Hidden in Plain Sight: The Value of Groundwater Irrigation in Vietnam

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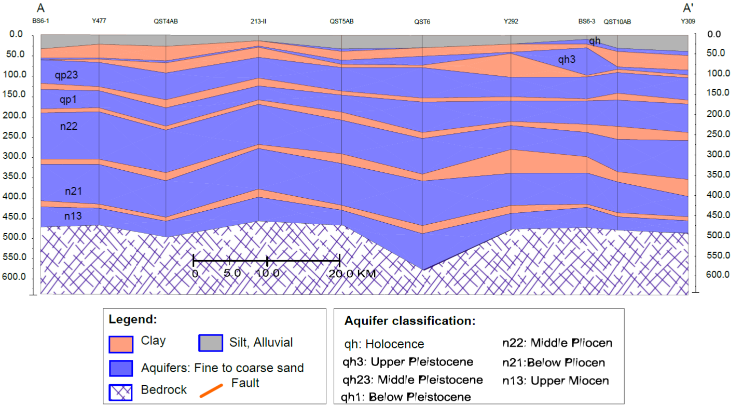
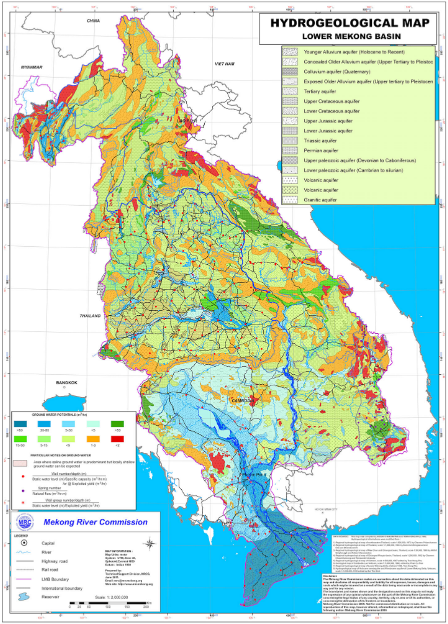
Introduction

- Groundwater is used for irrigation and household consumption in many part of Vietnam, as a main source of water, as a supplement for piped water, and as a backup resource at the time of shortages.
- Excessive use has been a major concern due to a lowering water table, contaminated underground aquifers, and land subsidence as a potential consequence of over withdrawal.
- Groundwater extraction is not paid by users. Administrative procedures (registration, licensing) are limited.
- Policy-wise: irrigation waiver has been issued to farmers since 2008.

Groundwater in Vietnam



Groundwater potential in the LMB



Types of groundwater users

Classified by the scale of the extraction volume, the depth of the bore well, the purpose of usage, bore ownership, and time of drilling:

- The largest and most well documented users are drilling wells operated by water supply companies.
- Drilling wells used by industrial factories are of relatively large volume use for production and service purposes.
- Wells managed by locally by the Rural Clean Water and Environmental Sanitation Center to supply water to household clusters.
- Small rural drilled wells, self-managed and exploited by the households to meet the water demands of the family.

Problems with groundwater in Vietnam

- Market failure in the exploitation and use of irrigation water: Irrigation is provided by irrigation system but can not exclude non-paying households.
- Negative external failure.

$\Rightarrow$ In order to deal with public and external goods, a reasonable irrigation water pricing system needs to be established at least sufficiently to recover the cost of water supply and to promote efficient water use.

Observations

Observed water head in Vinh Long.

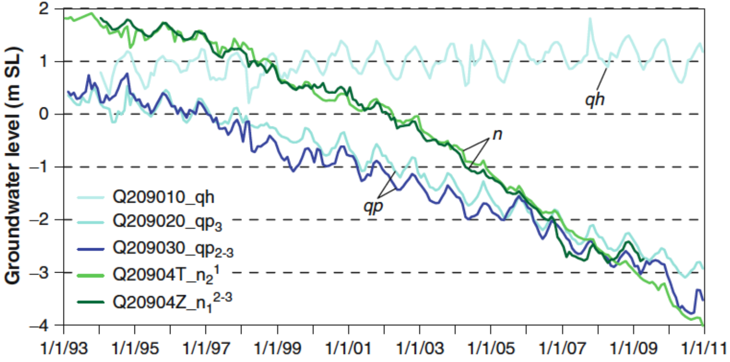


Fig. 7.6 Time series of groundwater level fluctuation in National Monitoring Station Q209 (elevation 2.1 msl, location see Fig. 7.3) since 1993. Five wells are screened in hydrogeological units qh, qp_2, qp_{2-3}, $n_2^{\ 1}$, $n_1^{\ 2-3}$ (Data source: CWRPI, Vietnam)

Land subsidence associated with groundwater extraction

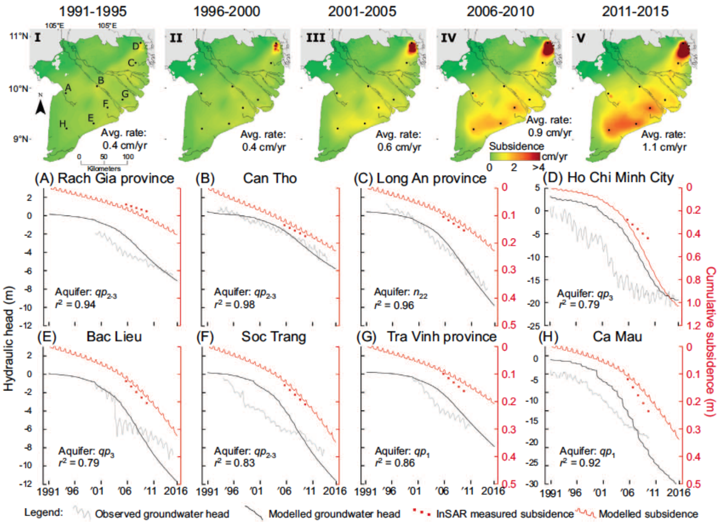


Figure 7. (*i*)-(*v*) Annual groundwater extraction-induced subsidence rates for each five year period. Monitoring well locations are marked alphabetically. (*a*)-(*h*) Modelled and measured hydraulic head time series at monitoring well locations. Cumulative calculated subsidence is shown in red. The periodic fluctuations in the subsidence graphs reflect the elastic response up to 2 cm to seasonal wetting and drying as the aquifer system expands and shrinks. The red dots represent InSAR-measured subsidence rates over 2006–2010 by Erban *et al* (2014) for visual comparison.

Irrigation policy and problems

- History
- Waiver since 2008
- Problems

Types of irrigation systems

Irrigation systems and how they are managed:

- Canal
- Groundwater: bore-well, dug well
- Spring/river/stream
- Ponds and lakes
- Others: rain, piped water etc

Canal irrigation

Source: The ADB, https://www.adb.org/results/bringing-clean-water-highlands-viet-nam

Groundwater irrigation in the Central Highland of Vietnam

Bore well

Dug well

Central groundwater station in the Central Highland

Research questions

1. What is the equivalent monetary value of ground water as a source of input to farming production?
2. What is the aggregate value of groundwater to the local and regional economy?

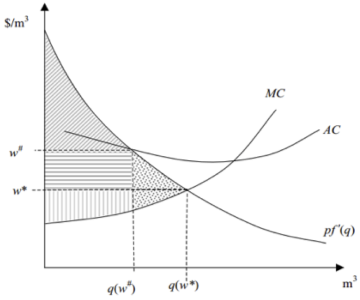
$\Rightarrow$ Knowing economic values of water will help adopt the optional water allocation policy to maximize total social welfare!

Types of prices

- Items for which market prices exist and prices reflect scarcity (most private goods).
- Market prices exist, but prices fail to reflect true social values (e.g. due to externalities).
- Market prices do not exist, although it is possible to identify shadow prices.
- Market prices do not exist, and shadow prices do not exist as well.

Concepts of water values

Total Value and Marginal Value of Water.



- The total value of water is different from the marginal value of the last unit of water used in the production of an output.
- The short-run and long-run value of water is different.
- At-site vs at-source values of water are different.
- Water value could be measured per period or as capitalized value into an asset.
- Water has both use and non-use value.

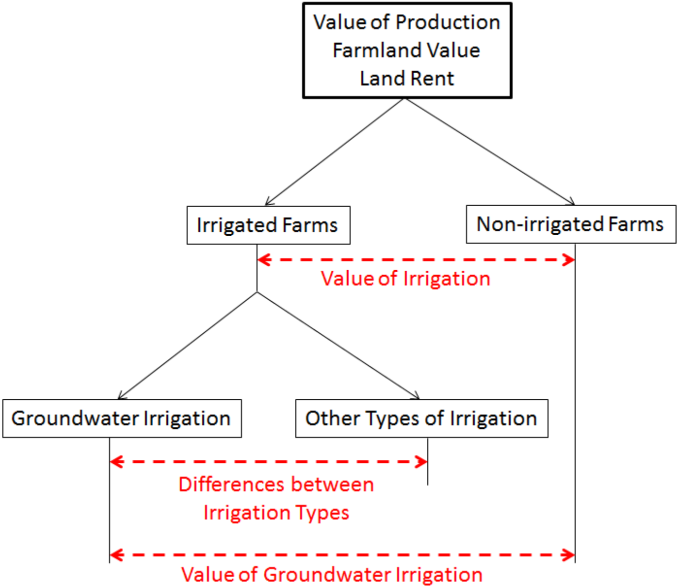
Methods of non-market valuation

- The *accounting approach* identifies the total value of water as the residual value to the total production value less all accountable cost of other inputs.

$$R_W = Q_Y \times P_Y - (P_M \times X_M + P_H \times X_H + P_K \times X_K + P_L \times X_L)$$

- Water, as an input to the production of crops, can be valued in a *production function* that links the transformation of inputs into output.
- In the absence of farm outputs, a *hedonic valuation approach* relies on land values, rather than farm outputs, to predict the contribution of land characteristics to the total value.
- However, none of the above methods are able to estimate the non-use value of water.

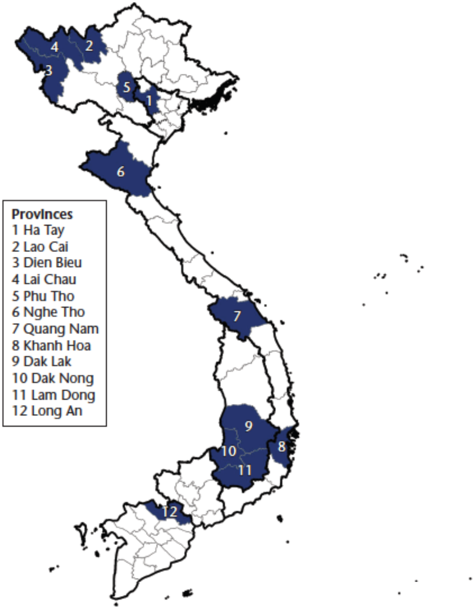
Structure of a with-and-without analysis



Data description

- The VARHS 2014 survey has a sample of 3,648 households in 12 provinces from north to south across Vietnam.
- We identify parcel-level information pertaining to production outputs, inputs, type of irrigation, and household characteristics, totaling 16,343 farm plots.

Locations of 12 VARHS provinces.

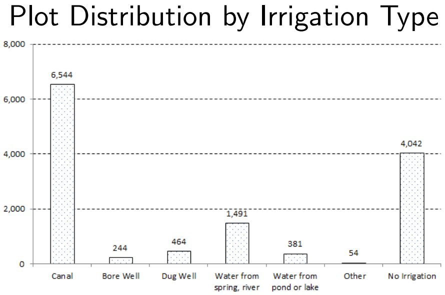


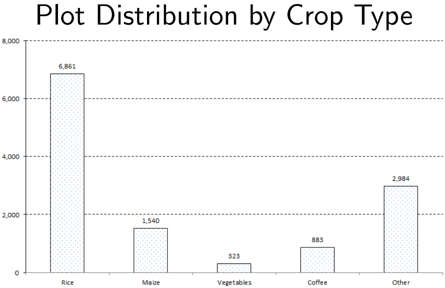
Surveys in the Central Highland and the Mekong River Delta of Vietnam

Variable description

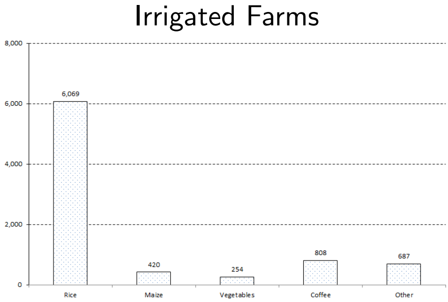
Name	Description
plotRiceTotU	Total amount of rice production per acre (kg/1000m2) counting all three previous growing seasons
plotMaizeTotU	Total amount of maize production per acre counting all three previous growing seasons
plotValueU	Market value of plot if for sale now
plotRentU	Rent paid or received in the last 12 months from this plot
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)
...	

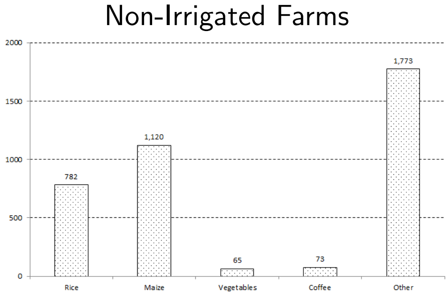
Sample property



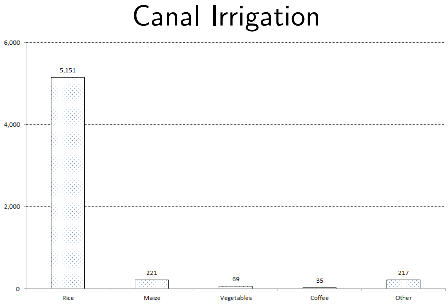


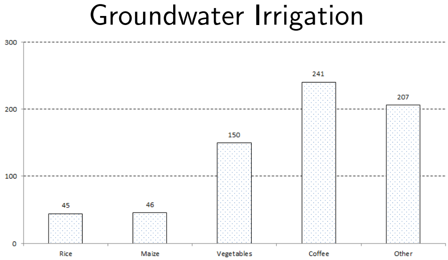
Crop type by irrigation status





Crop type by irrigation type





Econometric models

A standard production approach:

$$log(Y) = f(Inputs, Land, Labor, Climate, Others)$$

- Output can be measured as yields (total production per acreage planted or harvested), or values of output (yield multiplied by unit price, assuming small farmers and a competitive market).
- Inputs can be either observable such as weather conditions, such as temperature and precipitation, or unobservable such as land quality and farming efforts.
- A set of locational fixed effects could be included to control for unobserved unchanging factors such as climate (temperature, precipitation), local conditions (road, infrastructure), and other local factors.

$$Y = \alpha_0 + \alpha_1 \times D_{IRRI_i} + \sum_j {X^j}_i \times \alpha_j + \varepsilon_i$$

- Irrigation can be considered as an input to the production function, or as a property of the farmland. Farms having access to any source of water, either government-built canals, stream/river, or groundwater, may be more productive than those without irrigation.
- We do not observe the amount of water withdrawal, therefore the value of having irrigation is interpreted as the value of having access to water per acre of agricultural land, regardless of the withdrawal amount or water quality. Farmers decide to pump as much as allowed to maximize the value of crops grown on their land.

Model 1: Farmland production function

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

- Q_i is the production output, measured as the total amount of rice or maize in each unit of farmland (1000m2).
- D_{IRRI} is the state of irrigation. A farm could be irrigated ($D_{IRRI} = 1$) or non-irrigated ($D_{IRRI} = 0$). Among irrigated farms, it could be irrigated by groundwater, or irrigated by other method.
- $INPUT^j$, $LAND^k$, and $DEMO^n$ are vectors of production inputs, land characteristics, and household's demographics.
- ε is the residual, assuming an independent Gaussian distribution with a zero mean.

Problem with observational data

- Choice of crops are endogenous on irrigation access.
- Choice of crops is determined by restrictions placed in the land by the local government, by household's demand for income, and other physical characteristics of the land.
- Potential sample selection issue, which may bias the estimated coefficients of interest. If farmers deem that growing rice is less profitable than other crops, they may choose to switch to upland crops, if allowed to do so. In this case, the irrigation coefficient may be biased upward because the sample contains only most profitable rice growers.

Model 1: Farmland production function with a two-step Heckman sample correction method

$$
\begin{cases}
P(Rice_i|R_i) = \Phi(R_i\gamma + u_i) & (1) \\
\\
log(Q_i^{rice}) \qquad = \alpha_0 + \alpha_1 \times D_{IRRI_i} + ... + \rho\sigma_\varepsilon \boldsymbol{\lambda}(\boldsymbol{Z\gamma}) + \varepsilon_i & (2)
\end{cases}
$$

- $\Phi(.)$ is the cumulative distribution function of the standard normal distribution.
- ρ is the correlation coefficient of the residuals in the first and second stage.
- $\boldsymbol{\lambda}(.)$ is the inverse Mills ratio, the ratio of the probability density function to the cumulative distribution function $\boldsymbol{\lambda}(.) = \frac{\phi(.)}{\Phi(.)}$, measured at value $Z\gamma$.

Evidence of the sample selection (Heckman probit 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
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	

Model 2: Farmland value function

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

- *VALUE* is the land price per acre
- $LAND^k$ and $RESTRICT^m$ is the land characteristics and restrictions placed on the land. 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.
- Demographics and production inputs only affect the immediate output value, not land value, therefore not are not included in the land value equation.

Model 3: Farmland rent function

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

- *RENT* is the rent per acre paid or received by the farm owner or the renter.
- $LAND^k$ is the land characteristics. The rent value is determined mostly by its productive capacity, such as farms with better soil quality, flat slope, access to water and transports which drive a higher profit and therefore have a higher rent.
- Expectations over future increased market value unrelated to the immediate productivity are not expected to affect the rent price of farmland as a productive capital, so do restrictions placed on the land such as conversion or building permissions.

Type of measured values

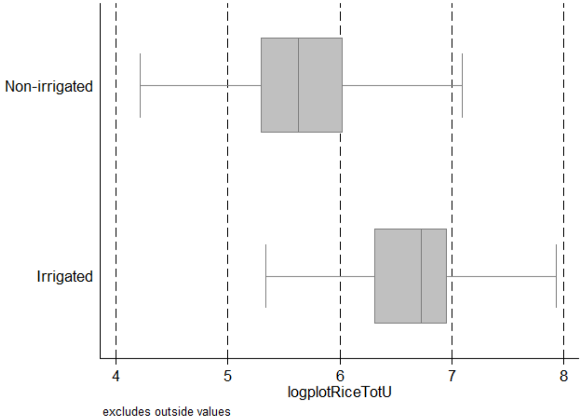
We estimate the *long-run capitalized at-source value of water (hedonic model), or the annual at-source value of water (production/land rent model)*.

- The annual value of irrigation can be identified as the difference between the values of farm outputs or land rents with and without irrigation, which is coefficient α_1.
- The accumulated/capitalized value of irrigation is the difference between farm values with and without irrigation. To calculate the annualized value of irrigation, a discounting factor r is applied to convert the difference in stock values of farmland to the flow of annual irrigation benefits ($\alpha_1 \times r$). $r = 5\%$ in this study.

Results

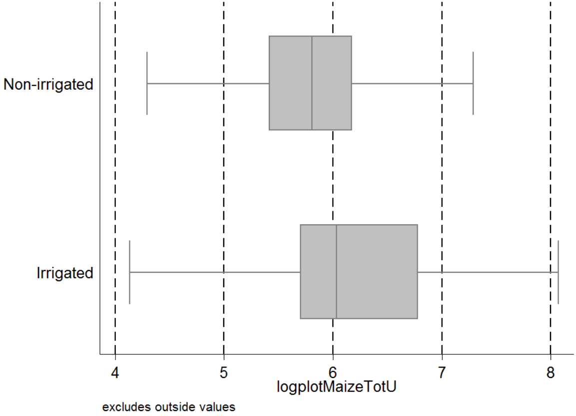
The Value of Irrigation - Rice Yields

Comparing Annual Yields of Rice (kg/acre, in logarithm) between Irrigated and Non-irrigated Farms



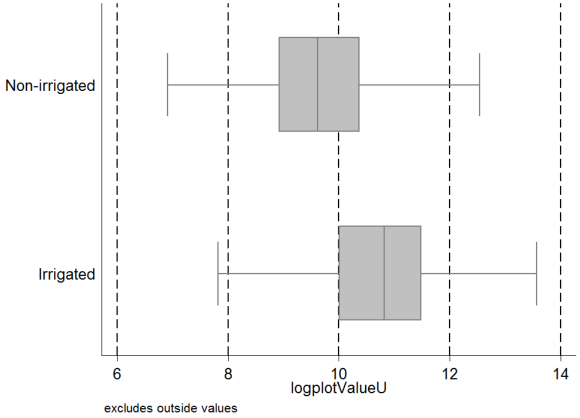
The Value of Irrigation - Maize Yields

Comparing Annual Yields of Maize (kg/acre, in logarithm) between Irrigated and Non-irrigated Farms



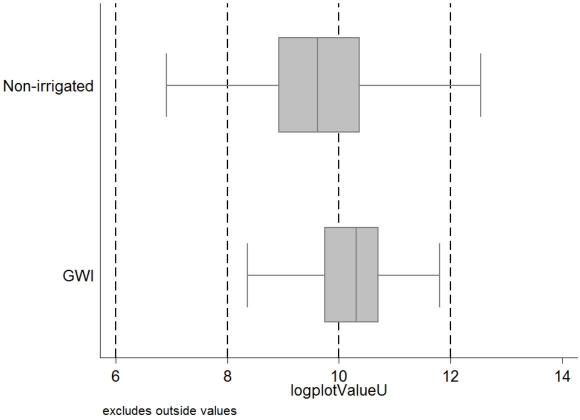
The Value of Irrigation - Farmland Values

Comparing Farmland Values (VND1000/acre, in logarithm) between Irrigated and Non-irrigated Farms



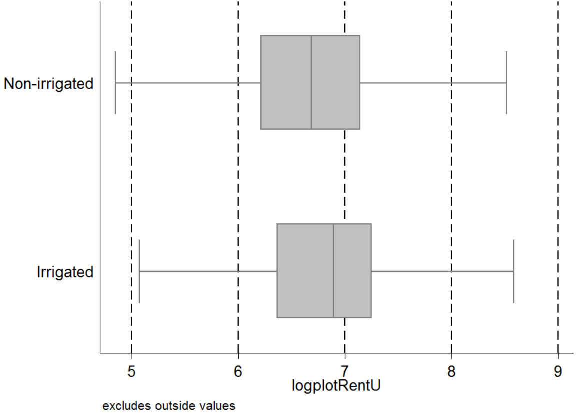
The Value of Groundwater Irrigation - Farmland Values

Comparing Farmland Values (VND1000/acre, in logarithm) between Groundwater Irrigated and Non-irrigated Farms



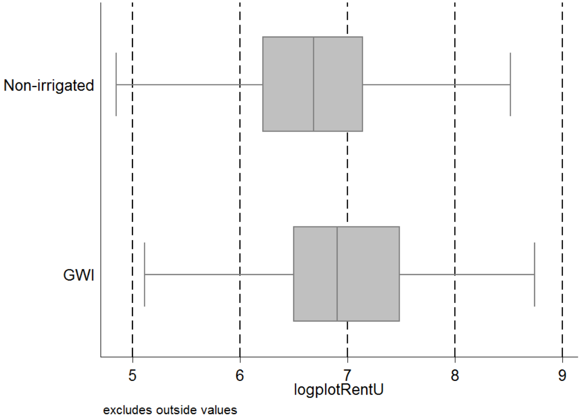
The Value of Irrigation - Farmland Rents

Comparing Farmland Rents (VND1000/acre, in logarithm) between Irrigated and Non-irrigated Farms



The Value of Groundwater Irrigation - Farmland Rents

Comparing Farmland Rents (VND1000/acre, in logarithm) between Groundwater Irrigated and Non-irrigated Farms



Model 1: Production function and Heckman correction

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
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
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
...				
R2	0.5098			
Obs	6,161			

The dependent variable is in logarithm.

Model 1: Production function and Heckman correction

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
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
landType1	0.5642	4.04	0.5050	4.6
landType2	-0.2153	-1.01	0.0458	0.12
...				
R2	0.3332			
Obs	1,512			

The dependent variable is in logarithm.

Model 2: Hedonic function of farmland values

Impact of Irrigation on Farmland Value

	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
...						
R2	0.3458		0.3271		0.1974	
Obs	4,369		3,616		871	

The dependent variable is in logarithm.

Impact of groundwater types on farmland value

	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
...				
R2	0.1944		0.2017	
Obs	807		817	

The dependent variable is in logarithm.

Model 3: Impact of irrigation on farmland 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
...						
R2	0.0665		0.0719		0.2564	
Obs	903		817		108	

The dependent variable is in logarithm.

Summarized findings

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

Method	**Irrigation (all)**		**Groundwater Irr.**
	Rice Farms	Maize Farms	
Production Method	10.10	3.18	–
Hedonic Valuation	20		6.32
Coffee	–		13.54
Land Rent Model	–		5.55

- Irrigation contributions to the farming economy are significant, up to one third of the net income per hectare, *on average*. Groundwater alone is worth VND1200bn/yr at the minimum.
- These calculated values of water are much higher than some existing studies using mechanistic models of crop-water use!
- These values are independent of crop choice.

Compared with other countries

Study	**Country**	**Method**	**Capitalized Value**	**Annualized Value**
Brozovic and Islam (2010)	USA	Hedonic, Matching	$712-723/acre*	$41-48/acre
Swanepoel et al (2015)	USA	Hedonic	$1574/acre	$16-25/acre-foot
Torrell et al (1990)	USA	Hedonic	$610/acre in NM1980	
MacGregor et al (2000)	Namibia	Residual Value	N$0.03 (f) - 0.64 (e)/m3	

$*$ 1 imperial acre = 4,046.86m2.

Discussion

- The administrative arrangements for managing water (both surface and groundwater) are to blame.
- Under-investment in water resources.
- Farmers and other water users have been given access to water with minimal and often no fees.

Policy implications

- Make the case that water is now scarce in ways that farmers and other water users will accept, and that remaining supplies have to be managed more efficiently.
- Begin introducing controls and/or fees on water use so that economic agents across the whole economy will modify their behavior with respect to water as resource.