Title: Empirical Estimation of the Value of Groundwater Irrigation in Vietnam

Author: Le Viet Phu

This paper has been submitted to the conference ‘Vietnam: political and economic challenges and opportunities’ at the Australian National University on 3 October 2019

This is a preliminary version. It is not for quoting or citations.

Do not remove this note.

Empirical Estimation of the Value of Groundwater Irrigation in Vietnam

Le Viet Phu
Fulbright University Vietnam

2019

Abstract

Groundwater is extensively used for irrigation and household consumption in many parts of Vietnam, as a main source of water, as a supplement for piped water, and as a backup resource during shortages. Having access to groundwater irrigation provides households with an alternative water source rather than relying on state-provided irrigation such as canals, or natural irrigation such as springs/rivers or rainwater. Excessive groundwater extraction has become a major concern due to a lowering water table, contaminated underground aquifers, and land subsidence. Using a large-scale plot-level data set, we showed that farmland with access to groundwater irrigation is significantly more valuable, which could be explained by the increased productivity associated with water availability. Charging a user's fee based on the estimated value of groundwater would help sustain this critical resource in the long term.

JEL Codes: Q12, Q15, Q25, Q51
Keywords: groundwater extraction, production function, hedonic regression, Heckman sample correction

1 Introduction

Groundwater is extensively used in Vietnam, for industrial to agricultural to daily domestic consumption. In the Mekong River Delta (MRD), groundwater is a common source of fresh water for millions of households, providing drinking water, agricultural irrigation in the dry season, and dilution of saline water in shrimp aquaculture. Official reports have counted more than one million private bore wells, pumping millions of cubic meters daily with little or no government control. While groundwater accounts for a mere 2% of the total water use in the MRD, it contributes more than 60% of the total water used for domestic purposes (Division for Water Resources Planning and Investigation for the South, 2013). In the Central Highlands, farmers have relied on groundwater as the unique source of water during the dry months to irrigate thousands of hectares of coffee.

The consequent over extraction and increasing scarcity of water have become a threat to local development and national security. Climate change exacerbates the pressure on water resources in the region. The last few years have become drier, and the rainfall pattern has shifted, causing more floods and droughts to occur (ICEM, 2013). The Mekong Delta is extremely susceptible due to several natural and socioeconomic factors. First, a very low elevation, barely a few meters above the sea level at its highest point, exposes the Delta to severe saline intrusion from both sea level rises and storm surges. Second, the Delta has been shrinking (Erban et al, 2014), partly due to groundwater extraction and partly due to its natural geologic features. Human actions also contribute to the problem. Countries upstream of the Mekong Basin have been building hydropower, blocking the flow of sand and sediments that are critical to the formation of the Delta (Mekong River Commission, 2011). As surface water is becoming increasingly polluted by intensive agriculture and aquaculture, the shift toward a cleaner water resource, ultimately groundwater, has become more evident. As a consequence, the water table has been declining at 1-2m every year all over the country (Catalin, 2014).

Pressure on water resources and increasing future irrigation needs require an efficient scheme to allocate and use water resources. Many countries have implemented irrigation water pricing as a policy tool. Farmers need to pay a reasonable price for irrigation water, reflecting the added value that it contributes to the production output. Charging an irrigation water price will encourage people to use water more economically and allocate water optimally to the best use. The Vietnamese government has implemented a scheme to collect an irrigation fee since 1984 (Linh, 2017). However, the collection effort was largely symbolic, and after all, the fee has been waived for small householders since 2009. Without paying a price for the use of water, farmers are free to use as much water as needed, further exacerbating the water shortage and excessive use of groundwater.

Few attempts have been made to identify the value of irrigation water in Vietnam. Among those, the reported values of irrigation vary widely, from VND 1,000-14,000/m3, depending on the water basin and crops (Asian Development Bank, 2009), to as low as VND 0.5-1.3 million/hectare/year (equivalent to VND 77-110/m3) for the case of rice crop in Linh (2017). These studies focused exclusively on the irrigation water supplied by government-built irrigation systems. Due to a large variation in farmer's willingness to pay (WTP) for improved irrigation services, Toan et al (2015) found that a unified water pricing policy would likely face opposition from those having an anti-charging motivation and a low WTP.

Regarding groundwater irrigation, Cheesman et al (2007) found that coffee growers tended to over use elemental nutrients, labors, and groundwater irrigation in the Central Highlands, and that shifting to a more efficient irrigation practice could raise productivity by half a ton per hectare, at the same time reduce the water need by 2300 cubic meters and the short-run irrigation cost by VND 2.7 million/hectare/year. Due to increasing awareness of groundwater contamination in the MRD, Danh and Khai (2017) identified the WTP for groundwater protection of approximately VND 140,000/household/year. No study has identified the value of groundwater contribution to farming. This study is the first to investigate the value of groundwater irrigation, in contrast to existing studies on the value of irrigation provided by government-built canals. The value, once identified, would help the government price in the cost of groundwater used in different farming systems. To encourage economic uses and ensure the sustainability of groundwater, users of this critical resource should be required to pay a price.

2 Method and Data

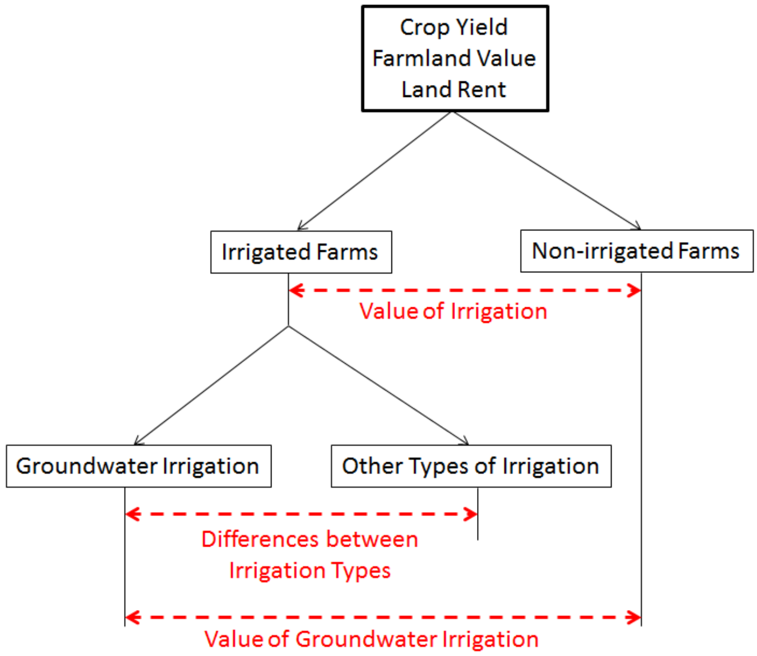
2.1 Econometric Models

Many methods are available for valuing market and nonmarket commodities, as in the case of water for agriculture, it is an input to the production process but is not often traded or priced explicitly. Water, as a critical input to agricultural production, can be measured by its contribution to the total value of production. This could be done by an accounting approach (also called the residual value method), which equates the value of water to the residual of the total value of production by subtracting all accountable costs of other inputs. Residual methods have been conducted in developing countries, including Berbel et al (2011), Kiprop et al (2015), Syaukat et al (2014), MacGrogor et al (2000), Kumar et al (2004), Hussain et al (2009), and Lange and Hassan (2006). Alternatively, the value of water can be identified indirectly through its contribution to the farm outputs in a production or hedonic model, using econometrics with microdata of farming practice. Comparing farmland with access to irrigation water with farmland without access, controlling for all other differences, will allow the identification of the value of irrigation. Examples include Brozovic and Islam (2010), Swanepoel et al (2015), Torrell et al (1990), Mukherjee and Schwabe (2014), Faux and Perry (1999), and Stage and Williams (2003).

We measure the outcome variables by three alternative definitions: the crop yields, the farmland value if the land is sold in the market, and the rent of farmland. Each of these outcomes carries a different interpretation, its own strengths and weakness regarding the accuracy of the measurement, and vulnerabilities to econometric model specification. However, they are all strongly related, and once estimated, the derived irrigation values are comparable between these measurements.

Figure 1 lays out the structure of the with-and-without analysis to identify the value of groundwater irrigation. First, we compare the three outcome variables of farmland with and without access to any source of irrigation. This will identify the contribution of irrigation to the farming economy, regardless of the type or ownership of irrigation. Second, within the sample of irrigated farms, we compare the outcomes between irrigation by groundwater and irrigation by other sources of water. This will help us characterize the difference in the outcome variables due to different irrigation types. Third, we specifically compare farmland with access to groundwater irrigation with those without any source of water.

Figure 1: The Structure of a With-and-Without Analysis.



Regarding the econometric techniques, we first estimate a production function of crop yields to identify the contribution of irrigation to irrigated farms. To correct for the sample selection issue, we present two results, corresponding to a least-squares estimate and a Heckman-corrected sample selection. Then, we estimate a hedonic model of farmland values based on access to irrigation water. In the third model, we show how irrigation water affects land rent. Then, we combine the results from different models to offer a robust assessment of the value of groundwater irrigation.

Model 1: Farmland production function

$$log(Q_i) = \alpha_0 + \alpha_1 \times D_{IRRI_i} + \sum_j INPUT^j{}_i \times \alpha_j + \sum_k LAND^k{}_i \times \alpha_k + \sum_l DEMO^n{}_i \times \alpha_n + \varepsilon_i \quad (1)$$

where Q_i is the production output, measured as the total amount of rice or maize in each unit of farmland (1000 m2). D_{IRRI} is the state of irrigation. A farm could be irrigated ($D_{IRRI} = 1$) or nonirrigated ($D_{IRRI} = 0$). Among irrigated farms, a farm could be irrigated by groundwater or by other methods. $INPUT^j$, $LAND^k$, and $DEMO^n$ are vectors of production inputs, land characteristics, and household demographics representing education and the labor force, respectively. ε is the residual, assuming an independent Gaussian distribution with a zero mean. Equation (1) could also include various interaction terms to account for the heterogeneous effects of irrigation on farmland depending on other characteristics such as the farm size or input intensities.

Establishing a causal interpretation of Model (1) is prone to sample selection pitfalls. The problem with using the observed output in Model (1) is that the type of farm output, mainly rice or maize crops, is not random. The choice of crops is determined by restrictions placed on the land by the local government, climate, and physical characteristics of the land. For example, if the best land is legally required to grow only rice, then we may observe that the most profitable farmland pertains to rice crops, while other less fertile lands are used for less valuable crops. Then, using a restricted sample of the most profitable lands in rice farming may overestimate the value of irrigation contributing to the total output. To correct for the potential sample selection issue, we utilized a two-step Heckman sample correction method (Wooldridge, 2012).

The Heckman procedure involves estimating two stages consecutively. For the first-stage selection model, we estimated the probability of observing a major crop being grown, either rice or maize, conditional on a set of explanatory variables R representing various farm restrictions, which may include legal requirements, soil quality, and access to irrigation water. In the second stage, the inverse Mills ratio (IMR) was added as an additional variable into the farmland production function to adjust for the sample selection issue. The IMR is the ratio of the probability density function to the cumulative distribution function. For example, a Heckman model of rice productivity is specified as follows:

$$\begin{cases} P(Rice_i|R_i) &= \Phi(R_i\gamma + u_i) \qquad (H1) \\ \\ log(Q_i^{rice}) &= \alpha_0 + \alpha_1 \times D_{IRRI_i} + ... + \rho\lambda(R_i\gamma) + \varepsilon_i \qquad (H2) \end{cases}$$

where $\Phi(.)$ is the cumulative distribution function of the standard normal distribution. $\lambda(.)$ is the inverse Mills ratio, $\lambda(.) = \frac{\phi(.)}{\Phi(.)}$, measured at value $R_i\gamma$.

Model 2: Hedonic regression of farmland value

A potential problem with using crop yields to estimate the value of irrigation is that it depends on the crop price. As the price fluctuates, the derived value of irrigation likely varies over time. An alternative approach is to use the transacted values of farmland in the land market. Assuming that the land price reflects a long-term equilibrium of land demand and land supply, the hedonic approach to farmland valuation produces a more stable estimate of the value of irrigation than the production function approach.

$$log(VALUE_i) = \alpha_0 + \alpha_1 \times D_{IRRI_i} + \sum_k LAND^k{}_i \times \alpha_k + \sum_l RESTRICT^m{}_i \times \alpha_m + \varepsilon_i \quad (2)$$

where $VALUE$ is the land price per acre, $LAND^k$ and $RESTRICT^m$ are the land characteristics and restrictions placed on the land, respectively. The restrictions placed on the land, such as permissions to convert a farm plot, crop choice, and having built-up structure, are expected to affect the land price, while demographics and production inputs may only affect the crop yield, not the land value, and therefore not are not included in the land value model.

Model 3: Farmland rent function

$$log(RENT_i) = \alpha_0 + \alpha_1 \times D_{IRRI_i} + \sum_k LAND^k{}_i \times \alpha_k + \varepsilon_i \quad (3)$$

where $RENT$ is the rent per acre paid or received by the farm owner or renter. $LAND^k$ is the land characteristics. The input, demographic variables or land restrictions are not included in the land rent equation. The rent of a farmland is determined mostly by its productive capacity. For example, farms with better soil quality, flat slope, access to water and transports are expected to have a higher profit and therefore have a higher rent. Expectations over future increased market value or any factor unrelated to the immediate productivity are not expected to affect the rent price of farmlands, as are restrictions placed on the land, such as having conversion or building permissions.

Calculating the Value of Irrigation Water

We estimate the long-run capitalized at-source value of water (hedonic regression model) or annual at-source value of water (production/land rent model), based on the concepts from Young and Loomis (2014). Depending on the choice of the dependent variables, the value of irrigation could be derived as follows:

1. The annual value of irrigation, as a percent of the value of total output or land rent, can be identified as coefficient α_1 in Model (1) and Model (3).

2. In Model (2), coefficient α_1 is the difference in values of farmland with and without access to irrigation. In a perfectly competitive market, this stock value is calculated as the present value of an infinite stream of annual values. A discount rate r can

be applied to convert the stock value of irrigation to the flow of the annual value of irrigation, ($\alpha_1 = \frac{\texttt{AnnualValue}}{r}$).

2.2 Data Sources

The Vietnam Access to Resources Household Survey (VARHS) is the only large-scale household survey that collects information pertaining to the production practices and irrigation systems used in farming. We used the VARHS 2014 survey, which has a sample of 3,648 households in 12 provinces from the north to the south of Vietnam (Figure 2) (Tarp, 2017). We identify parcel-level information about outputs, inputs, type of irrigation, and household characteristics, totaling 16,343 farm plots. In addition, we conducted two field surveys in the Central Highlands and Ca Mau province of the Mekong River Delta for in-depth interviews with local stakeholders. Both surveyed locations are heavily dependent on groundwater for coffee plantations or as the primary source of water for all economic and daily uses. In the Central Highlands, coffee plantations are dependent on groundwater for almost four months from December to April in the dry season when there is essentially no other source of water. In the Mekong River Delta, groundwater is the only source during certain periods, such as dry seasons, when surface water is too saline for crops.

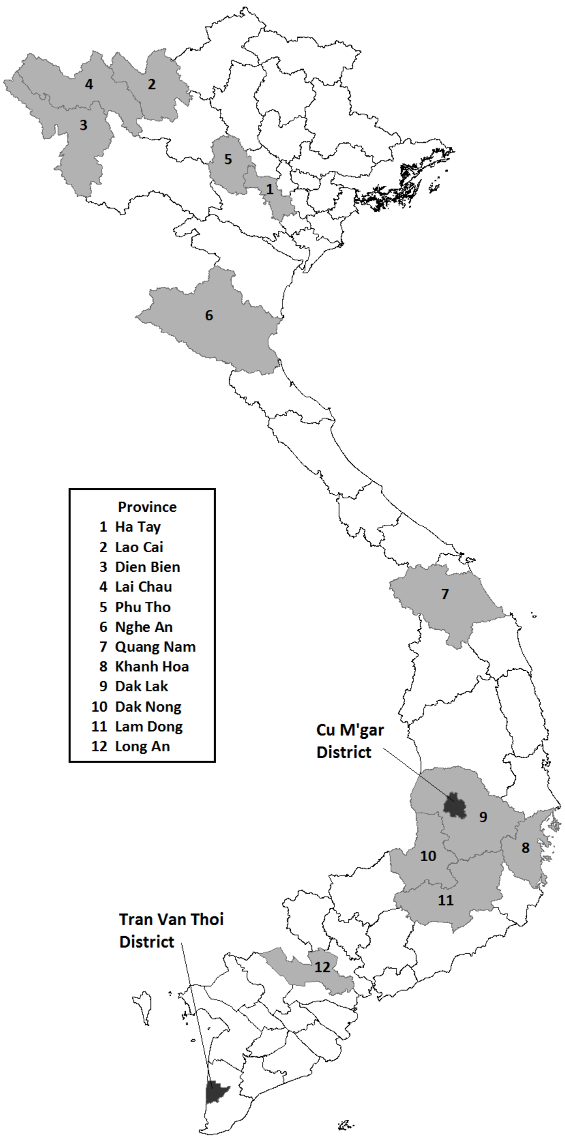
2.3 Description of Variables and Summary Statistics

Dependent Variables

The study examined three outcome variables: the crop yield, the farmland value, and the rent paid for or received from rented farmland. The annual crop yield is derived as the total amount of harvests (including both sold and self-consumed crops) from the three previous seasons in the preceding year per unit of farmland. The value of production is calculated by multiplying the annual yield by the average unit price per kilogram. The popular unit of measurement of agricultural land in Vietnam is the "*công*" or "Vietnamese acre", which equals 1000 m2. The two most common crops are rice and maize. From the sample, we observed that the most common crop in the first season is rice, which was grown on half of all plots, followed by maize (approximately 12%) and vegetables, including cash crops, such as coffee, cassava and peanuts. Some households, however, grow rice in all three seasons a year.

For the land-value model, the dependent variable is the perceived sales value of the land if it was to be sold at the time of survey. To eliminate the impact of urban development on farmland values, we discarded all residential land and gardened houses from the sample. The farmland belongs to one of the following types: annual croplands, perennial croplands, forestland, fish and shrimp ponds, and grassland/pasture. The reported farm values vary

Figure 2: Location of 12 VARHS provinces and two field surveys in Cu M'gar district, Dak Lak province, and Tran Van Thoi district, Ca Mau province.



greatly, underscoring a potential issue with perceived values in the real estate market. In addition, up to two-thirds of the sample did not report a farm value. The reason is that the farmland market is not well established in Vietnam, and with very few transactions, the asking price may not accurately reflect the value of agricultural land. As a result, we used an algorithm to detect extreme values based on the interquartile range and dropped observations with reported farm values below one million or above VND800 million per acre, totaling 189 plots, which is less than 4% of the number of observations in the land-value model.

Instead of the farmland value, an alternative approach is to use the annual land rent.

The agricultural rent is expected to be highly influenced by the land's productive capacity rather than the market price; thus, it is less influenced by speculative effects than if the land was considered as a real estate. The land market in Vietnam is undeveloped; therefore, using the asking price of farmland to infer the irrigation value may entail inaccuracies. Furthermore, farm owners might be inclined to overstate the price of their lands. However, the number of farmland plots with reported land rents is very limited, only available in less than 10% of all observations. We eliminated from the sample farmland with extremely low or high rents, either less than VND 100 thousand or greater than VND 10 million per acre. As a result, 57 observations were discarded, representing less than 6% of the number of observations in the land-rent model.

Farmland Characteristics

Many factors may influence the productivity of farmland, such as the physical properties of the soil, the slope, the location to market, infrastructure, the climate, and restrictions placed by the government on the land. In the model, we control for whether a farm is located in an urban or a rural area and whether it shares a common border with another plot. The land slope may adversely affect land productivity because sloping land is more prone to runoff and soil erosion than flat land. We also have information on whether the farm is identified as dry land, low-lying land, or stony soil or clay. The self-rated land quality, whether the farm has a similar or higher quality than the average farmland plot in the area, is also used. In addition, we included the total land area in all models to examine whether farm productivity exhibits economies of scale.

In a standard hedonic regression (also called the Ricardian method in studies of the impact of climate change), climate conditions, such as temperature (or growing degree days), precipitation, and occasionally, the extreme heating (or harmful degree days), during growing seasons are considered important inputs to crop agronomy (Mendelsohn, 1994; Schlenker et al, 2005; Phu, 2013). However, these variables are highly correlated with location factors. As a result, to check the sensitivity of the estimates, we included a set of location dummies representing communal differences in the climate conditions. Spatial correlations were addressed by clustered standard errors at the provincial level.

Regarding restrictions on the farm, we control for whether there is soil and water conservation structure, whether there is any physical structure, and whether the farm is allowed to convert to other uses. In general, the Vietnamese government strictly stipulates that agricultural land must be used for agricultural production. Conversion to built-up land could raise the land value by many times, creating incentives for landowners to obtain permission where possible. However, conversion from one crop to another, for example, from rice to upland crops, are more prevalent as long as the land remains classified as agricultural land. Finally, we also control for whether the land has been issued a red book, the official title of ownership, or not. Having a clear title allows the land to be traded legally, suggesting a higher price and liquidity for titled lands. We also included a variable representing the number of plots owned by the household and whether any investment was made in any plot. Note that these restrictions only affect the choice of crop grown on a piece of land or the land value if it was sold. Having obtained an ownership title or a conversion permit does not raise the productivity of the farmland. Therefore, the restrictions imposed on farmland by the government satisfy the exclusion restriction to be used in the Heckman two-step procedure.

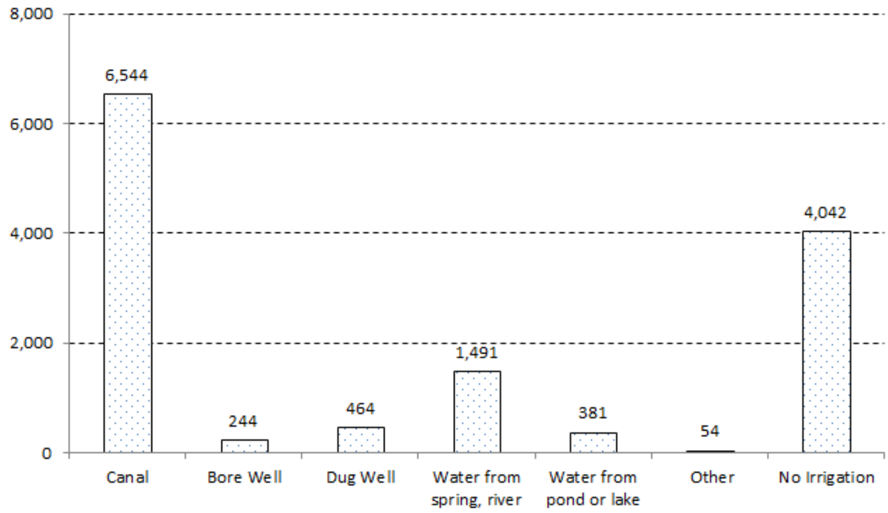
Production Inputs, Capital, and Labor

We included six major components of the cost of production: seeds and saplings, fertilizers and pesticides, hired labor, energy and fuels, machinery and equipment, and other costs. To account for the household's own supply of labor, we used two sets of variables for labor: the total number of days working on each type of production (rice, maize, livestock, aquaculture, forest, and other) and the family size. We used the total value of assets, counting all durable assets including household appliances and productive assets as the capital input. Related to social capital, households having a member belong to the communist party can have an easier access to credit or be given preferential treatment. Therefore, we expected that having this connection could potentially have a positive impact on production outcomes.

Irrigation Variables

At the plot level, we observe that up to 70% of farms are irrigated. Irrigation comes from various sources, including canals, bore wells, dug (open) wells, water from a spring or river, water from a pond or lake, and other sources. The most common type of irrigation is through canal (71% of irrigated farms), followed by water from a spring/river (16%) and groundwater (7%, including both bore well and dug well) (Figure 3). However, information on groundwater extraction and uses is severely limited. The exact coordinates of the well, well depth, pumped volume, water characteristics, and other subtle characteristics relating to the operation and maintenance of the well are generally not available. Due to the limited number of groundwater users, we grouped bore-well and dug-well irrigation into a single groundwater irrigation category. Typically, a dug well is more expensive to own but is only available in areas where the water level is not too deep. Below a certain depth, a bore well is the only choice. We do not consider groundwater use for daily household consumption in the analysis. Sample images of three groundwater irrigation systems are presented in Figure 7 in the Appendix, which include a bore well and a dug well, a central groundwater pump and storage tank for a cluster of households, and a large groundwater supply and sanitation system for a commune.

Figure 3: Plot Distribution by Irrigation Types



Demographics

We controlled for the characteristics of household heads, including whether he/she belongs to the Kinh ethnicity, gender, age, marital status, and the number of schooling years he/she has obtained at the time of survey. We also included the highest obtained degree, such as having no degree, short- and long-term training, vocational training, college, university, or a master's or doctoral degree.

The complete description of the variables and summary statistics are available in Tables 2-5 and Figures 8-13 in the attached Appendix.

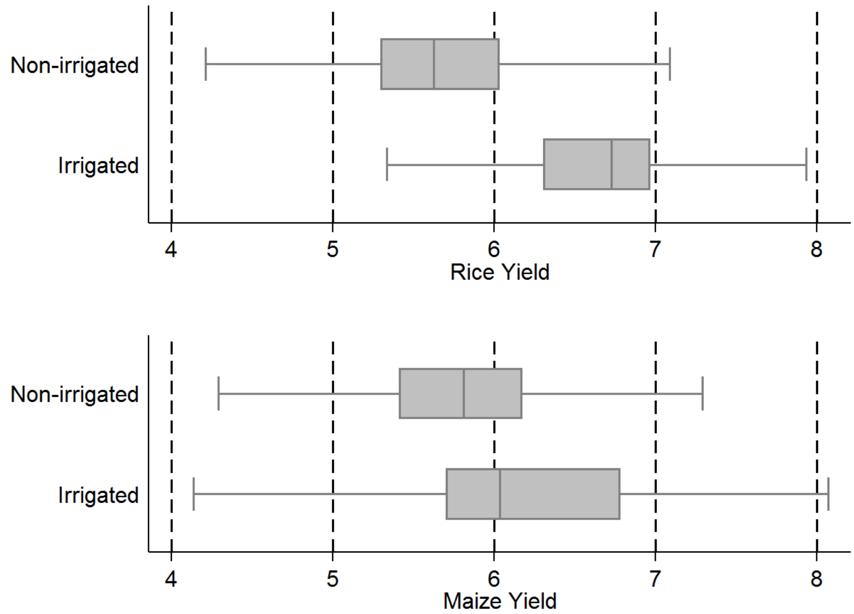
3 Results and Discussion

The Value of Irrigation

The estimated least-squares estimates of the production model (Model 1) of rice (Table 6, column 1) and maize (Table 7, column 1) show that the irrigation coefficient is positive and significant as expected. Farms with access to irrigation water have a higher productivity than nonirrigated farms. Rice productivity is higher by approximately 60% in farmland that has access to irrigation, confirming the importance of irrigation in rice farming.[1] However, the impact of irrigation on maize yields is unclear. This is also evident from the distribution of rice and maize yields in Figure 4.

[1]Because the dependent variable is the logarithm of yield, and irrigation is a discrete variable, we calculated the impact of irrigation on the output as $[e^{\alpha_1} - 1]$.

Figure 4: Comparing Annual Yields of Rice (top) and Maize (bottom) (kg/acre, in logarithm) between Irrigated and Non-irrigated Farms



Other coefficients of interest are the plot area (-), distance to home (-), land slope (-), dry land (-), and low-lying land (-). These results are not surprising. Farm owners with small lands often intensify their practice to offset for having less land by increasing the number of crop rotations or increasing the use of inputs. We observed from the survey that 6,861 plots out of 16,343 surveyed plots grew rice in the first season, but only 4,571 did so in the second season, and 115 in the third season in the same year. As a result, the production output per acre of land may be higher for smaller farms than for larger farms. This carries two potential implications: first, economies of scale are not necessarily observed in rice farming, and second, increased use of inputs, especially chemical fertilizers and pesticides, could be a response to having a small farmland. Regarding other coefficients, the distance to the farm increases the cost of production through transport and losses. Sloping land makes it difficult to retain water and is prone to runoffs, resulting in lower land productivity. Additionally, annual crop land is more productive than other land used for rice cropping, supposedly due to the presence of infrastructure and other services to support regular farming. Among inputs, fertilizers and labor days are the most important factors, in addition to household assets, such as tractors, transport means, and other machines.

To address a potential sample selection issue, we examined the first stage of the Heckman procedure in Table 8. If there is no selection issue, the error terms from the selection equation ($H1$) and the production equation ($H2$) of Model 1 are independent ($\rho = 0$). The LR test of independence was soundly rejected even at the 1% significance level,

$\chi_2(1) = 27$, strongly demonstrating the presence of sample selection. Examining the first and third columns in Table 8, it is clear that irrigation is a significant determinant in having farms used for rice cropping. Those without irrigation were likely used for other crops, supposedly of lower value than rice. Farms with conservation practices on soil or water and other government restrictions are highly associated with rice cropping. Farms already issued with an official title (a red book) are also likely used for rice cropping, indicative of the long-term requirement to invest in farming infrastructure to support growing rice, such as irrigation, pump, and tillage. The value of irrigation in rice farming, adjusted for sample selection, is lower but still results in approximately 32% higher productivity than that of nonirrigated farms (Table 6, column 3). For plots growing maize, despite the least-squares estimate indicating no difference between irrigated and nonirrigated farms, the Heckman procedure now shows that irrigated farms are up to 26% more productive than nonirrigated farms (Table 7, column 3).

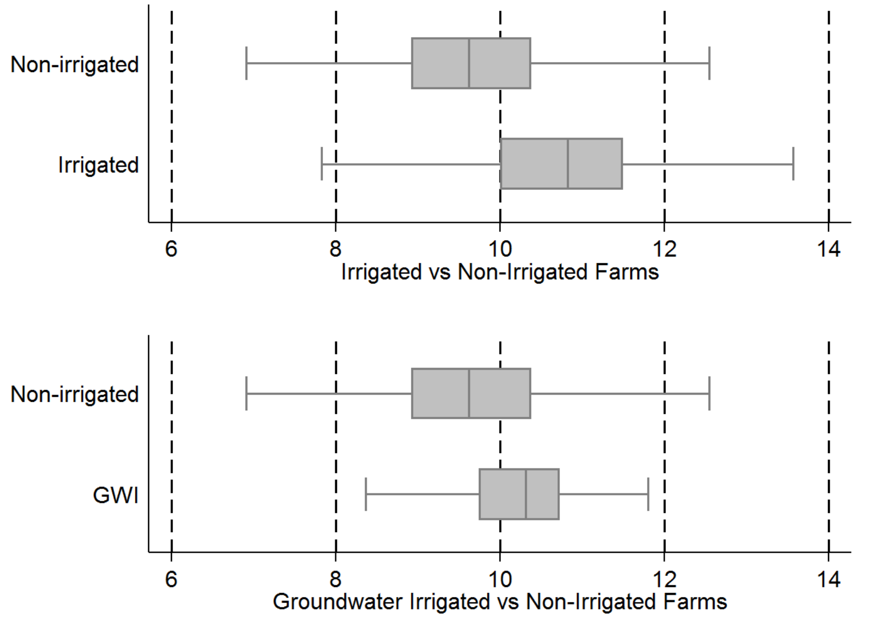
Translating these values to monetary terms, having irrigation will raise the value of rice farm production by up to 32% and maize production by 26%. Assuming a household grows an average of two crops per year, with an average paddy productivity of 6 tons/ha, and at the price of VND 4 million per ton, the value of irrigation per year is 2*6*4*.32 = VND 15.20 million/hectare/year, equivalent to a quarter of the total value of production. For maize, with an average yield of 4 ton/hectare, at the price of VND 4 million/ton, the value of irrigation is 2*4*4*.26 = VND 8.32 million/hectare/year. Of course, these values would vary, depending on the number of rotations, specific productivities, and prices at the farm gate.

Based on the land-value model (Model 2), irrigated lands are up to 46% more valuable than nonirrigated lands (Table 9, columns 1-2; Figure 5). Based on the average farm price of VND 878 million/hectare, irrigation adds approximately VND 405 million/hectare to farmland value compared to nonirrigated farms. Therefore, an annualized value of irrigation, assuming a constant discount rate of 5%, is approximately VND 20.25 million per hectare per year.

The Value of Groundwater Irrigation

To identify the value of groundwater irrigation, we took two different approaches. First, we compared farms irrigated by groundwater with farms irrigated by other sources of water. Second, we compared farms irrigated by groundwater with nonirrigated farms. The idea is that if groundwater is indistinguishable from other sources of irrigation, then farmers could use one source or another as a perfect substitute for groundwater. Additionally, comparing groundwater irrigated farms with nonirrigated farms truly identifies the value of groundwater in case groundwater is not considered a first choice if other sources are available.

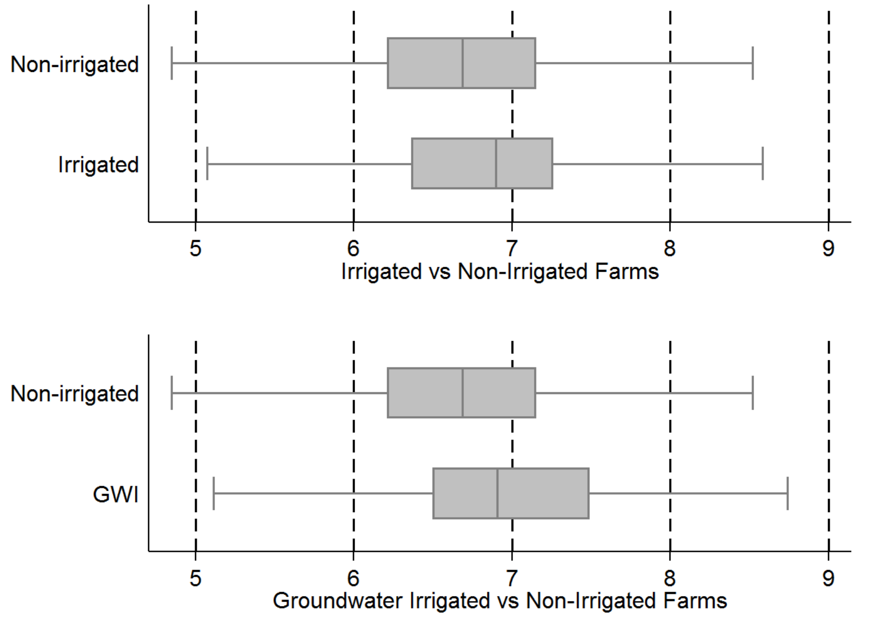
Figure 5: Comparing Farmland Values (VND 1000/acre, in logarithm) of Irrigated with Non-irrigated Farms and of Groundwater Irrigated with Non-irrigated Farms



Based on the land-value model (Model 2), there is no difference between farms irrigated by groundwater and those irrigated by other water sources, even with a large sample of 3,616 irrigated farm parcels (Table 9, columns 3-4). We therefore established that the upper bound of groundwater irrigation is approximately VND 20 million per hectare of irrigated land, assuming that all water sources are indistinguishable. Most importantly, farms irrigated by groundwater are clearly more valuable than nonirrigated farms by about 32% or VND 126.4 million per hectare, on average (Table 9, columns 5-6; Figure 5). Converting this number to annualized value, groundwater irrigation adds VND 6.32 million/hectare/year to farm income. We further separated groundwater uses into bore wells and dug wells. Then, only dug-well irrigation was shown to have the most significant impact on farmland value. Without further information, it is not possible to know whether the difference between those two types is due to water availability, cost of extraction, or other farming characteristics. Because the Ricardian hedonic model of farmland value assumes that farmers automatically switch crops or inputs to maximize income from their land, the values derived in Table 9 and 10 are independent of which crops were grown on the ground.

We estimated the impact of irrigation on land rents (Model 3) in Table 11 and Figure 6. We did not observe any significant difference in rents between irrigated farms and nonirrigated farms or between farms irrigated by groundwater and those irrigated by other methods. However, the fitness of those models is poor. Comparing the rents of farms irrigated by groundwater with the rents of nonirrigated farms, the rents were significantly higher in groundwater irrigated farms by up to 47%, on average, or approximately VND 5.55 million/hectare/year. This result largely agrees with that of the land-value model, strengthening the overall assessment that groundwater irrigation raises farmland values and land rents and that there is no significant difference among different types of irrigation, groundwater or other sources in their contribution to the overall value of farming.

Figure 6: Comparing Farmland Rents (VND1000/acre, in logarithm) of Irrigated with Non-irrigated Farms and of Groundwater Irrigated with Non-irrigated Farms



Because groundwater is a significant determinant for certain crop systems on the ground, we also attempted to estimate the hedonic model for two major cash crops, coffee and vegetables. Coffee plantations using groundwater are most commonly located in the two Central Highlands provinces of Dak Lak and Dak Nong. We found that groundwater irrigation raises the value of farmland by almost 51% compared to farms irrigated by other sources or nonirrigated farms, equivalent to VND 182 million per hectare. Using a 5% discount rate to convert this value to an annualized value, groundwater irrigation brings VND 9.1 million per hectare. However, groundwater irrigation does not seem to affect the land value of other upland crops. Note that the estimated annualized value is based on a relatively low discount rate of 5% used in many developed countries with a mature financial market. In developing countries, such as Vietnam, the discount rate could be higher due to the instability over property rights, changing market conditions, and a shorter time horizon over the future income flow. Raising the discount rate will proportionately raise the value of groundwater irrigation.

To calculate the price per volumetric unit (m3) of groundwater, we divided these values by the average volume of extraction by each typical cropping system on the ground. For

Table 1: Values of Irrigation and Groundwater Irrigation by Methods. (million VND/hectare/year)

Method	Irrigation (inclusive)		Groundwater Irrigation
	Rice	Maize	
Production Method	15.20	8.32	–
Hedonic Valuation	20.25		6.32
Coffee	–		9.10
Land Rent Model	–		5.55

The official exchange rate in the year of the survey was USD/VND = 21,388.

example, for coffee in the Central Highlands of Vietnam, one typical hectare of Robusta coffee needs approximately 4,000 cubic meters of water. Then, the value of groundwater for coffee is approximately VND2,275/m3.

4 Concluding Remarks

We estimated the value of groundwater irrigation used in household agricultural production. We used parcel-level data and econometric models to examine whether having access to groundwater raises the value of production, farmland value, and land rent. The calculated values of groundwater irrigation converge to approximately VND5-10 million/hectare/year, accounting for almost a third of farming profit. This added benefit of groundwater, if it remains unpaid by its users, will necessarily exacerbate the emerging water crisis in the region. In the face of climate change and increasing water diversions in the Upper Mekong Basin, a sustainable water policy is warranted. The Vietnamese government should start collecting a fee for the extraction of groundwater to encourage its efficient allocation and conscious use.

References

Asian Development Bank 2009. Socialist Republic of Viet Nam: Water Sector Review. Kellogg Brown & Root Pty Ltd, Australia.

Berbel, Julio, Azahara Mesa-Jurado, and Juan Maximo Piston, 2011. Value of irrigation water in Guadalquivir Basin (Spain) by residual value method. *Water Resource Management,* 25:1565-79.

Brozovic, Nicholas, and Shahila Islam, 2010. Estimating the value of groundwater in irrigation. Paper prepared for presentation at the Agricultural Applied Economics Association 2010.

Catalin, Stefan 2014. Groundwater vulnerability in Vietnam and innovative solutions for sustainable exploitation. *Journal of Vietnamese Environment,* 6(1): 13-21.

Cheesman, Jeremy, Tran V.H. Son, and Jeff Bennett 2007. Valuing irrigation water for coffee production in Dak Lak, Viet Nam: a marginal productivity analysis. Australian Centre for International Agricultural Research (ACIAR) Project: ADP/2002/015. ISSN 1832-7435.

Danh, Vo T., Huynh V. Khai 2017. Estimating residents' willingness to pay for groundwater protection in the Vietnamese Mekong Delta. *Applied Water Science,* 7(1): 421-31.

Division for Water Resources Planning and Investigation for the South (DWRPIS) 2013. Assessing the impacts of Climate Change to the Groundwater Resources in the Vietnam Mekong Delta: Recommendation for Responses 2013. Ho Chi Minh, Vietnam.

Erban, Laura, , Steven Gorelick, and Howard Zebker 2014. Groundwater extraction, land subsidence, and sea-level rise in the Mekong Delta, Vietnam. *Environment Research Letter*, 9-084010.

Faux, John, and Gregory M. Perry, 1999. Estimating irrigation water value using hedonic price analysis: A case study in Malheur county, Oregon. *Land Economics,* 75(3): 440-52.

Hussain, Ijaz et al, 2009. Economic value of irrigation water: Evidence from a Punjab canal. *The Lahore Journal of Economics,* 14(1): 69-84.

International Centre for Environmental Management (ICEM) and United States Agency for International Development (USAID) 2013. USAID Mekong ARCC Climate Change Impact and Adaptation Study: Summary. Bangkok: USAID Mekong ARCC Project.

Kiprop, Jonah K. et al, 2015. Determining the economic value of irrigation water in Kerio Valley Basin (Kenya) by residual value method. *Journal of Economics and Sustainable Development,* 6(7):102-07.

Kumar, M. Dinesh, Lokesh Singhal, and Pabitra Rath, 2004. Value of groundwater: Case study in Banaskantha. *Economic and Political Weekly,* 3498-3503, July 31, 2004.

Lange, Glenn-Marie, and Rashid Hassan, 2006. The economics of water management in Southern Africa: An environmental accounting approach. Edward Elgar Publishing, Inc. ISBN-13: 978-1-84376-472-4.

Linh, Ha D. 2017. Irrigation valuation and irrigation policy in Vietnam. Master's of public policy thesis, Fulbright Economics Teaching Program.

MacGregor, James et al, 2000. Estimating the economic value of water in Namibia. 1st WARFSA/Waternet Symposium: Sustainable Use of Water Resources, Maputo.

Mekong River Commission 2011. Assessment of basin-wide development scenarios: Cumulative impact assessment of the riparian countries' water resources development plans, including mainstream dams and diversions. Vientiane: MRC.

Mendelsohn, Robert, William D. Nordhaus, and Daigee Shaw, 1994. The Impact of Global Warming on Agriculture: A Ricardian Analysis. *American Economic Review,* 84(4): 753-71.

Mukherjee, Monobina, and Kurt A. Schwabe, 2014. Where's the salt? A spatial hedonic analysis of the value of groundwater to irrigated agriculture. *Agricultural Water Management,* 145: 110-22.

Phu, V. Le 2013. Three Essays on the Impact of Climate Change and Weather Extremes on the US Agriculture. Dissertation, University of California at Berkeley.

Schlenker, Wolfram, Michael W. Hanemann, and Anthony C. Fisher, 2005. Will U.S. Agriculture Really Benefit from Global Warming? Accounting for Irrigation in the Hedonic Approach. *American Economic Review,* 95(1): 395-406.

Stage, Jesper, and Rick Williams, 2003. Implicit water pricing in Namibian farmland markets. *Development South Africa,* 20(5): 633-45.

Syaukat, Yusman, Fitria Nur Arifah, and Fahma Minha, 2014. Economic value and service fee of irrigation water in the districts Bogor and Kudus, Indonesia. *Journal of ISSAAS,* 20(2):157-72.

Swanepoel, G.D., Joleen Hadrich, and Christopher Goemans, 2015. Estimating the contribution of groundwater irrigation to farmland values in Phillips county, Colorado. *Journal of the ASFMRA,* 165-78.

Tarp, Finn, 2017. Growth, Structural Transformation, and Rural Change in Viet Nam. United Nations University World Institute for Development Economics Research (UNU-WIDER).

Toan, Truong, Suzanne O'Keefe, and Lin Crase 2015. Farmer heterogeneity and water pricing reform: A case study from Vietnam. *International Journal of Water Resources Development,* 961-77.

Torrell, L. Allen, James D. Libbin, and Michael D. Miller, 1990. The market value of water in the Ogallala aquifer. *Land Economics,* 66(2): 163-75.

Young, Robert A., and John B. Loomis, 2014. Determining the value of water: Concepts and methods. RFF Press, ISBN: 978-0-415-83850-4.

Wooldridge, Jeffrey M. 2012. Introductory Econometrics: A Modern Approach (Fifth Edition). South-Western, Ohio USA. ISBN-13: 978-1-111-53104-1.

Extra tables and figures are available in the Supplementary Information

Empirical Estimation of the Value of Groundwater Irrigation in Vietnam

Supplementary Information

Figure 7: Different Groundwater Irrigation Systems in Vietnam.

Bore well

Dug well

A central groundwater station for up to a dozen of households in the Central Highlands

A large central groundwater pumping and processing station for a commune in Ca Mau

Source: Author's photos.

Figure 8: Crop Type in All Farms

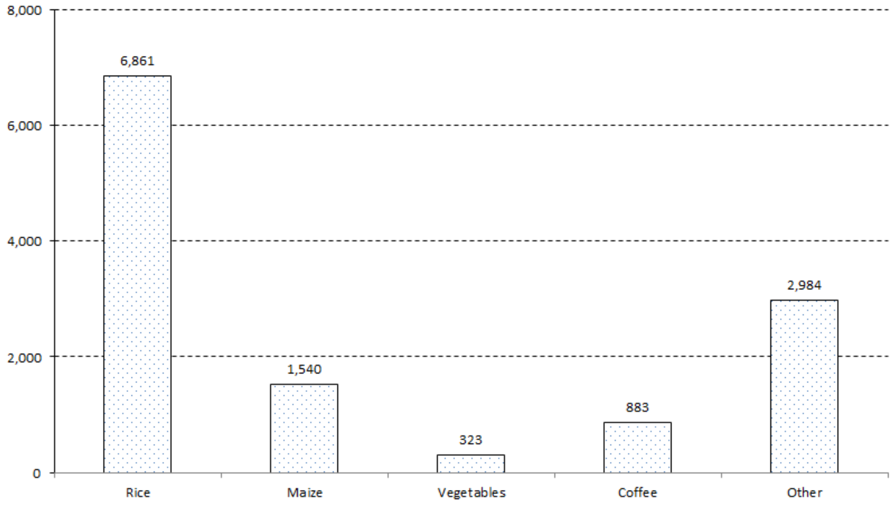


Figure 9: Crop Type in Irrigated Farms

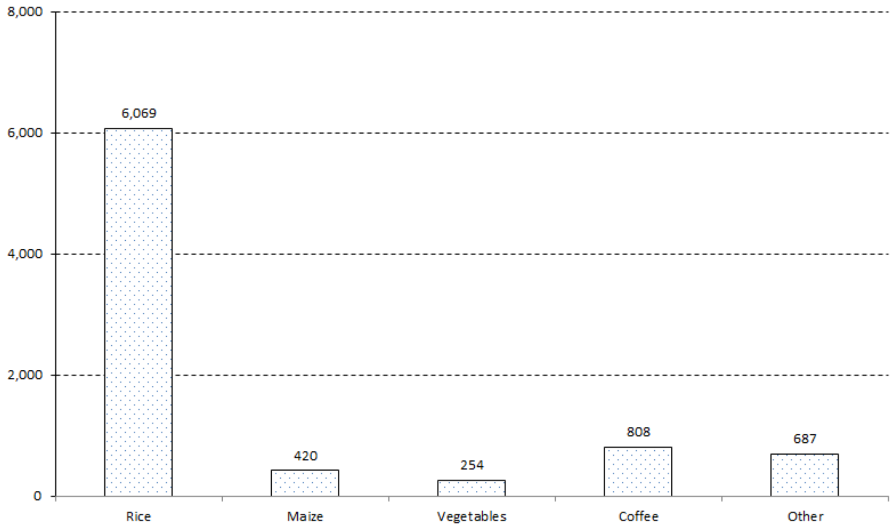


Figure 10: Crop Type in Non-Irrigated Farms

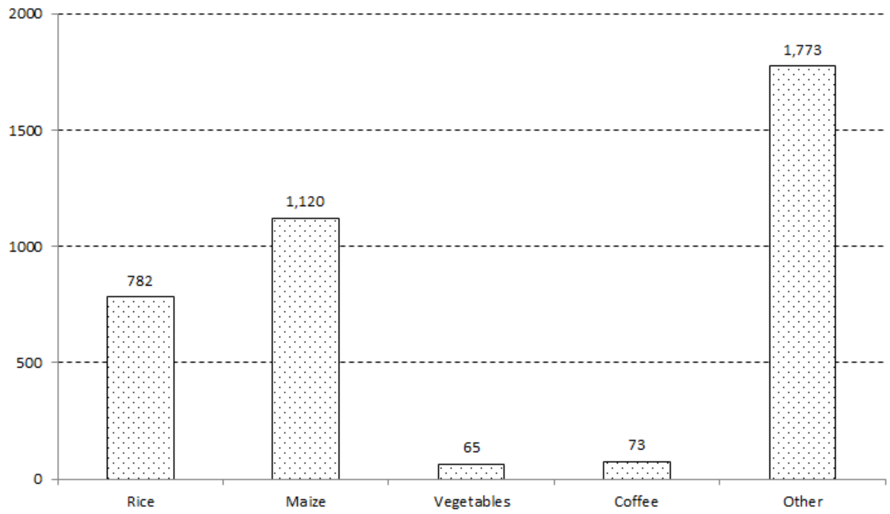


Figure 11: Crop Type, Canal Irrigation

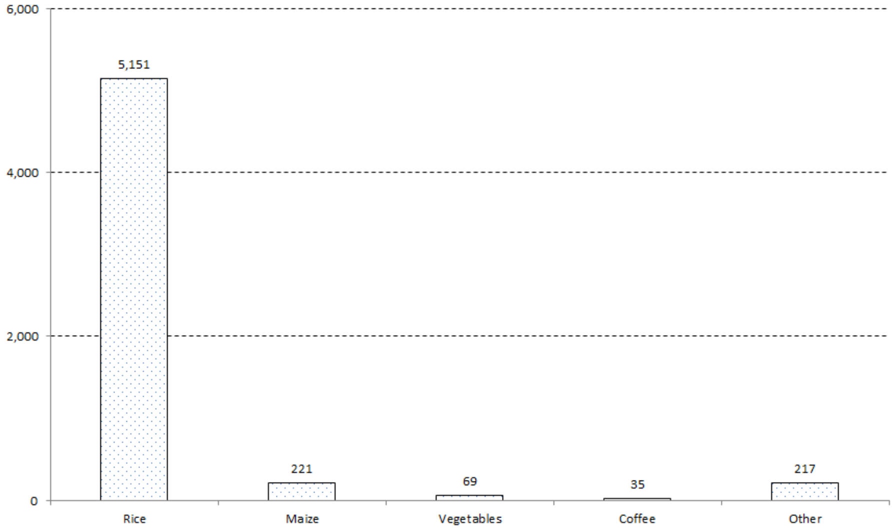


Figure 12: Crop Type, Groundwater Irrigation

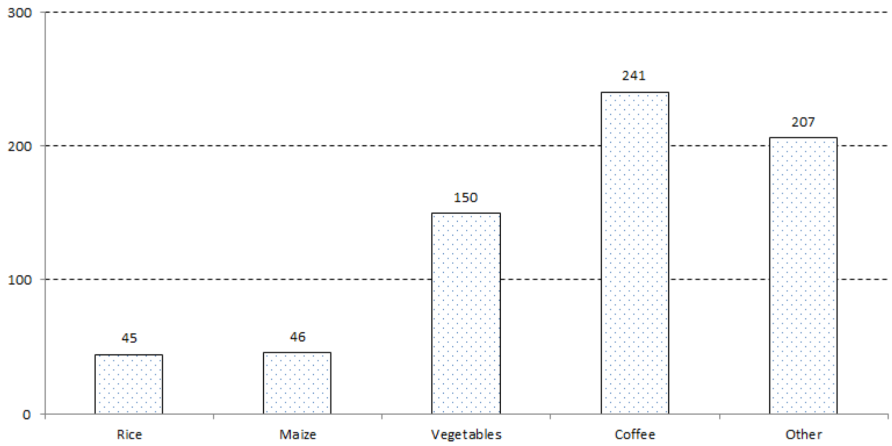


Figure 13: Crop Type, River/Spring Irrigation

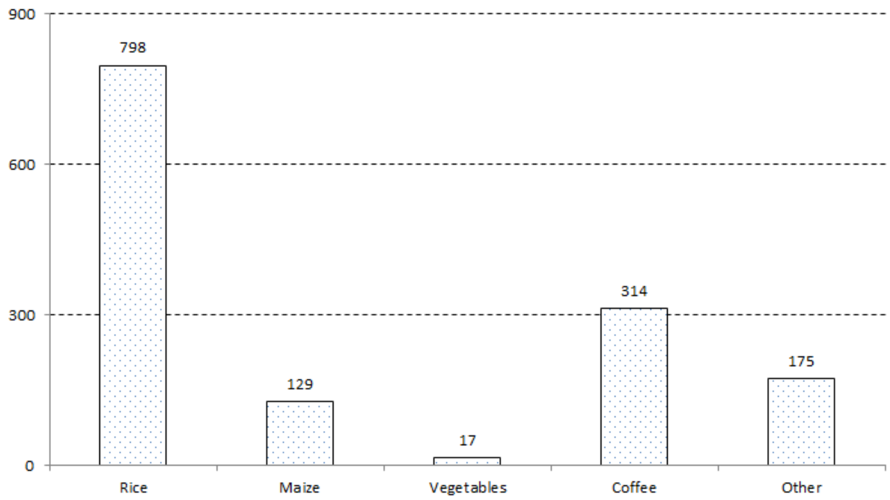


Table 2: Description of Variables
Plot-level Data

Variable Name	Description
plotRiceTotU	Total amount of rice production per acre (kg/1000m2) counting all three previous growing seasons
plotMaizeTotU	Total amount of maize production per acre (kg/1000m2) counting all three previous growing seasons
plotValueU	Market value of plot if for sale now (VND1000/1000m2)
plotRentU	Rent paid or received in the last 12 months from this plot (VND1000/1000m2)
rice	Plot growing rice
maize	Plot growing maize
plotIrrigation	Plot with irrigation
plotGWI	Plot irrigated by groundwater
plotGWI1	Plot irrigated by bore well
plotGWI2	Plot irrigated by dug well
plotArea	Plot area, acre (1000m2)
plotDistance	Distance from home to plot (m)
plotJux	Plot adjacent to another
plotSlope	Plot slope, rated from 1 (flat) to 4 (steep)
plotProb2	Plot described as dry land
plotProb3	Plot described as low-lying land
plotProb6	Plot described as stony soils/clay
Plot Quality	(Base is being less than average)
plotQuality2	Plot quality rated as same as average
plotQuality3	Plot quality rated as better than average
Type of land	
1	Annual crop land
2	Perennial crop land
3	Forest land
4	Fish and shrimp pond
5	Grass land/pasture
6	House with garden
7	Other
plotConservation	A soil and water conservation structure was present on this plot
plotStructure	Plot has a permanent or semi-permanent structure
plotConvert	Permission to convert the plot to non-agricultural use
plotRestrict	Any formal restriction on the choice of crops
plotRiceOnly	Only grow rice in all seasons
plotRiceSemi	Must grow rice in some seasons
plotPerennial	Grow and harvest perennial crops
plotRedbook	Have a red book for this land

Table 3: Description of Variables
Household-level Data

Variable Name	Description
rural	Plot located in rural area
ethnicK	Ethnicity of household head is Kinh
housePlotOwnershipNo	Number of plots owned by the house
housePlotInvest	Investment made in plot
headSex	Sex of household head
headAge	Age of household head
headMarital	Marital status of household head
headEduc	Number of school years obtained by household head
houseFamilySize	Number of family members
headDegree	Highest degree obtained by household head (base is no degree)
2	Short-term training
3	Long-term training
4	Vocational training
5	College
6	University
7	Master's and Phd degrees
houseAgriSeeds	Cost of seeds
houseAgriFertilizer	Cost of fertilizer
houseAgriLabor	Cost of labor
houseAgriFuel	Cost of fuel
houseAgriMachine	Cost of machine
houseAgriOtherCost	Other cost
houseRiceDay	Number of days working on rice production
houseMaizeDay	Number of days working on maize production
houseOtherDay	Number of days working on other production
houseLivestockDay	Number of days working on livestock production
houseAquaDay	Number of days working on aquaculture production
houseForestDay	Number of days working on forest production
houseAssetValue	Total value of assets (VND1000)
houseCom	House has a member belong to the communist party

Table 4: Summary Statistics Plot-level Data.

Name	Obs	Mean	Std. Dev.	Min	Max
plotRiceTotU	6,833	786.5207	397.6159	7.8511	3000
plotMaizeTotU	1,721	489.2082	404.5318	2.8571	3750
plotValueU	5093	87873.97	134210.1	1000	793650.8
plotRentU	960	1212.114	1124.074	100	10000
rice	16343	0.4209	0.4937	0	1
maize	16343	0.1058	0.3076	0	1
plotIrrigation	13220	0.6943	0.4607	0	1
plotGWI	16343	0.0433	0.2036	0	1
plotGWI1	16343	0.0149	0.1213	0	1
plotGWI2	16343	0.0284	0.1661	0	1
rural	16343	0.9736	0.1602	0	1
plotArea	13867	2.3810	5.2095	0.003	210
plotDistance	13867	1458.6470	4719.7910	0	400000
plotJux	13867	0.1005	0.3007	0	1
plotSlope	13220	1.5437	0.7427	1	4
plotProb2	13220	0.2184	0.4132	0	1
plotProb3	13220	0.0275	0.1636	0	1
plotProb6	13220	0.0148	0.1206	0	1
plotQuality2	13215	0.8983	0.3023	0	1
plotQuality3	13215	0.0374	0.1897	0	1
Land Type					
1	13867	0.7432	0.4369	0	1
2	13867	0.0958	0.2943	0	1
3	13867	0.0119	0.1084	0	1
4	13867	0.0191	0.1369	0	1
5	13867	0.0006	0.0240	0	1
6	13867	0.1019	0.3025	0	1
7	13867	0.0275	0.1637	0	1
plotConservation	13220	0.6241	0.4844	0	1
plotStructure	13220	0.1453	0.3524	0	1
plotConvert	11869	0.2116	0.4084	0	1
plotRestrict	13220	0.3649	0.4814	0	1
plotRiceOnly	13867	0.1851	0.3884	0	1
plotRiceSemi	13867	0.1404	0.3474	0	1
plotPerennial	13867	0.1718	0.3773	0	1
plotRedbook	16343	0.5725	0.4947	0	1

Table 5: Summary Statistics Household-level Data.

Name	Obs	Mean	Std. Dev.	Min	Max
rural	3,648	0.9583	0.1999	0	1
ethnicK	3,648	0.6524	0.4763	0	1
housePlotOwnershipNo	3,648	3.9227	2.5381	0	16
housePlotInvest	3,648	0.1837	0.3873	0	1
headSex	3,648	0.7991	0.4008	0	1
headAge	3,648	51.2788	14.1220	18	100
headMarital	3,648	0.8202	0.3841	0	1
headEduc	3,646	6.6127	4.0264	0	12
houseFamilySize	3,648	5.26	2.50	1	20
headDegree					
2	3,648	0.1382	0.3451	0	1
3	3,648	0.0211	0.1438	0	1
4	3,648	0.0436	0.2042	0	1
5	3,648	0.0134	0.1151	0	1
6	3,648	0.0181	0.1333	0	1
7	3,648	0.0005	0.0234	0	1
houseAgriSeeds	3,134	1902.10	4857.52	0	112236
houseAgriFertilizer	3,134	10640.41	25970.02	0	560000
houseAgriLabor	3,133	2584.14	7935.61	0	147000
houseAgriFuel	3,134	1033.47	3560.32	0	84000
houseAgriMachine	3,134	1392.5950	3525.0010	0	80000
houseAgriOtherCost	3,134	966.3886	2697.6590	0	36200
houseRiceDay	3,187	61.3552	72.8107	0	840
houseMaizeDay	3,187	16.6210	36.8799	0	520
houseOtherDay	3,187	55.1352	107.3006	0	1170
houseLivestockDay	3,187	55.9103	69.4260	0	710
houseAquaDay	3,187	4.1123	21.5189	0	367
houseForestDay	3,187	1.1776	7.6282	0	170
houseAssetValue	3,597	43690.59	279197.60	50	1.58E+07
houseCom	3,209	0.1309	0.3373	0	1

Table 6: Impact of Irrigation on Farmland Output - Rice

	OLS		Heckman-Corrected	
	Coef.	**t**	**Coef.**	**z**
plotIrrigation	0.4673	6.29	0.2748	8.37
plotArea	-0.0543	-2.34	-0.0510	-20.01
plotDistance	0.0000	-3.68	0.0000	-5.61
plotJux	0.0443	1.17	0.0473	2.31
plotSlope	-0.2291	-10.65	-0.2102	-17.72
plotProb2	-0.0885	-2.11	-0.0938	-6.12
plotProb3	-0.1611	-2.35	-0.1786	-5.85
plotProb6	-0.0387	-0.42	-0.0202	-0.29
plotQuality2	-0.0166	-0.46	-0.0197	-0.83
plotQuality3	0.0322	0.4	0.0046	0.12
landType1	0.4461	4.28	0.0591	0.6
landType2	0.2473	1.5	-0.1887	-0.64
landType3	-2.0968	-4.7	-1.8727	-4.63
rural	-0.0858	-1.02	-0.0731	-1.81
ethnicK	0.1643	3.06	0.1657	9.5
housePlotOwnershipNo	-0.0198	-3.81	-0.0238	-10.42
housePlotInvest	-0.0272	-0.63	-0.0236	-1.54
headSex	0.0242	0.51	0.0421	1.6
headAge	0.0029	3.58	0.0028	5.38
headMarital	-0.0074	-0.15	-0.0306	-1.1
headEduc	0.0056	1.48	0.0040	1.95
houseFamilySize	-0.0037	-0.81	-0.0007	-0.28
houseAgriSeeds	3.76E-06	0.92	3.34E-06	1.74
houseAgriFertilizer	6.59E-06	3.08	6.20E-06	9.57
houseAgriLabor	5.86E-07	0.2	5.75E-07	0.35
houseAgriFuel	6.04E-06	1.16	7.63E-06	2.4
houseAgriMachine	4.44E-06	1.36	4.01E-06	1.93
houseAgriOtherCost	1.94E-06	0.54	3.42E-06	1.05
houseRiceDay	0.0006	3.12	0.0005	6.25
houseMaizeDay	-0.0009	-1.85	-0.0008	-3.96
houseOtherDay	-0.0004	-1.64	-0.0003	-3.65
houseLivestockDay	0.0003	2.59	0.0003	3.25
houseAquaDay	0.0005	0.78	0.0002	0.71
houseForestDay	0.0019	2.3	0.0011	1.36
houseAssetValue	2.84E-07	2.05	2.98E-07	2.8
houseCom	-0.0083	-0.25	-0.0198	-1.04
Constant	5.9067	55.97	6.5695	47.13
R2	0.5098			
Obs	6,161			

All OLS models were estimated with robust standard errors clustered at the provincial level. Some outputs were omitted from the table. The full result is available from the author upon request.

Table 7: Impact of Irrigation on Farmland Output - Maize

	OLS		Heckman-Corrected	
	Coef.	**t**	**Coef.**	**z**
plotIrrigation	0.0845	1.38	0.2306	2.60
plotArea	-0.0425	-3.62	-0.0386	-5.22
plotDistance	0.0000	-1.98	0.0000	-2.59
plotJux	-0.0789	-0.62	-0.1168	-1.62
plotSlope	-0.1328	-2.35	-0.1070	-3.83
plotProb2	0.0129	0.28	0.0066	0.17
plotProb3	-0.1658	-1.03	-0.1594	-1.15
plotProb6	0.0185	0.2	0.0394	0.41
plotQuality2	0.0183	0.2	-0.0578	-0.84
plotQuality3	0.0928	0.43	-0.0130	-0.1
landType1	0.5642	4.04	0.5050	4.6
landType2	-0.2153	-1.01	0.0458	0.12
rural	-0.6640	-2.27	-0.5440	-2.8
ethnicK	0.3491	3.13	0.3975	7.01
housePlotOwnershipNo	0.0064	0.62	0.0177	2.22
housePlotInvest	-0.1188	-1.03	-0.0870	-2.06
headSex	0.0750	0.52	0.0559	0.58
headAge	-0.0013	-0.33	0.0003	0.2
headMarital	-0.0682	-0.38	-0.0698	-0.67
headEduc	0.0101	1.24	0.0100	1.91
houseFamilySize	-0.0037	-0.61	-0.0053	-0.74
houseAgriSeeds	-5.41E-06	-0.46	-0.00002	-2.04
houseAgriFertilizer	0.00001	2.99	0.00001	4.69
houseAgriLabor	6.76E-06	1.17	3.22E-06	0.63
houseAgriFuel	-6.49E-06	-0.19	-3.42E-06	-0.21
houseAgriMachine	3.17E-06	0.2	5.44E-06	0.54
houseAgriOtherCost	0.00002	3.07	0.00001	0.97
houseRiceDay	-0.0011	-1.98	-0.0012	-3.73
houseMaizeDay	0.0017	2.79	0.0020	5.02
houseOtherDay	-0.0001	-0.16	-0.0004	-0.98
houseLivestockDay	0.0002	0.58	0.0002	0.7
houseAquaDay	0.0076	2.59	0.0082	4.26
houseForestDay	0.0011	0.57	-0.0006	-0.26
houseAssetValue	3.02E-07	0.42	1.38E-07	0.28
houseCom	-0.0204	-0.28	0.0135	0.27
Constant	6.2377	12.58	6.2420	20.5
R2	0.3332			
Obs	1,512			

Table 8: Heckman Selection Models of Crop Choice

	Rice		Maize	
	Coef.	**z-stat**	**Coef.**	**z-stat**
plotConservation	0.3323	7.96	-0.2870	-6.43
plotStructure	-0.1313	-1.67	-0.2508	-2.52
plotConvert	0.3417	6.28	0.1015	1.83
plotRestrict	-0.8946	-8.06	0.4030	4.06
plotRiceOnly	1.1142	9.81	-1.0406	-9.3
plotRiceSemi	1.3415	11.58	-0.4853	-4.53
plotPerennial	-0.4872	-5.18	-0.2263	-2.61
plotRedbook	0.7908	25.33	0.0854	2.36
plotIrrigation	1.0072	23.05	-0.7996	-17.6
landType1	2.4436	18.46	0.7814	6.11
landType2	-0.5960	-2.25	-1.2154	-5.6
landType3	0.8198	2.28		
Constant	-3.5666	-24.94	-1.0946	-8.06
Mills λ	-0.2402	-8.19	-0.1632	-1.69
ρ	-0.5345		-0.2751	
σ	0.4494		0.5932	
$\chi_2(1)$ $(\rho = 0)$	27.23		21.21	
Prob $> \chi_2$	0		0	
Obs	11,239		11,686	
Censored obs	5,587		10,382	
Uncensored obs	5,652		1,304	

Table 9: Land Value Models

	Irri. vs Non-irri.		GWI vs. Other Irri.		GWI vs. Non-irri.	
	Coef.	**t-stat**	**Coef.**	**t-stat**	**Coef.**	**t-stat**
Irrigation Type	0.3796	2.16	-0.2870	-1.3	0.2744	1.84
plotArea	-0.0504	-3.15	-0.0529	-2.84	-0.0319	-2.75
plotDistance	-0.00003	-1.65	-0.00002	-1.62	0.0000	-1.22
plotJux	-0.1596	-1.2	-0.1930	-1.49	0.0286	0.16
plotSlope	-0.8278	-2.7	-0.9059	-2.66	-0.5686	-2.9
plotProb2	-0.4343	-3.12	-0.5605	-4.29	-0.0409	-0.16
plotProb3	0.0469	0.21	0.0369	0.14	0.1431	0.62
plotProb6	-0.2946	-0.84	-0.5015	-3.64	0.0431	0.07
landType1	-0.1521	-0.37	-0.1193	-0.58	-0.0883	-0.53
landType2	0.3654	0.96	-0.1560	-0.78	0.4050	0.72
plotQuality2	-0.1059	-0.84	-1.3146	-1.84	-0.0081	-0.03
plotQuality3	-0.1058	-0.61	-0.6799	-1.44	0.4491	1.67
rural	0.5202	1.31	0.6730	1.45	-0.3263	-0.96
housePlotOwnershipNo	-0.0080	-0.47	-0.0146	-0.74	-0.0007	-0.05
housePlotInvest	-0.1268	-1.04	-0.0634	-0.45	-0.2407	-1.22
plotConservation	0.2378	1.04	0.3067	1.06	-0.0404	-0.19
plotStructure	0.1322	0.93	0.1502	0.96	-0.0687	-0.24
plotConvert	-0.6055	-2.53	-0.6937	-3.16	-0.1637	-0.61
plotRestrict	-0.6245	-2.19	-0.8173	-3.06	-0.3992	-1.65
plotRiceOnly	0.1434	0.65	0.3042	1.1	0.2746	0.71
plotRiceSemi	0.1293	0.37	0.2912	0.83	0.1732	0.27
plotPerennial	0.0891	0.49	0.1894	0.55	-0.1533	-0.59
plotRedbook	-0.0249	-0.19	-0.0073	-0.05	-0.0171	-0.11
Constant	11.5783	12.57	13.0771	11.76	11.4962	13.06
R2	0.3458		0.3271		0.1974	
Obs	4,369		3,616		871	

Table 10: Land Value Models - Types of GWI

	Bore wells. vs Non-irri.		Dug Wells vs. Non-irri.	
	Coef.	**t-stat**	**Coef.**	**t-stat**
Irrigation Type	0.0926	0.27	0.4484	2.18
plotArea	-0.0377	-2.48	-0.0346	-2.77
plotDistance	0.0000	-1.19	0.0000	-1.22
plotJux	0.0142	0.07	0.0181	0.09
plotSlope	-0.6107	-3.06	-0.5554	-2.86
plotProb2	-0.0576	-0.23	0.0211	0.08
plotProb3	0.1034	0.39	0.1351	0.55
plotProb6	0.1150	0.18	0.1063	0.17
landType1	-0.0546	-0.32	-0.0418	-0.25
landType2	0.4609	0.83	0.4053	0.65
plotQuality2	0.0283	0.09	-0.0506	-0.16
plotQuality3	0.4084	1.33	0.4189	1.54
rural	-0.4010	-1.04	-0.3679	-0.93
housePlotOwnershipNo	-0.0009	-0.07	0.0081	0.53
housePlotInvest	-0.1871	-0.9	-0.2976	-1.44
plotConservation	-0.0043	-0.02	0.0420	0.2
plotStructure	-0.1533	-0.55	-0.1409	-0.47
plotConvert	-0.1981	-0.65	-0.1616	-0.56
plotRestrict	-0.3283	-1.39	-0.4857	-1.51
plotRiceOnly	0.2010	0.48	0.2899	0.79
plotRiceSemi	0.1251	0.21	0.4562	0.69
plotPerennial	-0.0939	-0.37	-0.2110	-0.71
plotRedbook	-0.0125	-0.08	-0.0298	-0.19
Constant	11.5929	13.85	11.4678	12.83
R2	0.1944		0.2017	
Obs	807		817	

Table 11: Impact of Irrigation on Land Rents

	Irri. vs Non-irri.		GWI vs. Other Irri.		GWI vs. Non-irri.	
	Coef.	**t-stat**	**Coef.**	**t-stat**	**Coef.**	**t-stat**
Irrigation Type	0.0551	0.46	0.0425	0.29	0.3867	1.81
plotDistance	0.00003	1.55	0.00002	1.03	0.0001	1.52
plotArea	-0.0206	-3.3	-0.0179	-3.09	-0.0509	-2.92
plotJux	0.0760	0.66	0.1567	2.39	-0.1728	-0.36
plotSlope	0.1109	1.15	0.0805	0.67	0.2206	1.93
plotProb2	-0.3684	-3.91	-0.3705	-3.24	-0.3374	-1.85
plotProb3	0.0584	0.31	0.0726	0.4	1.1170	2.32
plotProb6	0.6915	5.67	1.2101	5.93	-0.9105	-1.7
plotQuality2	0.2543	1.77	0.4178	2	-0.1972	-0.39
plotQuality3	0.3997	2.56	0.5276	2.21	0.8321	2.1
landType1	-0.5404	-0.88	-0.1031	-0.15	-1.8745	-16.7
landType2	-0.1011	-0.16	0.3934	0.5	-1.8429	-7.32
rural	-0.2741	-0.95	-0.2295	-0.76	-0.0452	-0.12
Constant	7.1903	13.48	6.6354	11.86	8.5441	34.48
R2	0.0665		0.0719		0.2564	
Obs	903		817		108	