 remainder of 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 the data we use. 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 with major findings and policy implications derived from the study.

2. HOUSEHOLD RICE PRODUCTION MODEL

Yield Function

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 patterns affect 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, u is the random noise. Z also includes other fixed and quasi-fixed inputs that are exogenous (including climate); α 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.

Econometric Considerations

Decisions regarding use of inputs such as irrigation, fertilizer, and hired labor may be endogenous in the household production decision, producing inconsistent parameter estimates (Doraszelski and Jaumandreu 2009). 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.

The problem of sample selection bias arises when some rural households change their production portfolio by choosing not to grow rice, and hence are not included in the estimation of rice yields. 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.

In econometrics modeling, an outcome variable considering both sample selection and endogeneity can be estimated in several ways. One approach is the double-hurdle model to accommodate double censoring, such as in Bettin, Lucchetti, and Zazzaro (2012). A second approach is the instrument variable and Heckman technique (Wooldridge 2002). A third approach is to use control functions and the Heckman technique (Wooldridge 2002, 2007). This paper takes the control function approach because it fits best to the research question and offers some distinct advantages over standard two-stage least squares (2SLS) for models that are nonlinear in parameters, including improved efficiency and precision (Wooldridge 2008).

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 yields in equation (1). The control function approach is used to handle endogeneity in the use of hired labor, fertilizer, and irrigation (see Appendix A). The estimates of yield function are control function estimates, because the inclusion of the residuals from the reduced-form equations "controls" for the endogeneity of inputs in the structural equation. Heckman (1979) demonstrates that an ordinary least squares (OLS) regression using the selected sample generally leads to inconsistent estimation of coefficients. He proposed a technique to adjust the bias from sample selection to produce consistent and asymptotically normal results.

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.

$$y_1 = z_1\delta_1 + \sum_j \alpha_j y_{2j} + u_1, \text{j} = 1,2,\ldots,\text{J}, \tag{2}$$

$$y_{2j} = z\delta_{2j} + v_{2j}, \tag{3}$$

$$y_3 = 1(z\delta_3 + v_3 > 0), \tag{4}$$

where y_1, y_{2j}, y_3 represent rice yield, endogenous input(s) of rice production, and an indicator function for the selection of the observation into the sample, respectively. z_1 is a vector of exogenous covariates; z is a vector of exogenous covariates that includes z_1 variables (also in the rice yield equation) and a vector z_2 of instruments that affect each of the endogenous inputs y_{2j} but have no direct influence on the 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 are growing rice. Since nonrice crop yields are excluded from equations (2) and (3), equation (4) helps correct biases in the estimated parameters resulting from any nonrandomness of the selected sample. The Heckman (1979) sample selection technique is used to correct the bias of any nonrandomness 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 techniques to obtain generalized residuals for endogenous variables $\widehat{GR_J}$.
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 $\widehat{\lambda_3}$ into 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

$$y_1 = z_1\delta_1 + \sum_j \alpha_j y_{2j} + \sum_j \eta_j \widehat{GR_J} + \gamma\widehat{\lambda_3} + e, \text{j} = 1,2,\ldots,\text{J}, \tag{5}$$

where η is a vector of parameters associated with the generalized 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 nonrandomness of structural parameters.

Steps 2 and 3 can be combined into one step by using maximum likelihood. Wooldridge (2002) suggests that the maximum likelihood approach is more efficient that the procedure described above if error terms in equations (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 to test:

4. 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.
5. 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 (Wooldridge 2002).
6. 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.

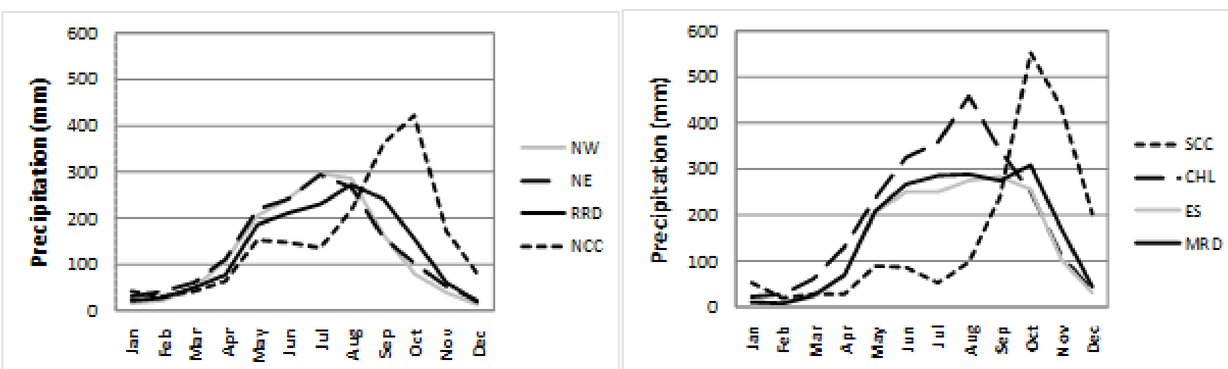
Additionally, interaction terms between poverty status and inputs are introduced to quantify the effect of poverty on the household's ability to increase yield and mitigate the negative impact of adverse weather. Hence, the structural model is not linear in inputs because the model includes two groups 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. RICE FARMING, CLIMATE, AND HOUSEHOLDS IN VIETNAM

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, Huong, and Long (2003). The paper uses the 2004 and 2006 rounds of Vietnam Household Living Standards Survey (VHLSS) from Vietnam's General Statistics Office (Vietnam, GSO, various years). Both surveys include information on household crop production and village-level information on access to community and social services (for example, 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 diverse agroecological conditions of Vietnam are reflected in the rainfall and temperature records of the 25 weather stations in the country.[1] General climate pattern is represented by monthly average rainfall and temperature from 1979 to 2007. Figures 3.1 and 3.2 show the mean monthly rainfall and reference evapotranspiration calculated with the FAO Penman-Monteith method (Allen et al. 1998), by agroecological region. The Asian monsoon regime has a dominating influence in Vietnam. Spatially, rainfall is more uniform in the central and southern regions but varies greatly in the north even over short distances. Typhoons, flooding, and droughts occur frequently in the country. Climate change has affected the country, as rainfall is more erratic with more frequent extreme events in recent years (Figure 3.3). Since the mid-1980s, there has been a warming trend in annual average temperature, and the temperature increase is more noticeable in the deltas (Figure 3.4). These adverse hydroclimatic disasters result in serious damage to agriculture. We combine these 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 3.1.

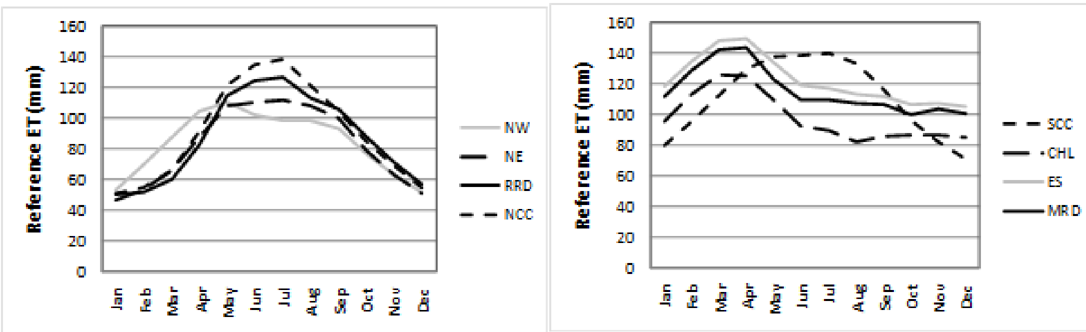
Figure 3.1—Average monthly precipitation in agroecological regions of Vietnam



Source: Zhu and Trinh 2010.

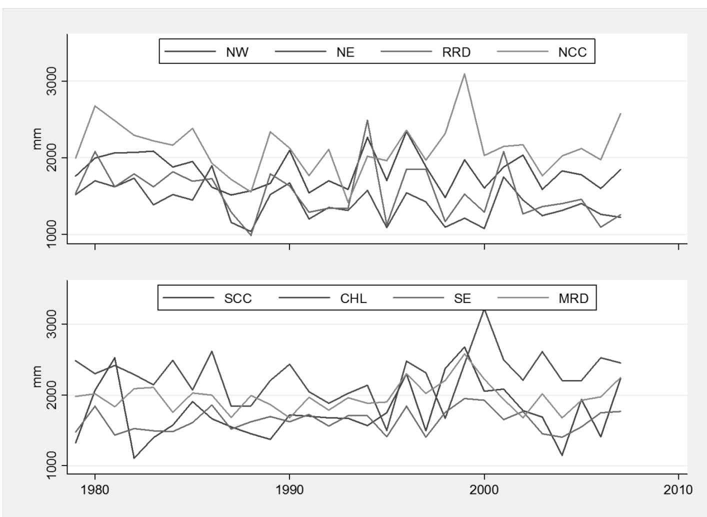
[1] Vietnam has relatively complicated terrain, characterized by numerous mountains, many rivers, and a long and meandering coastline. Of the total land area, agricultural land makes up about 28 percent and plains cover about 25 percent. The country is divided into eight agroecological zones based on its climate and biophysical environment (Appendix Figure B.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 Northwest (NW), Northeast (NE), and Red River Delta (RRD) agroecological zones. The RRD 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 Southeast (SE) zone includes regions with low to medium elevation, and the Mekong River Delta (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 floodwater for two to four months every year.

Figure 3.2—Average monthly reference evapotranspiration in agroecological regions of Vietnam



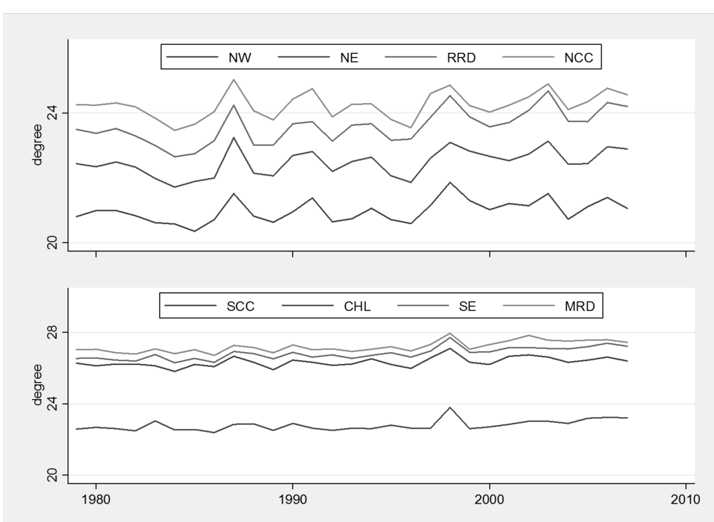
Source: Zhu and Trinh 2010.

Figure 3.3—Long-term precipitation in Vietnam



Source: Authors' calculation.

Figure 3.4—Long-term temperature in Vietnam



Source: Authors' calculation.

Table 3.1—Descriptive statistics of VHLSS 2004 and 2006

	2004		2006	
Variable	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**
Household crop production				
Number of households	5571		5429	
Total crop area (ha)	1.0	1.2	1.5	2.4
Rice area (ha)	0.3	0.8	0.8	2.0
Share of households producing rice (%)	82.6	38.0	83.3	37.3
Share of rice in total crop area (%)	29.8	30.3	40.1	33.6
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 producing rice				
Number of households	4599		4525	
Total crop 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 total crop area (%)	73.7	25.8	81.3	21.9
Inputs for rice production				
Output (metric 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 using irrigation (%)	72.1	44.9	71.3	45.2
Irrigation cost (000 dong/ha)	0.3	0.3	0.2	0.2
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)	11.1	11.1	10.9	10.7
Share of being poor (%)	22.5	41.7	20.8	40.6
Share of being remote (%)	22.8	42.0	21.9	41.4
Share of infrastructure program (%)	59.5	49.1	57.3	49.5

Table 3.1—Continued

Variable	2004 Mean	2004 Std. Dev.	2006 Mean	2006 Std. Dev.
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
Floods over the past 3 years (time)	0.3	0.6	0.3	0.6
Floods in this year (time)	0.1	0.2	0.0	0.2
Typhoons over the past 3 years (time)	0.2	0.4	0.3	0.6
Typhoons in this year (time)	0.1	0.2	0.0	0.2
Droughts over the past 3 years (time)	0.2	0.5	0.2	0.5
Droughts in this year (time)	0.0	0.2	0.0	0.2

Source: Authors' calculation based on VHLSS 2004 and 2006.
Notes: ha = hectares; kg = kilograms; km = kilometers; mm = millimeters.

Despite the country's rapid economic transformation, rice still dominates in Vietnamese crop cultivation, grown by the majority of households on one-third to half of the annual crop harvested area. The majority of the rice producers are smallholders who typically operate on small plots in a land-constrained environment. This suggests that focusing on increasing farm productivity may offer the single most important pathway of income generation. Average rice yields in the survey period have stagnated at 4.7 to 4.8 tons[2] per hectare, which is consistent with the national trend reported by Nguyen, Yu, and Breisinger (2010). The majority of agricultural labor working in paddy fields is family labor; hired labor accounts for only 4.2 percent of total labor employed for rice production. Adoption of modern inputs is high in Vietnam compared with 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 2011). Furthermore, about 14 to 20 percent of households become specialized in rice cultivation by focusing exclusively on rice in their annual crop fields.

More than one-third of rice-growing households are classified as poor, much higher than the national average; and about one-quarter of rice-farming households are headed by a member of an ethnic minority. Overall, access to infrastructure (irrigation and electricity) and public services improved marginally in two years, whereas 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. In Vietnam, the 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, which is captured by the household-level private irrigation expenditure variable.

[2] Output is measured in metric tons.

This descriptive household survey analysis and review of the literature lead to a number of hypotheses. Based on agronomic and economic theory, higher rice yields are observed under intensified production processes characterized by higher input usage (labor, fertilizer, and household irrigation). The quality of the labor force is reflected by the household head's literacy: a literate farmer is expected to be better equipped to adopt a 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 generally expected to be less productive (ADB 2006). For instance, rice yields are usually compromised among the poor and ethnic minorities due to financial constraints.

Concerning potential policy interventions for improving agricultural productivity, previous research by Fan, Huong, and Long (2004) suggests that investment in roads yields high returns in every region in Vietnam, whereas education investment produces larger impacts in the southeast and delta regions. 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 access to infrastructure 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 is expected to be negative as well. Other infrastructure variables such as the availability of electricity are supposed to boost yields 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.

As for the relation between weather and agriculture, agriculture is sensitive to short-term changes in weather that affect the production of crops. Low levels of rainfall and high temperatures can cause drought, whereas intense rainfall over a short period of time may cause floods. Both cases can have negative effects on agricultural production. 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 yields generally report a negative response when temperatures exceed optimal levels for biological processes, including for rice (Rosenzweig and Hillel 1995; Peng et al. 2004).

4. DISCUSSION OF EMPIRICAL RESULTS

The explanatory variables from the VHLSS and climate records are classified into five groups regarding their effects on the rice yield, endogenous input, and selection equations: inputs for rice production, household characteristics, commune characteristics, climate factors, and control variables. Table 4.1 summarizes the variables used in the analysis. The first group relates to inputs used directly for rice production at the household level, including family and hired labor, fertilizer, irrigation, machine rental, chemicals, market participation (share of sales in total harvest), and the importance of rice in crop production (share of rice area in total crop area). Household characteristics include household head age, gender, educational grade, marital status, ethnic group, and literacy, and household size and poverty status. The third group describes commune characteristics, which include characteristics of commune infrastructure such as irrigation and electricity coverage, distance to market and transportation, and access to agricultural extension. Dummy variables are used to capture commune poverty status, remoteness, and the existence of ongoing government infrastructure programs. The fourth group includes both short- and long-term climatic factors. Long-term climate patterns are captured by averages and interannual variability of rainfall and temperature over the period of 1979–2007, whereas short-term weather variables are proxied by external shocks such as flood, drought, and typhoon over the last three years. The bottom panel of Table 4.1 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 consistent estimation of parameters in the structural equation.

Table 4.1—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
Household characteristics					
share of sale in total harvest	X	X	X	X	X
share of rice in total crop area	X	X	X	X	X
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

Table 4.1—Continued

	Yield	Endogenous input demand			Sample selection
		Irrigation	Fertilizer	Hired labor	
Climate factor					
average precipitation	X	X	X	X	X
average temperature	X	X	X	X	X
variability of precipitation	X	X	X	X	X
variability 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				

Source: Authors.

To properly interpret the estimated parameters of the model in equations (2) through (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 the 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.

Endogenous Input Demand—Farmers' Responses to Climatic Changes

The estimation results of demand for endogenous inputs are summarized in the first three columns of Table 4.2. In general, input usage is positively correlated with other inputs (chemicals and equipment rental), market participation (rice sale), reliance on rice for income (share of rice in total cropland), education (grade), household wealth (per capita income), and commune infrastructure (irrigation coverage and access to market and transportation). The effect of the 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 include small household size and access to electricity. Electric-powered machinery can substitute for workers and lower irrigation expense. Households with better access to agricultural extension stations, government infrastructure construction programs, or a location within a poor community generally have high demand for hired labor. Demand for fertilizer and irrigation is depressed in households headed by an ethnic minority or in poor communes.

Table 4.2—Estimation results for endogenous input functions and sample selection function

	Endogenous input			Sample selection
	Hired labor	Fertilizer	Irrigation	
Inputs for rice production				
family labor	-0.50	0.06	0.03	0.46
	(0.03)***	(0.01)***	(0.02)	(0.03)***
chemical	0.10	0.21	0.09	0.13
	(0.03)***	(0.02)***	(0.02)***	(0.00)***
machinery rental	0.09	0.03	0.07	0.14
	(0.02)***	(0.01)***	(0.01)***	(0.00)***
Household characteristics				
share of sale in total rice harvest	0.07	0.01	0.03	0.05
	(0.01)***	(0.00)***	(0.01)***	(0.00)***
share of rice in total crop area	0.78	-0.16	0.56	
	(0.14)***	(0.07)**	(0.08)***	
male	0.16	0.01	-0.11	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	0.00	0.03	0.03	-0.01
	(0.02)	(0.01)***	(0.01)***	(0.00)*
marital status	-0.00	0.07	-0.07	0.01
	(0.13)	(0.03)**	(0.05)	(0.03)
being minority	0.00	-0.36	-1.11	0.41
	(0.19)	(0.06)***	(0.14)***	(0.04)***
being a poor household	-0.15	0.01	0.03	-0.02
	(0.12)	(0.03)	(0.05)	(0.02)
per capita household income	1.07	0.05	-0.00	0.11
	(0.11)***	(0.03)*	(0.05)	(0.03)***
household size	-0.03	-0.08	0.02	0.07
	(0.13)	(0.04)**	(0.06)	(0.03)**
literate	0.21	0.37	-0.06	-0.04
	(0.19)	(0.10)***	(0.10)	(0.04)
Commune characteristics				
share of irrigated annual crop land	-0.02	0.03	0.07	-0.00
	(0.02)	(0.01)***	(0.01)***	(0.00)
having power supply	-1.14	1.60	-0.49	-0.54
	(0.53)**	(0.32)***	(0.25)*	(0.08)***
distance to nearest market	-0.03	-0.02	-0.03	-0.00
	(0.02)**	(0.00)***	(0.01)***	(0.00)
distance to nearest extension	-0.04	-0.01	-0.01	-0.00
	(0.02)*	(0.01)	(0.01)	(0.01)
distance to nearest transportation	-0.23	-0.31	-0.62	0.23
	(0.20)	(0.07)***	(0.14)***	(0.05)***
being a poor commune	0.49	-0.16	-0.55	0.07
	(0.18)***	(0.06)***	(0.12)***	(0.04)
being a remote commune	-0.01	-0.01	0.00	-0.01
	(0.01)	(0.00)	(0.01)	(0.00)*
having infrastructure program	-0.19	0.02	-0.05	0.01
	(0.11)*	(0.03)	(0.06)	(0.02)

Table 4.2—Continued

	Endogenous input			Sample
	Hired labor	Fertilizer	Irrigation	selection
Climate factor				
average precipitation	0.00	-0.00	-0.00	0.00
	(0.00)	(0.00)***	(0.00)*	(0.00)
average temperature	0.43	-0.03	-0.11	0.07
	(0.04)***	(0.02)	(0.03)***	(0.01)***
variability of precipitation	-0.00	-0.00	0.01	-0.00
	(0.00)**	(0.00)***	(0.00)***	(0.00)**
variability of temperature	-8.16	-0.71	3.82	-0.98
	(1.22)***	(0.34)**	(0.66)***	(0.27)***
drought over the past 3 years	-0.25	0.03	-0.10	0.03
	(0.15)*	(0.06)	(0.09)	(0.03)
flood over the past 3 years	-0.01	0.04	0.16	-0.05
	(0.11)	(0.03)	(0.06)***	(0.02)**
typhoon over the past 3 years	0.09	0.04	-0.10	-0.03
	(0.12)	(0.04)	(0.07)	(0.03)
drought over the past year	1.22	0.11	-0.10	-0.14
	(0.40)***	(0.13)	(0.22)	(0.08)*
flood over the past year	-0.54	-0.04	-0.18	0.03
	(0.25)**	(0.08)	(0.13)	(0.05)
typhoon over the past year	-0.30	0.06	0.14	0.09
	(0.27)	(0.09)	(0.16)	(0.06)
Constant	-14.96	0.41	-4.98	-3.29
	(1.86)***	(0.76)	(1.14)***	(0.53)***
Observations	9124	9124	9124	25579
R^2/pseudo R^2	0.27	0.41	0.50	0.44
F/χ^2 test for all instruments = 0	124.81	20.17	148.99	4522.0
p-value of F/χ^2 test for all instruments = 0	0.00	0.00	0.00	0.00
Partial R^2on excluded instruments	0.02	0.13	0.03	0.01
F test for excluded instruments = 0	26.51	165.08	36.16	47.16
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.
Notes: Endogenous inputs are estimated using ordinary least squares, and sample selection equation is estimated using maximum likelihood estimation 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, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Climate patterns can have a substantial impact on input demand. When the average temperature rises, farmers choose to spend more for hired labor but cut back on irrigation expense to make better use of the inputs. Demand for hired labor and fertilizer drops under highly variable climate, as farmers increase irrigation investment to compensate for the erratic rainfall and temperature pattern. Coefficients of weather events reveal rice farmers' coping strategy when faced with adverse weather. Spending on irrigation is higher in areas with high flood occurrence during the study period as farmers take advantage of extra nutrients in the soil from sediment in the medium term by increasing irrigation use. Similarly, demand for hired labor is low in areas prone to droughts over the past three years, but producers spend considerably more to hire extra labor to fight drought in the 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 the medium-term weather pattern, and adjust input levels in the current season to minimize losses when faced with external weather shocks.

Sample Selection—Factors Influencing Rice Production

The set of factors that affects demand for inputs and rice yield also influences the selection of rural households into the estimation sample. The last column of Table 4.2 presents estimation results of a probit model of rice production in the household surveys. As in the case of endogenous inputs, a household is more likely to grow rice if it has more family members, spends more on chemicals and machine rental, actively participates in markets, reports higher income, has low education, and is headed by an ethnic minority. Producers located in remote communes or with low access to electricity and transportation tend to include rice in their production portfolio. Consistent with input demand, temperature plays an important role in a household's decision about growing rice: an environment characterized by a warm and dependable temperature is more favorable for rice production and hence households are more likely to report rice production. Past flood and drought discourage producers from growing rice, as rice growers choose to modify input levels based on recent weather shocks.

Determinants of Rice Yields

Table 4.3 presents several approaches for analyzing the determinants of rice yield in Vietnam. First, OLS and 2SLS estimates are summarized in columns (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). Columns (3) through (5) present the maximum likelihood Heckman estimates, controlling for sample selection bias and heterogeneity of the rice yield. Heckman estimation replaces the assumptions in 2SLS 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 the selected sample is introduced into the structural function of rice yield through the Heckman procedure to correct sample selection bias. In addition, newly generated regressors of interaction terms between an input and its residual are included in the regression through control functions to account for correlations of unobservable factors and rice yield (column [4]). To measure the impact of poverty on producers' input use, we also introduced interaction between household poverty status and endogenous variables in column (5).

Table 4.3—Estimation results of rice yield function

	OLS	2SLS	Heckman		
Dependent variable = rice yield	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Inputs for rice production					
family labor	0.012	0.035	0.048	0.047	0.047
	(0.00)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***
hired labor	0.005	0.051	0.056	0.057	0.058
	(0.00)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***
fertilizer	0.101	0.136	0.137	0.164	0.170
	(0.01)***	(0.02)***	(0.02)***	(0.02)***	(0.02)***
irrigation	0.028	0.028	0.048	0.050	0.044
	(0.00)***	(0.02)	(0.02)**	(0.02)**	(0.02)*
Household characteristics					
share of rice in total crop land	-0.045	-0.076	-0.091	-0.084	-0.081
	(0.01)***	(0.02)***	(0.02)***	(0.02)***	(0.02)***
share of sale in total rice harvest	0.008	0.003	0.003	0.003	0.003
	(0.00)***	(0.00)***	(0.00)***	(0.00)***	(0.00)***
male	0.013	0.010	0.013	0.012	0.011
	(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	0.003	-0.000	-0.001	-0.000	-0.000
	(0.00)***	(0.00)	(0.00)	(0.00)	(0.00)

Table 4.3—Continued

Dependent variable = rice yield	OLS (1)	2SLS (2)	Heckman (3)	Heckman (4)	Heckman (5)
marital status	-0.014 (0.01)*	-0.013 (0.01)	-0.011 (0.01)	-0.010 (0.01)	-0.010 (0.01)
being minority	-0.018 (0.01)	0.024 (0.03)	0.054 (0.03)*	0.052 (0.03)	0.055 (0.03)*
being a poor household	-0.026 (0.01)***	0.014 (0.01)	0.016 (0.01)**	0.016 (0.01)**	0.027 (0.03)
Commune characteristics					
share of irrigated annual crop land	0.007 (0.00)***	0.006 (0.00)***	0.004 (0.00)*	0.005 (0.00)**	0.004 (0.00)*
having power supply	0.055 (0.05)	0.027 (0.08)	0.030 (0.06)	0.014 (0.06)	0.019 (0.06)
distance to nearest market	-0.003 (0.00)***	-0.001 (0.00)	0.000 (0.00)	-0.000 (0.00)	-0.000 (0.00)
distance to nearest extension	0.000 (0.00)	0.003 (0.00)	0.003 (0.00)*	0.002 (0.00)	0.002 (0.00)
being a poor commune	-0.063 (0.01)***	-0.033 (0.02)	-0.009 (0.03)	-0.016 (0.02)	-0.014 (0.02)
Climate factor					
average precipitation	-0.000 (0.00)	0.000 (0.00)	0.000 (0.00)	0.000 (0.00)	0.000 (0.00)
average temperature	-0.015 (0.00)***	-0.038 (0.01)***	-0.037 (0.01)***	-0.038 (0.01)***	-0.038 (0.01)***
variability of precipitation	0.000 (0.00)**	0.000 (0.00)	0.000 (0.00)	0.000 (0.00)	0.000 (0.00)
variability of temperature	0.023 (0.08)	0.441 (0.15)***	0.404 (0.14)***	0.451 (0.13)***	0.445 (0.13)***
drought over the past 3 years	-0.027 (0.01)**	-0.014 (0.01)	-0.011 (0.01)	-0.008 (0.01)	-0.007 (0.01)
flood over the past 3 years	0.018 (0.01)***	0.017 (0.01)**	0.013 (0.01)*	0.014 (0.01)**	0.014 (0.01)*
typhoon over the past 3 years	0.006 (0.01)	0.003 (0.01)	0.004 (0.01)	0.005 (0.01)	0.004 (0.01)
drought over the past year	0.075 (0.02)***	0.009 (0.03)	0.001 (0.02)	0.009 (0.02)	0.009 (0.02)
flood over the past year	-0.027 (0.02)	0.000 (0.02)	0.008 (0.02)	0.004 (0.02)	0.004 (0.02)
typhoon over the past year	0.022 (0.02)	0.029 (0.02)	0.029 (0.02)	0.028 (0.02)	0.028 (0.02)
Predicted/pseudo residuals					
hired labor residual			-0.053 (0.01)***	-0.054 (0.01)***	-0.058 (0.01)***
fertilizer residual			-0.046 (0.02)**	-0.009 (0.02)	-0.034 (0.02)*
irrigation residual			-0.021 (0.02)	-0.006 (0.02)	-0.003 (0.02)
inverse of the Mills ratio			0.033 (0.02)	0.022 (0.02)	0.021 (0.02)
Residual interactions					
irrigation × its residual				0.004 (0.00)***	0.004 (0.00)***
fertilizer × its residual				0.016 (0.00)***	0.017 (0.00)***
hired labor × its residual				-0.002 (0.00)***	-0.002 (0.00)***
poor × hired labor					-0.006 (0.00)
poor × hired labor residual					0.010 (0.00)**

Table 4.3—Continued

Dependent variable = rice yield	OLS (1)	2SLS (2)	Heckman (3)	(4)	(5)
poor × hired labor X hired labor residual					-0.000
					(0.00)
poor ×fertilizer					-0.010
					(0.02)
poor × fertilizer residual					0.042
					(0.02)***
poor × fertilizer × fert. residual					0.001
					(0.00)
poor × household irrigation					0.013
					(0.01)**
poor × hh. irrigation residual					-0.007
					(0.01)
poor × hh. irr. X irr. residual					0.001
					(0.00)
poor × commune irrigation					0.001
					(0.00)
Constant	1.980	2.438	2.486	2.479	2.474
	(0.14)***	(0.22)***	(0.19)***	(0.18)***	(0.18)***
Observations	9124	9124	25579	25579	25579
R^2/log likelihood	0.46	0.13	-9318	-9148	-9117
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		15.14			
F statistic of endogeneity of instruments		41.40			
p-value of endogeneity of instruments		0.00			
rho (correlation of yield residual with sample selection residual)			0.000	0.000	0.000
			(0.006)	(0.007)	(0.007)
sigma (sigma of rice yield)			0.244	0.239	0.238
			(0.005)	(0.005)	(0.005)
p-value of Wald test of indep. eqns. (rho = 0)			0.999	1.000	1.000

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

The results in Table 4.3 show that the coefficients of labor and fertilizer in 2SLS estimation are considerably larger in magnitude than those 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 the standard error slightly. The discussion will be focused on Heckman model results.

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 both home and hired labor are about 0.05. A 1 percent increase in fertilizer spending in the field can increase paddy yield by 0.14 to 0.17 percent, and a 1 percent increase in irrigation spending can lead to a 0.04 to 0.05 percent increase in yield. Higher rice yields are generally observed among households with diversified production. Households that actively participate in the market enjoy a small yield advantage.

Most ethnic minorities live in the mountainous and poorer regions of the north and the Central Highlands, and mainly depend on agricultural incomes. Increasing rice production can thus help rural ethnic-minority households to boost income, escape poverty, and improve their food security (Nguyen 2006; Swinkels and Turk 2006). The coefficient of the household head's ethnicity is negative and statistically insignificant in OLS estimation, but it becomes positive and significant using Heckman as reported in columns (3) and (5), suggesting the existence of possible correlations between household characteristics and other unobservable household factors.

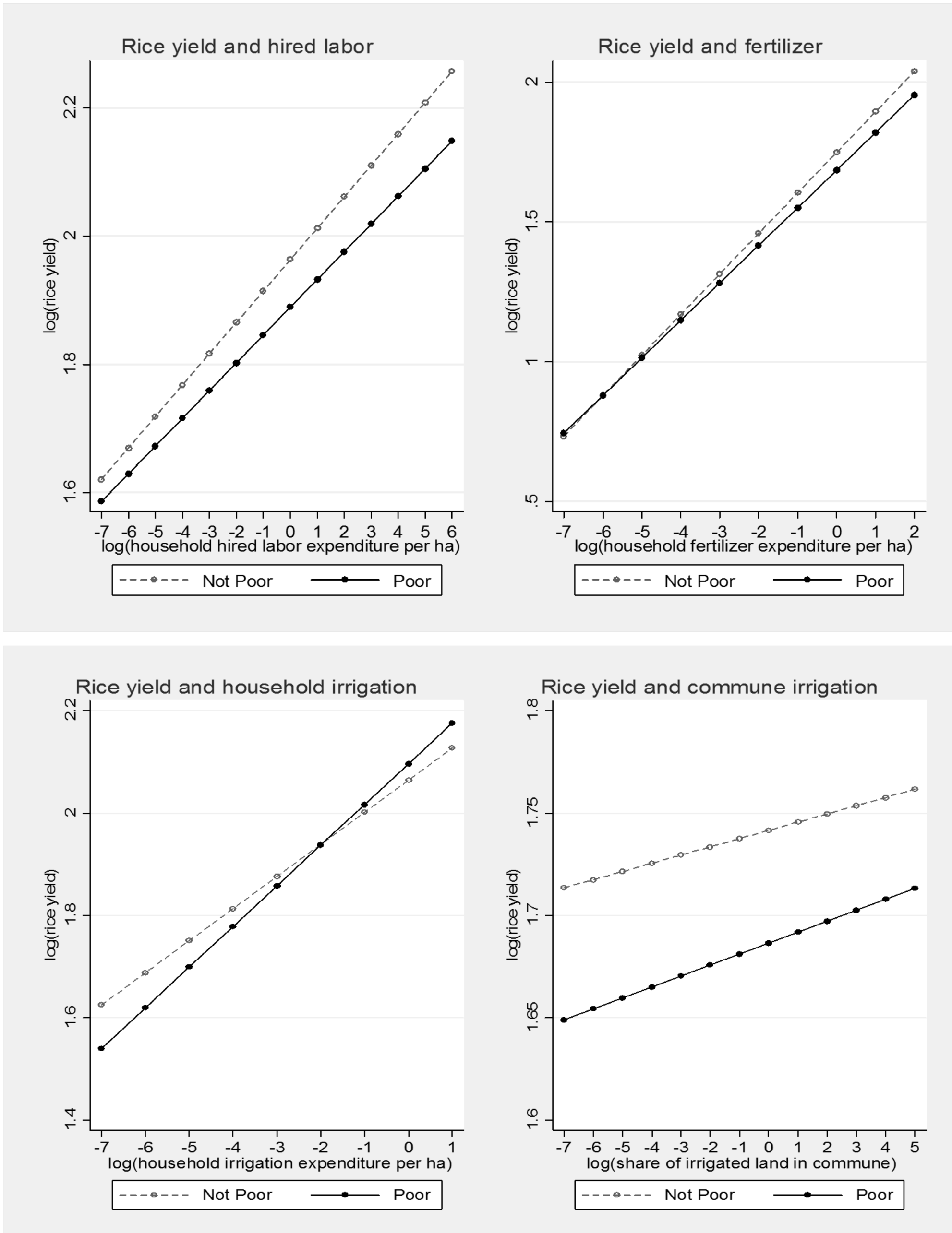
Although several of the coefficients on commune characteristics are statistically significant in OLS, they are not significant in 2SLS, indicating that OLS results could be misleading due to inconsistency and bias. However, most of the coefficients on demographics and commune characteristics are quite similar in the 2SLS and Heckman estimations, likely due to the exogeneity of these variables. The results of the input demand function suggest that investment in rural infrastructure improves yields indirectly through the positive correlation between infrastructure and endogenous inputs. Moreover, the Heckman estimation confirms that infrastructure can contribute to yield growth directly by facilitating access to market and knowledge.

Climate change has an impact on rice production in Asia, which is consistent with other studies (Zhai and Zhuang 2009; Zhu and Trinh 2010; Lobell et al. 2008). We observe a negative correlation between rice yield and long-term average temperature in the yield equation. High temperature can also be a restrictive factor to rice production indirectly because farmers are forced to spend more on irrigation, discouraging fertilizer and other input use. In addition, the input demand function has demonstrated that large variability in weather patterns, especially in temperature, discourage farmers from investing and can reduce productivity. Table 4.3 concurs with this finding and reports positive correlation between reliable temperature and crop yield. Although past weather events could affect farmers' demand for inputs, their direct impacts on rice yields are mostly insignificant except for floods. As we suspected, higher yield is reported in areas with high occurrence of flood, because rice yields tend to be usually higher in fertile river deltas and coastal areas with extensive waterways, which are also more likely to experience floods.

The coefficients on residuals are statistically significant for endogenous inputs (hired labor and fertilizer) as shown in column (3). This result implies that they are 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 is introduced to capture potential nonlinear correlations between rice yield inputs and unobservable factors (columns [4] and [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 inputs, their residuals, and poverty in the rice yield equation highlights the different impact of inputs on yield by poverty status (column [5]). As presented in Figure 4.1, the upward trend suggests the positive contribution of input intensification in yield improvement for both poor and nonpoor households. What's more, rice yield increases faster in nonpoor 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 on hired labor increases from 20,000 to 50,000 dong per hectare (from -4 to -3 in log term in *x*-axis), average rice yield is projected to increase from 6.0 to 6.3 tons per hectare (1.78 to 1.83 in log term in *y*-axis) for nonpoor 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. Poor households face more physical, knowledge, and credit constraints that 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 4.1.

Figure 4.1—Elasticities of rice yield to inputs



Source: Authors' estimation using VHLSS 2004 and 2006.

The response line of rice yield to household irrigation expense for the poor households crosses with that of nonpoor households. Whereas nonpoor households report higher average rice yields at very low irrigation use, poor households begin to catch up as irrigation expense reaches higher levels and may even surpass nonpoor households when irrigation use is at the 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 tons per hectare for nonpoor households, which is 5.7 percent higher than poor households' average. Again, the graph shows that the average yield of poor households is less responsive to irrigation intensity than their nonpoor counterparts in most cases (poor households usually spend less on inputs). Moreover, the yield gain of poor households grows when irrigation use increases. 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.

Fertilizer response tells a similar story as the average rice yield grows as fertilizer expenditure increases. In most cases, the predicted yield for the poor falls below that of the nonpoor, although we find poor households enjoying a small yield advantage at low levels of fertilizer spending. However, the yield gap between poor and nonpoor households is smaller when compared with irrigation. This is not surprising given the wide application of chemical fertilizer in the country (about 97 percent of households use fertilizer in rice production).

The coefficient on the inverse of the Mills ratio is insignificant in Table 4.3 even after accounting for heterogeneity of rice yield through inclusion of interaction terms of the residuals and endogenous inputs in the structural equation (columns [3] through [5]). The structural error term is uncorrelated with the error of the sample selection equation because the Wald test yields a p-value of 0.999. This suggests that the unobservable factors associated with selecting rice producers into the estimation sample are separable from unobservables that are correlated with rice yield.

Discussion of Instruments

In Table 4.2, the joint F and χ^2 tests show that the entire set of instruments z is valid for both the input demand and sample selection equations. This discussion will focus on the validity of excluded instruments z_2 (Table 4.2).

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 the χ^2 statistic in selection equations 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 from 26.51 to 165.08 for endogenous inputs and is 47.16 for sample selection (Table 4.2), all with p-values = 0.00, confirming the validity of instruments for individual endogenous variables. In addition, the partial R^2 statistic measures the correlation between an endogenous variable and the excluded instruments after partialling out the effect of exogenous variables, showing that the predictive power of the instruments is decent in endogenous inputs and sample selection equations (Table 4.2).

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 4.3 2SLS) indicate that the inputs into the yield function are endogenous (regression-based test of exogeneity statistic is 41.40 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 Yogo 2005) using the Cragg-Donald minimum eigenvalue statistic. In this paper, there are four endogenous regressors (including the sample selection variable) and 31 instruments, and the eigenvalue statistic of three endogenous regressors and eight excluded instruments is 15.14. From Table 1 of Stock and Yogo (2005) the critical value of 2SLS relative bias (the bias of the 2SLS estimator relative to the bias of the OLS estimator) at 5 percent is 15.18 and at 10 percent is 9.01. It suggests that if we are willing to tolerate a 5 percent relative bias, we can reject the null hypothesis test of weak instruments and conclude that our instruments are not weak.

Sensitivity Analysis

To examine the robustness of this analysis, the Heckman model with endogenous inputs is applied under different 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 consumption quantity, available only for 2006, is used to substitute for fertilizer value in the estimation to examine price-induced endogeneity. Appendix Table B.1 compares the estimated results of fertilizer demand and the yield equation based on fertilizer expense and quantity in 2006. The coefficients of the fertilizer quantity equation are either similar to or larger than those of the fertilizer expense equation, suggesting that the amount of fertilizer use is more responsive to external factors such as household and community characteristics. The F-test statistic for excluded instruments is 49.13, far above 10 with p-value = 0.000. The partial R^2 value is 0.10 in the fertilizer expense equation and 0.08 in the quantity equation, suggesting that the excluded variables are valid with predictive power. The eigenvalue statistic of 7.14 falls between 10 and 20 percent critical value (based on Stock and Yogo's [2005] tabulation), indicating that fertilizer quantity is a weaker instrument compared with fertilizer value.

The coefficients for the Heckman estimation models are quite close in most cases but understandably differ for fertilizer. Combined with the demand equation, the results show that studies based on input value might lead to yield responses at a different magnitude, but the impact does not spread to contaminate other parameter estimations. Figure 4.2 compares yield elasticities under different definitions of fertilizer and demonstrates some common trends: yield responds 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 at low fertilizer levels, but average yield rises at a faster pace among nonpoor households as fertilizer use increases.

Figure 4.2—Elasticities of rice yield to inputs, left figure based on fertilizer value and right figure on fertilizer quantity

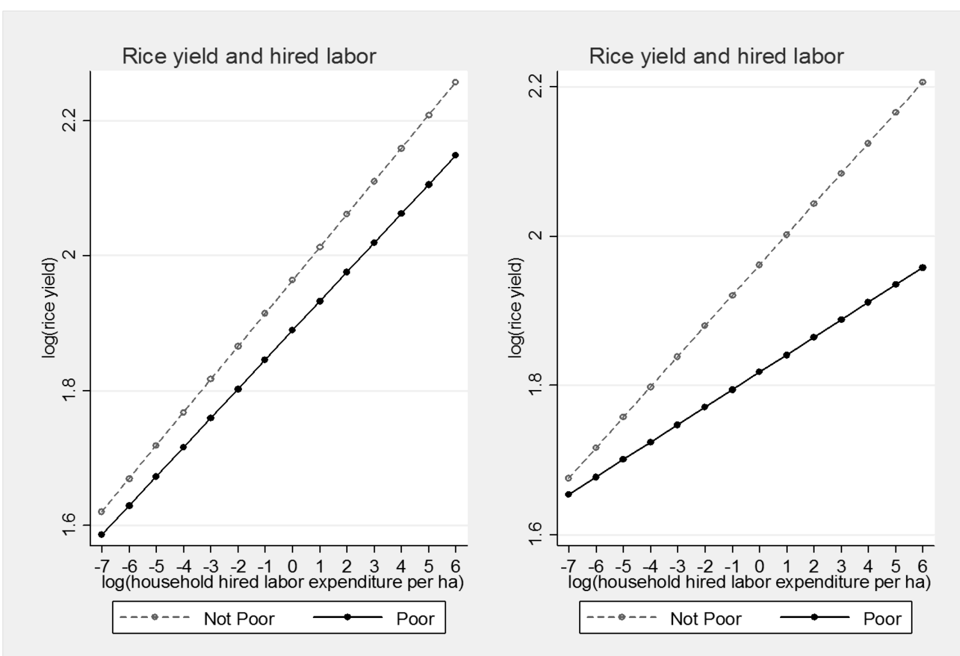


Figure 4.2—Continued

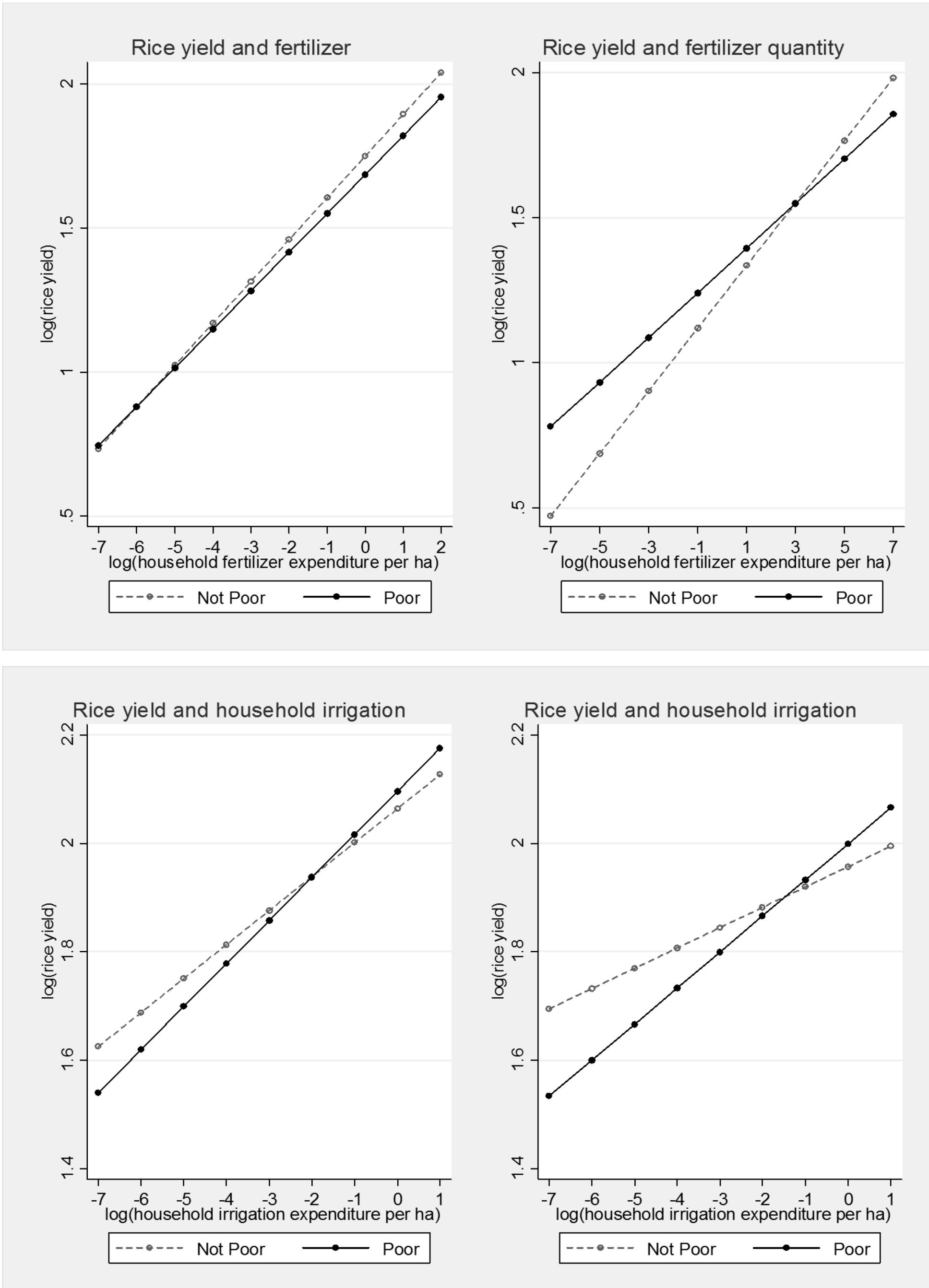
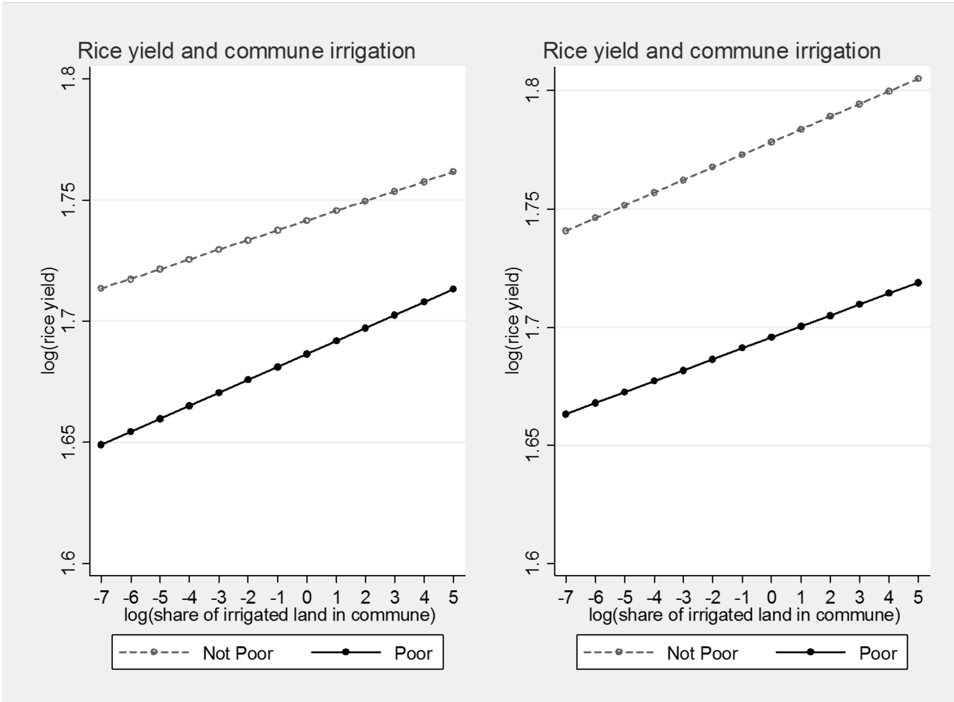


Figure 4.2—Continued



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

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 producers of rice. If ranked by rice production in 2006 of the sample, the Mekong River Delta and Red River Delta together account for about 70 percent of total rice production in Vietnam. We will assess the difference in rice yield functions between the deltas and other regions under different biophysical conditions. The comparison of coefficients for the deltas and other agroecological zones are shown in Appendix Table B.2, and yield response by household poverty status is illustrated in Figure 4.3. Similar to the stories in Figures 4.1 and 4.2, there is generally an upward trend between input use and rice yield, and average yields of poor households are lower than those of their nonpoor counterparts. However, the yield response line can be quite different between major and minor rice-producing zones. For example, rice production is highly labor intensive. The top two graphs illustrate the positive correlation between hired labor use and rice yield. As expected, the average yield is lower among the poor households. However, the response line for the poor is steeper than that of the nonpoor in the delta zones, suggesting that the predicted yield gain should be greater in nondelta zones if hired labor expense increases by the same amount. In other words, the poor in the delta are catching up with the nonpoor in yield through intensification. On the other hand, the yield gap between poor and nonpoor households grows larger as input levels increase, implying that there are other factors limiting yield improvement. Given the substantial regional variations in crop production, localized policy packages targeting poverty reduction are key for promoting adaptation to climate change and poverty reduction.

Figure 4.3—Elasticities of rice yield to inputs, left figure based on delta zones and right figure on other agroecological zones

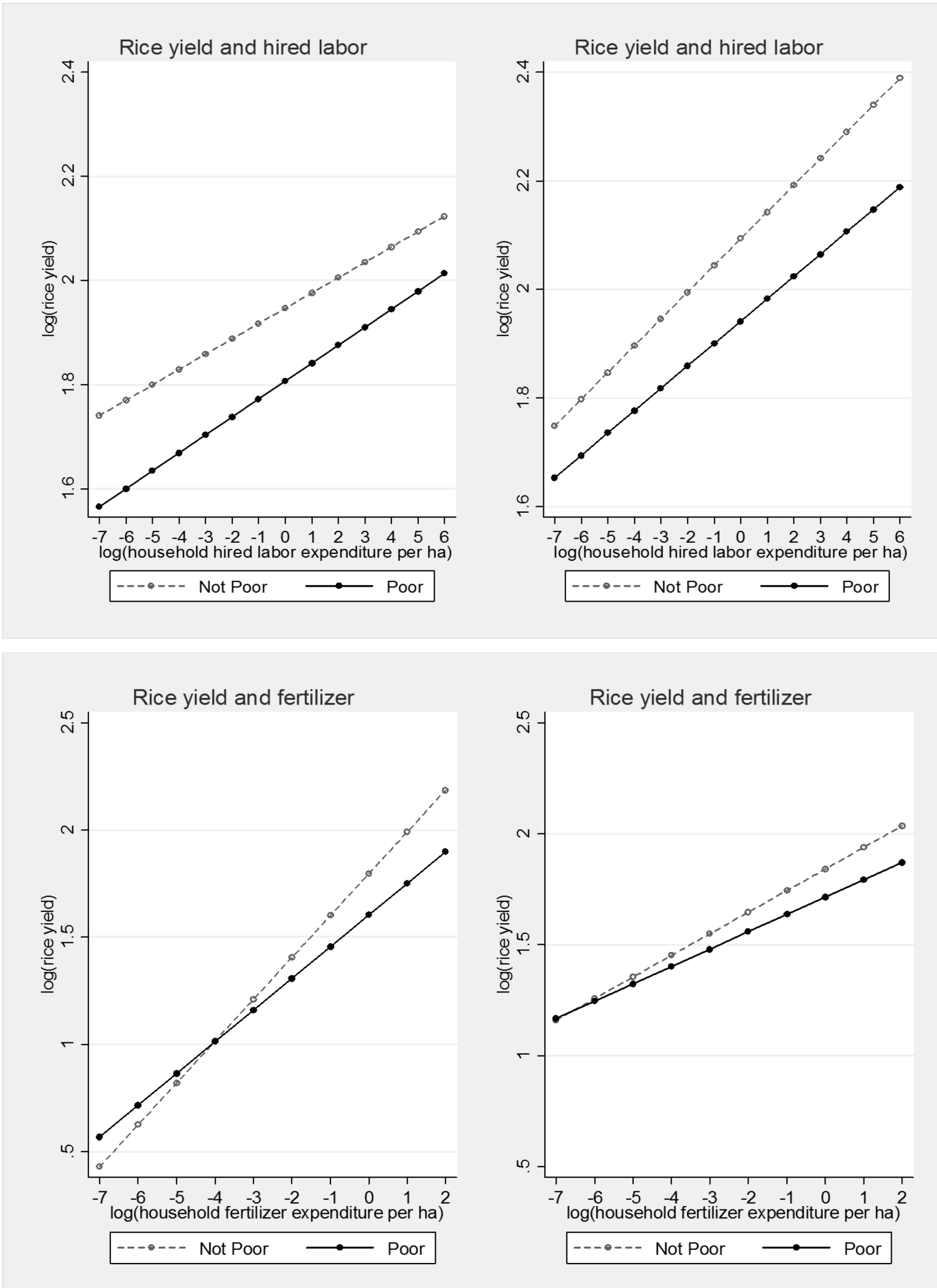
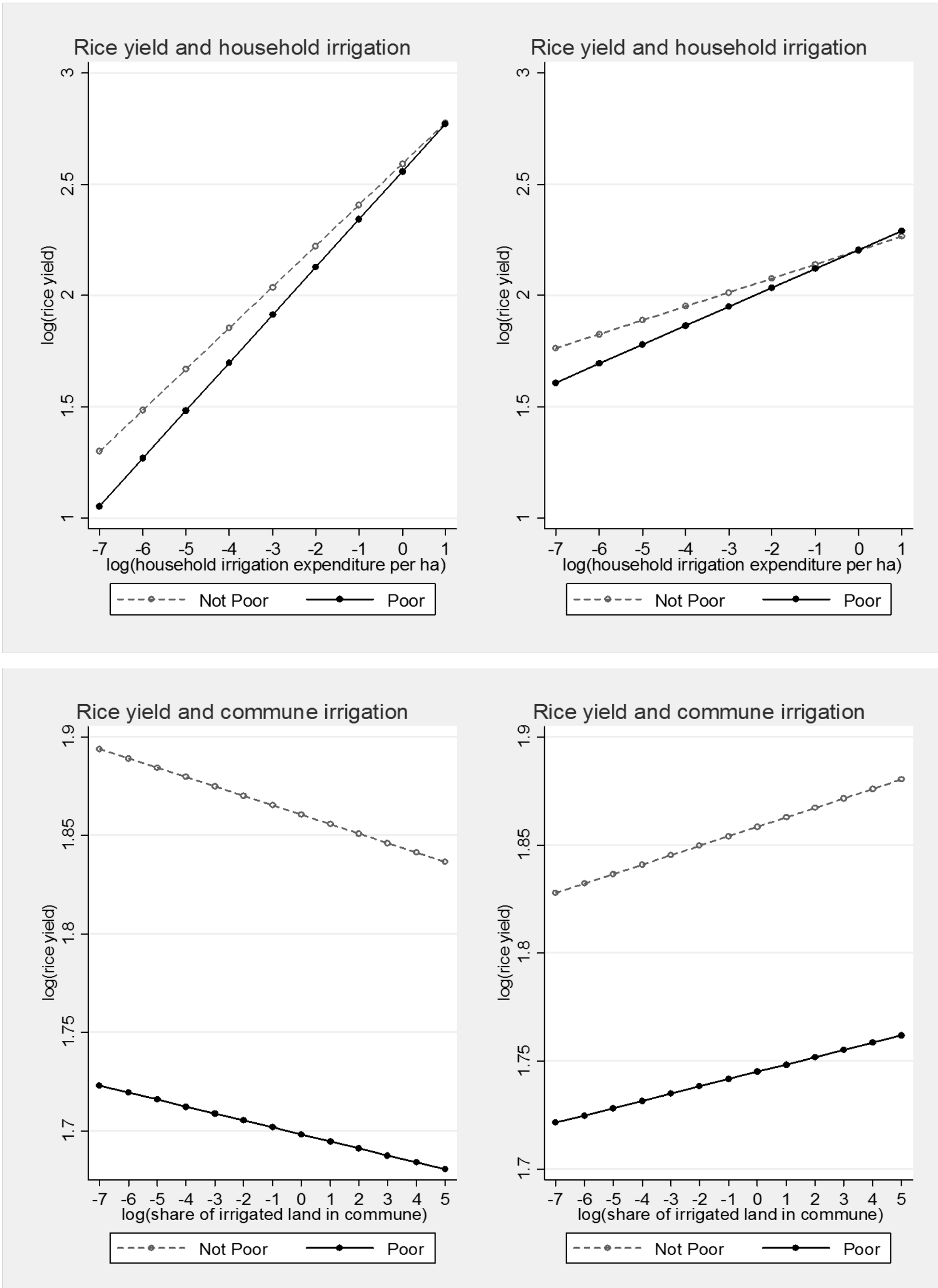


Figure 4.3—Continued



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

Third, to investigate the potential impact of outliers in this estimation, we also run the same model specification excluding extreme values of yield at both ends. The largest and smallest five observations for rice yields, together 0.11 percent of the sample, are dropped from the estimation. The coefficients in Appendix Table B.3 are quite similar in many cases, showing the robustness of the model specification.

The estimated coefficients on the inverse of the Mills ratio are statistically significant in the second and third sensitivity tests, namely sample breakdown by agroecological zone or excluding extreme values (Appendix Tables B.2 and B.3). This finding justifies the model specification of Heckman with the control function approach because it corrects for sample selectivity bias, even though we did not find statistical evidence in the full sample.

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).

5. CONCLUSIONS AND POLICY IMPLICATIONS

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, the 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. Natural endowment and changing climate conditions play important roles both in producers' decisions about growing rice and in determining rice yields. Changes in climate can also affect crop yields indirectly by affecting the intensity of input use (irrigation, labor, and fertilizer) as farmers opt to increase or decrease input use depending on biophysical conditions. In addition, we find that Vietnamese farmers adjust their production with respect to climate change through decisions on whether to grow rice and the intensity of input use, which is consistent with production theory. Farmers choose to allocate inputs according to long-term climate patterns while quickly adjusting input levels within the season to minimize losses when faced with external weather shocks.

We also show that improved agricultural management practices and investment in rural infrastructure and human capital can mitigate the negative impact of climate change and are thus key elements of climate adaptation policy (Falco, Veronesi, and Yesuf 2011). Specifically we find that instead of directly affecting crop yields, improvements in rural infrastructure can contribute to yield growth indirectly by facilitating input 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).

Although our results suggest a generally positive response to input intensification, yield responses differ starkly across different agroecological conditions and the poverty status of households. For instance, whereas additional communal irrigation canals may not help boost rice yields in the deltas, in other regions rice farmers are likely to strongly benefit from additional irrigation facilities (Figure 4.1). Similarly, the poor report lower crop yields due to more challenging geographic conditions, insufficient road connections, and lack of market access.

These results support the argument that the promotion of modern technology and infrastructure is an effective instrument to promote climate change resilience, poverty reduction, and development among ethnic minorities at the same time. The recent stagnation in rice productivity also underscores the urgent need for substantial investment in agricultural research and development (R&D) to reinvigorate productivity growth (Minot, Baulch, and Epprecht 2006; Nin-Pratt, Yu, and Fan 2010). In Vietnam, the economic return is estimated to be 12.22 dong for each dong used for agricultural R&D (Fan, Huong, and Long 2004). In preparation for future climate change, it is thus also important to invest in agricultural R&D in order to supply farmers with high-input-responsive, high-yield, drought- and flood-tolerant crop varieties.

Vietnam has proved that agriculture-led growth can rapidly reduce poverty. Results of this study suggest that if Vietnamese farmers are supported in their fight against climate change, the country is likely not only to continue its successes in reducing rural poverty but also to become a champion in climate change adaptation.

APPENDIX A: THE CONTROL FUNCTION APPROACH

Parameter estimates can 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 Vuong 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 a more precise and efficient estimator than the instrument variable (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 (A1), y_2 the endogenous explanatory variable (a scalar), and *z* the vector of exogenous variables including *X* and *M* in equation (A1) with unity as its first element. Consider the model

$$y_1 = z_1\delta_1 + a_1 y_2 + u_1, \tag{A1}$$

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

$$\mathrm{E}(z' u_1) = 0. \tag{A2}$$

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

$$y_2 = z\pi_2 + v_2 \tag{A3}$$

$$\mathrm{E}(z' v_2) = 0,$$

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

$$u_1 = \rho_1 v_2 + e_1, \tag{A4}$$

where $\rho_1 = \mathrm{E}(v_2 u_1)/\mathrm{E}(v_2^2)$ is the population regression coefficient. By definition, $\mathrm{E}(v_2 e_1) = 0$ and $\mathrm{E}(z' e_1) = 0$ 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 (A4) into equation (A1) gives

$$y_1 = z_1\delta_1 + a_1 y_2 + \rho_1 v_2 + e_1, \tag{A5}$$

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 that 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

$$y_1 = z_1\delta_1 + a_1 y_2 + \rho_1 \hat{v}_2 + \text{error}, \tag{A6}$$

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 CF 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 generalized residual from reduction-form regression to the structural regression. The CF estimates are no longer the same as 2SLS estimates, generating a more precise estimator than the 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.

APPENDIX B: SUPPLEMENTARY TABLES AND FIGURE

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

	Fertilizer demand		Heckman basic		Heckman interaction		Heckman pov. inter.	
Dependent variable = rice yield	**expense**	**quantity**	**expense**	**quantity**	**expense**	**quantity**	**expense**	**quantity**
Inputs for rice production								
household labor	0.06	0.09	0.029	0.028	0.031	0.030	0.030	0.029
	(0.01)***	(0.03)***	(0.01)**	(0.01)**	(0.01)***	(0.01)**	(0.01)***	(0.01)**
hired labor			0.038	0.039	0.040	0.041	0.044	0.046
			(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***
fertilizer			0.130	0.078	0.146	0.099	0.166	0.118
			(0.02)***	(0.01)***	(0.03)***	(0.02)***	(0.03)***	(0.02)***
irrigation			0.040	0.026	0.045	0.035	0.035	0.027
			(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Household characteristics								
share of sale in total rice harvest	0.02	0.02	0.002	0.003	0.002	0.003	0.002	0.003
	(0.00)***	(0.01)***	(0.00)	(0.00)*	(0.00)	(0.00)*	(0.00)	(0.00)*
share of rice in total crop land	-0.20	-0.18	-0.050	-0.055	-0.046	-0.052	-0.043	-0.052
	(0.10)**	(0.19)	(0.02)**	(0.02)**	(0.02)*	(0.02)**	(0.02)*	(0.02)**
male	0.02	0.06	0.003	-0.003	0.001	-0.004	-0.001	-0.005
	(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	0.02	0.04	-0.001	-0.001	-0.000	-0.001	-0.000	-0.001
	(0.01)***	(0.01)***	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
marital status	0.06	0.10	-0.022	-0.023	-0.021	-0.021	-0.021	-0.020
	(0.04)	(0.07)	(0.01)**	(0.01)**	(0.01)**	(0.01)**	(0.01)**	(0.01)**
being minority	-0.33	-0.46	0.058	0.032	0.061	0.040	0.069	0.048
	(0.07)***	(0.13)***	(0.05)	(0.05)	(0.04)	(0.05)	(0.04)	(0.05)
being a poor household	-0.06	-0.04	0.009	0.007	0.006	0.005	0.056	0.244
	(0.04)	(0.08)	(0.01)	(0.01)	(0.01)	(0.01)	(0.05)	(0.13)*
Commune characteristics								
share of irrigated annual crop land	0.03	0.04	0.005	0.006	0.005	0.005	0.005	0.005
	(0.01)**	(0.02)**	(0.00)*	(0.00)**	(0.00)*	(0.00)**	(0.00)	(0.00)*
having power supply	1.98	3.70	0.150	0.112	0.119	0.057	0.134	0.093
	(0.46)***	(0.89)***	(0.10)	(0.11)	(0.10)	(0.11)	(0.10)	(0.11)
distance to nearest market	-0.02	-0.04	-0.001	-0.001	-0.001	-0.001	-0.000	-0.001
	(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	-0.20	-0.60	-0.038	-0.057	-0.036	-0.051	-0.029	-0.042
	(0.08)***	(0.17)***	(0.03)	(0.03)**	(0.03)	(0.03)*	(0.03)	(0.03)

Table B.1—Continued

	Fertilizer demand		Heckman basic		Heckman interaction		Heckman pov. inter.	
Dependent variable = rice yield	**expense**	**quantity**	**expense**	**quantity**	**expense**	**quantity**	**expense**	**quantity**
Climate factor								
average precipitation	-0.00	-0.00	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)
average temperature	-0.04	-0.12	-0.023	-0.022	-0.024	-0.022	-0.025	-0.022
	(0.02)	(0.05)**	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***
variability of precipitation	-0.00	-0.00	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)
variability of temperature	-1.21	-1.52	0.387	0.408	0.409	0.409	0.425	0.409
	(0.43)***	(0.79)*	(0.15)**	(0.15)***	(0.15)***	(0.15)***	(0.15)***	(0.15)***
drought over the past 3 years	0.03	0.11	-0.029	-0.035	-0.027	-0.031	-0.024	-0.027
	(0.08)	(0.14)	(0.01)**	(0.01)**	(0.01)*	(0.01)**	(0.01)*	(0.01)*
flood over the past 3 years	0.02	-0.01	0.020	0.025	0.019	0.024	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	0.03	0.03	-0.016	-0.015	-0.013	-0.014	-0.013	-0.015
	(0.04)	(0.08)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
drought over the past year	0.16	0.41	0.035	0.024	0.042	0.032	0.038	0.027
	(0.14)	(0.26)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
flood over the past year	0.10	0.19	-0.031	-0.035	-0.033	-0.033	-0.034	-0.035
	(0.11)	(0.20)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
typhoon over the past year	0.12	0.14	0.055	0.062	0.054	0.061	0.053	0.059
	(0.11)	(0.24)	(0.02)**	(0.02)***	(0.02)**	(0.02)***	(0.02)**	(0.02)***
Predicted/pseudo residuals								
hired labor residual			-0.035	-0.036	-0.039	-0.041	-0.045	-0.048
			(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***
fertilizer residual			-0.041	-0.034	-0.021	-0.042	-0.056	-0.070
			(0.02)*	(0.01)**	(0.02)	(0.02)***	(0.03)**	(0.02)***
irrigation residual			-0.014	0.001	-0.007	0.005	-0.002	0.009
			(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
inverse of the Mills ratio			0.020	0.007	0.015	0.004	0.016	0.004
			(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Residual interactions								
irrigation × its residual								
fertilizer × its residual								
hired labor × its residual								
					0.003	0.003	0.003	0.003
poor × hired labor					(0.00)**	(0.00)**	(0.00)*	(0.00)*
					0.009	0.004	0.012	0.006
poor × hired labor residual					(0.00)***	(0.00)***	(0.00)***	(0.00)***
					-0.002	-0.002	-0.002	-0.002

Table B.1—Continued

Dependent variable = rice yield	Fertilizer demand		Heckman basic		Heckman interaction		Heckman pov. inter.	
	expense	quantity	expense	quantity	expense	quantity	expense	quantity
poor × hired labor X hired labor residual					(0.00)***	(0.00)***	(0.00)***	(0.00)***
							-0.012	-0.015
poor ×fertilizer							(0.01)**	(0.01)**
							0.019	0.021
poor × fertilizer residual							(0.01)***	(0.01)***
							-0.001	-0.001
poor × fertilizer × fert. residual							(0.00)	(0.00)
							-0.032	-0.035
poor × household irrigation							(0.03)	(0.02)*
							0.064	0.047
poor × hh. irrigation residual							(0.02)***	(0.02)***
							-0.001	-0.002
poor × hh. irr. X irr. residual							(0.00)	(0.00)
							0.027	0.027
poor × commune irrigation							(0.01)***	(0.01)***
							-0.015	-0.017
Excluded instruments								
chemical	0.17	0.28						
	(0.02)***	(0.05)***						
machinery rental	0.03	0.05						
	(0.01)***	(0.01)***						
per capita household income	0.04	0.10						
	(0.03)	(0.07)						
household size	-0.10	-0.14						
	(0.04)**	(0.08)*						
being literate	0.42	0.82						
	(0.13)***	(0.24)***						
distance to nearest transportation	-0.34	-0.36						
	(0.08)***	(0.16)**						
being a remote commune	0.00	0.01						
	(0.01)	(0.01)						
having infrastructure program	0.00	0.08						
	(0.04)	(0.08)						
Constant	0.98	7.38	2.061	1.576	2.117	1.532	2.070	1.379
	(1.00)	(1.94)***	(0.22)***	(0.26)***	(0.22)***	(0.26)***	(0.22)***	(0.27)***
Observations	4525	4525	11055	11055	11055	11055	11055	11055
R^2/log likelihood	0.39	0.33	-2874	-2893	-2835	-2847	-2801	-2808
p-value of F/χ^2 test for joint coefficients = 0	11.9	10.9	0.00	0.00	0.00	0.00	0.00	0.00
Partial R^2 on excluded instruments	0.10	0.08						

Table B.1—Continued

Dependent variable = rice yield	Fertilizer demand		Heckman basic		Heckman interaction		Heckman pov. inter.	
	expense	quantity	expense	quantity	expense	quantity	expense	quantity
F test for excluded instruments = 0	63.06	49.13						
p-value of F/χ^2 test for excluded instruments = 0	0.00	0.00						
rho (correlation of yield residual with sample selection residual)			-0.090	-0.092	-0.084	-0.083	-0.081	-0.080
			(0.05)	(0.054)	(0.05)	(0.053)	(0.049)	(0.052)
sigma (sigma of rice yield)			0.239	0.240	0.236	0.237	0.235	0.235
			(0.007)	(0.007)	(0.007)	(0.007)	(0.006)	(0.006)
p-value of Wald test of indep. eqns. (rho = 0)			0.071	0.088	0.098	0.120	0.103	0.125

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

Table B.2—Comparison of estimation results for delta and nondelta agroecological zones

Dependent variable = rice yield	2SLS		Heckman basic		Heckman interaction		Heckman pov. inter.	
	delta	nondelta	delta	nondelta	delta	nondelta	delta	nondelta
Inputs for rice production								
family labor	0.020	0.042	0.031	0.087	0.030	0.074	0.021	0.073
	(0.01)**	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***
hired labor	0.032	0.037	0.032	0.051	0.033	0.050	0.032	0.051
	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***
fertilizer	0.236	0.112	0.231	0.120	0.263	0.141	0.205	0.148
	(0.08)***	(0.02)***	(0.05)***	(0.02)***	(0.05)***	(0.02)***	(0.06)***	(0.02)***
irrigation	0.157	0.036	0.211	0.061	0.201	0.059	0.164	0.049
	(0.06)***	(0.02)*	(0.04)***	(0.02)***	(0.04)***	(0.02)***	(0.04)***	(0.02)***
Household characteristics								
share of rice in total crop land	-0.112	-0.083	-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	0.003	0.003	0.003
	(0.00)**	(0.00)**	(0.00)***	(0.00)**	(0.00)***	(0.00)**	(0.00)***	(0.00)**
male	0.043	-0.001	0.050	-0.002	0.045	-0.000	0.043	-0.000
	(0.02)**	(0.02)	(0.01)***	(0.01)	(0.01)***	(0.01)	(0.01)***	(0.01)
age	-0.002	-0.001	-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	0.003
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)*	(0.00)	(0.00)**
marital status	0.005	-0.014	0.014	-0.016	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	0.034	-0.059	0.084	-0.052	0.073	-0.064	0.076
	(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	-0.003	0.106	0.018
	(0.02)*	(0.01)	(0.01)***	(0.01)	(0.01)***	(0.01)	(0.05)**	(0.03)

Table B.2—Continued

Dependent variable = rice yield	2SLS		Heckman basic		Heckman interaction		Heckman pov. inter.	
	delta	nondelta	delta	nondelta	delta	nondelta	delta	nondelta
Commune characteristics								
share of irrigated annual crop land	-0.005	0.007	-0.007	0.004	-0.006	0.006	-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	0.061	-0.045	0.056	-0.054	0.053	-0.026	0.077
	(0.04)	(0.07)	(0.03)	(0.06)	(0.03)**	(0.06)	(0.03)	(0.05)
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	-0.050	0.065	-0.007	0.057	-0.021	0.042	-0.015
	(0.03)	(0.03)*	(0.02)***	(0.03)	(0.02)**	(0.03)	(0.02)*	(0.03)
Climate factor								
average precipitation	0.000	-0.000	0.001	0.000	0.001	0.000	0.001	-0.000
	(0.00)	(0.00)	(0.00)***	(0.00)	(0.00)***	(0.00)	(0.00)**	(0.00)
average temperature	0.000	-0.037	0.000	-0.033	0.000	-0.036	0.000	-0.036
	(0.00)	(0.01)***	(0.00)	(0.01)***	(0.00)	(0.01)***	(0.00)	(0.01)***
variability of precipitation	0.000	0.000	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)
variability of temperature	0.000	0.312	0.000	0.186	0.000	0.393	0.000	0.333
	(0.00)	(0.37)	(0.00)	(0.36)	(0.00)	(0.35)	(0.00)	(0.30)
drought over the past 3 years	0.002	-0.003	0.027	0.002	0.020	0.006	-0.011	0.005
	(0.05)	(0.01)	(0.03)	(0.01)	(0.03)	(0.01)	(0.03)	(0.01)
flood over the past 3 years	-0.012	0.021	-0.020	0.019	-0.017	0.020	-0.010	0.015
	(0.01)	(0.01)**	(0.01)**	(0.01)**	(0.01)**	(0.01)**	(0.01)	(0.01)*
typhoon over the past 3 years	-0.012	0.030	-0.007	0.030	-0.005	0.029	0.000	0.028
	(0.02)	(0.01)**	(0.01)	(0.01)***	(0.01)	(0.01)**	(0.01)	(0.01)***
drought over the past year	-0.121	0.028	-0.157	0.009	-0.167	0.016	-0.137	0.008
	(0.11)	(0.03)	(0.07)**	(0.03)	(0.06)**	(0.03)	(0.07)*	(0.03)
flood over the past year	0.043	-0.030	0.044	-0.010	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	0.013	0.068	0.013	0.067	0.013	0.063	0.002
	(0.05)	(0.03)	(0.04)*	(0.02)	(0.04)*	(0.02)	(0.03)*	(0.02)
Predicted/pseudo residuals								
hired labor residual			-0.029	-0.047	-0.031	-0.046	-0.029	-0.049
			(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***
fertilizer residual			-0.149	-0.030	-0.132	0.017	-0.114	-0.014
			(0.05)***	(0.02)*	(0.05)**	(0.02)	(0.06)**	(0.02)
irrigation residual			-0.174	-0.039	-0.139	-0.010	-0.111	-0.010
			(0.04)***	(0.02)*	(0.04)***	(0.02)	(0.04)***	(0.02)
inverse of the Mills ratio			0.055	0.073	0.042	0.049	0.203	0.054
			(0.02)***	(0.02)***	(0.02)**	(0.02)**	(0.02)***	(0.02)***

Table B.2—Continued

Dependent variable = rice yield	2SLS delta	2SLS nondelta	Heckman basic delta	Heckman basic nondelta	Heckman interaction delta	Heckman interaction nondelta	Heckman pov. inter. delta	Heckman pov. inter. nondelta
Residual interactions								
irrigation × its residual					0.006	0.006	0.006	0.005
					(0.00)***	(0.00)***	(0.00)***	(0.00)***
fertilizer × its residual					0.016	0.017	0.014	0.018
					(0.00)***	(0.00)***	(0.01)**	(0.00)***
hired labor × its residual					-0.001	-0.000	-0.000	-0.000
					(0.00)*	(0.00)	(0.00)	(0.00)
poor × hired labor							0.006	-0.008
							(0.01)	(0.00)
poor × hired labor residual							-0.005	0.011
							(0.01)	(0.01)**
poor × hired labor X hired labor residual							-0.000	-0.000
							(0.00)	(0.00)
poor ×fertilizer							-0.044	-0.023
							(0.04)	(0.02)
poor × fertilizer residual							0.079	0.043
							(0.04)*	(0.02)**
poor × fertilizer × fert. residual							0.005	-0.001
							(0.01)	(0.00)
poor × household irrigation							0.026	0.016
							(0.01)**	(0.01)**
poor × hh. irrigation residual							-0.018	-0.001
							(0.01)	(0.01)
poor × hh. irr. X irr. residual							0.001	0.002
							(0.00)	(0.00)
poor × commune irrigation							0.001	-0.001
							(0.00)	(0.00)
Constant	1.519	2.356	0.938	2.196	1.159	2.197	1.360	2.156
	(0.50)***	(0.20)***	(0.38)**	(0.19)***	(0.36)***	(0.18)***	(0.37)***	(0.18)***
Observations	3836	5288	9207	16372	9207	16372	9199	16341
Log likelihood			-2134.9	-6376.5	-2081.1	-6251.9	-1702.6	-5885.7
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	3.088	7.63						
F statistic of endogeneity of instruments	37.71	11.56						
p-value of endogeneity of instruments	0.00	0.00						
rho (correlation of yield residual with sample selection residual)			0.000	0.006	0.000	0.008	-0.813	0.013
			(0.013)	(0.011)	(0.014)	(0.012)	(0.043)	(0.017)
sigma (sigma of rice yield)			0.200	0.264	0.198	0.258	0.210	0.242
			(0.009)	(0.007)	(0.009)	(0.006)	(0.008)	(0.005)
p-value of Wald test of indep. eqns. (rho = 0)			1.000	0.609	1.000	0.501	0.000	0.442

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

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

Table B.3—Comparison of estimation results excluding extreme values

Dependent variable = rice yield	2SLS full sample	2SLS excluding extreme values	Heckman basic full sample	Heckman basic excluding extreme values	Heckman interaction full sample	Heckman interaction excluding extreme values	Heckman pov. inter. full sample	Heckman pov. inter. excluding extreme values
Inputs for rice production								
family labor	0.035	0.033	0.048	0.049	0.047	0.048	0.047	0.047
	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***
hired labor	0.051	0.050	0.056	0.057	0.057	0.057	0.058	0.058
	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***
fertilizer	0.136	0.135	0.137	0.136	0.164	0.163	0.170	0.170
	(0.02)***	(0.02)***	(0.02)***	(0.02)***	(0.02)***	(0.02)***	(0.02)***	(0.02)***
irrigation	0.028	0.027	0.048	0.052	0.050	0.054	0.044	0.043
	(0.02)	(0.02)	(0.02)**	(0.02)**	(0.02)**	(0.02)**	(0.02)*	(0.02)**
Household characteristics								
share of rice in total crop land	-0.076	-0.072	-0.091	-0.091	-0.084	-0.084	-0.081	-0.077
	(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	0.003
	(0.00)***	(0.00)***	(0.00)***	(0.00)***	(0.00)***	(0.00)***	(0.00)***	(0.00)***
male	0.010	0.013	0.013	0.016	0.012	0.015	0.011	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	-0.002	-0.001	-0.002
	(0.00)***	(0.00)***	(0.00)***	(0.00)***	(0.00)***	(0.00)***	(0.00)***	(0.00)***
grade	-0.000	-0.001	-0.001	-0.002	-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	-0.013	-0.014	-0.011	-0.012	-0.010	-0.010	-0.010	-0.011
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
being minority	0.024	0.020	0.054	0.059	0.052	0.057	0.055	0.052
	(0.03)	(0.03)	(0.03)*	(0.03)*	(0.03)	(0.03)*	(0.03)*	(0.03)*
being poor	0.014	0.016	0.016	0.018	0.016	0.018	0.027	0.048
	(0.01)	(0.01)*	(0.01)**	(0.01)***	(0.01)**	(0.01)***	(0.03)	(0.03)*
Commune characteristics								
share of irrigated annual crop land	0.006	0.006	0.004	0.004	0.005	0.005	0.004	0.003
	(0.00)***	(0.00)***	(0.00)*	(0.00)*	(0.00)**	(0.00)**	(0.00)*	(0.00)
having power supply	0.027	0.042	0.030	0.046	0.014	0.031	0.019	0.063
	(0.08)	(0.08)	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)
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	-0.033	-0.032	-0.009	-0.002	-0.016	-0.009	-0.014	-0.007
	(0.02)	(0.02)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Climate factor								
average precipitation	0.000	0.000	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)
average temperature	-0.038	-0.038	-0.037	-0.036	-0.038	-0.037	-0.038	-0.038
	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.00)***

Table B.3—Continued

Dependent variable = rice yield	2SLS full sample	2SLS excluding extreme values	Heckman basic full sample	Heckman basic excluding extreme values	Heckman interaction full sample	Heckman interaction excluding extreme values	Heckman pov. inter. full sample	Heckman pov. inter. excluding extreme values
variability of precipitation	0.000	0.000	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)
variability of temperature	0.441	0.416	0.404	0.372	0.451	0.417	0.445	0.425
	(0.15)***	(0.15)***	(0.14)***	(0.13)***	(0.13)***	(0.12)***	(0.13)***	(0.12)***
drought over the past 3 years	-0.014	-0.011	-0.011	-0.006	-0.008	-0.004	-0.007	-0.007
	(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	0.008	0.014	0.010	0.014	0.008
	(0.01)**	(0.01)	(0.01)*	(0.01)	(0.01)**	(0.01)	(0.01)*	(0.01)
typhoon over the past 3 years	0.003	0.004	0.004	0.006	0.005	0.007	0.004	0.009
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
drought over the past year	0.009	0.008	0.001	-0.002	0.009	0.005	0.009	-0.002
	(0.03)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
flood over the past year	0.000	0.004	0.008	0.014	0.004	0.010	0.004	0.014
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
typhoon over the past year	0.029	0.027	0.029	0.027	0.028	0.026	0.028	0.020
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Predicted/pseudo residuals								
hired labor residual			-0.053	-0.054	-0.054	-0.055	-0.058	-0.058
			(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***
fertilizer residual			-0.046	-0.046	-0.009	-0.011	-0.034	-0.040
			(0.02)**	(0.02)**	(0.02)	(0.02)	(0.02)*	(0.02)**
irrigation residual			-0.021	-0.026	-0.006	-0.011	-0.003	-0.004
			(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
inverse of the Mills ratio			0.033	0.042	0.022	0.031	0.021	0.034
			(0.02)	(0.02)**	(0.02)	(0.02)	(0.02)	(0.02)*
Residual interactions								
irrigation × its residual					0.004	0.004	0.004	0.004
					(0.00)***	(0.00)***	(0.00)***	(0.00)***
fertilizer × its residual					0.016	0.015	0.017	0.017
					(0.00)***	(0.00)***	(0.00)***	(0.00)***
hired labor × its residual					-0.002	-0.001	-0.002	-0.002
					(0.00)***	(0.00)***	(0.00)***	(0.00)***
poor × hired labor							-0.006	-0.001
							(0.00)	(0.00)
poor × hired labor residual							0.010	0.005
							(0.00)**	(0.00)
poor × hired labor X hired labor residual							-0.000	0.000
							(0.00)	(0.00)
poor ×fertilizer							-0.010	-0.027
							(0.02)	(0.02)
poor × fertilizer residual							0.042	0.050
							(0.02)***	(0.02)***

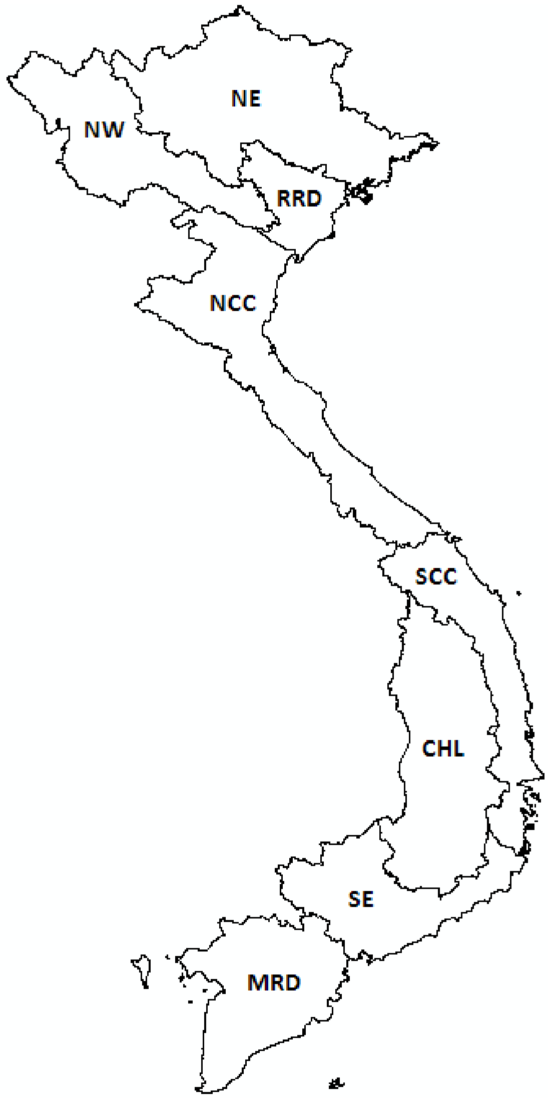
Table B.3—Continued

	2SLS		Heckman basic		Heckman interaction		Heckman pov. inter.	
Dependent variable = rice yield	**full sample**	**excluding extreme values**	**full sample**	**excluding extreme values**	**full sample**	**excluding extreme values**	**full sample**	**excluding extreme values**
poor × fertilizer × fert. residual							0.001	-0.001
							(0.00)	(0.00)
poor × household irrigation							0.013	0.014
							(0.01)**	(0.01)**
poor × hh. irrigation residual							-0.007	-0.009
							(0.01)	(0.01)
poor × hh. irr. X irr. residual							0.001	0.001
							(0.00)	(0.00)
poor × commune irrigation							0.001	0.001
							(0.00)	(0.00)
Constant	2.438	2.422	2.486	2.482	2.479	2.478	2.474	2.404
	(0.22)***	(0.22)***	(0.19)***	(0.19)***	(0.18)***	(0.18)***	(0.18)***	(0.17)***
Observations	9124	9116	25579	25571	25579	25571	25579	25536
Log likelihood	0.13	0.14	-9318	-9053	-9148	-8893	-9117	-8401
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	15.14	14.98						
F statistic of endogeneity of instruments	41.4	42.68						
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	-0.002
			(0.006)	(0.007)	(0.007)	(0.007)	(0.007)	(0.009)
sigma (sigma of rice yield)			0.244	0.237	0.239	0.233	0.238	0.222
			(0.005)	(0.005)	(0.005)	(0.004)	(0.005)	(0.004)
p-value of Wald test of indep. eqns. (rho = 0)			0.999	0.999	1.000	0.999	1.000	0.861

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

Notes: 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 B.1—Agroecological zones of Vietnam



Source: Authors' preparation.

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